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ChaMP

This paper contains research conducted within the network "Challenges for Monetary Policy Transmission in a Changing World Network" (ChaMP). It consists of economists from the European Central Bank (ECB) and the national central banks (NCBs) of the European System of Central Banks (ESCB).

ChaMP is coordinated by a team chaired by Philipp Hartmann (ECB), and consisting of Diana Bonfim (Banco de Portugal), Margherita Bottero (Banca d'Italia), Emmanuel Dhyne (Nationale Bank van België/Banque Nationale de Belgique) and Maria T. Valderrama (Oesterreichische Nationalbank), who are supported by Gonzalo Paz-Pardo and Jean-David Sigaux (both ECB), 7 central bank advisers and 8 academic consultants.

ChaMP seeks to revisit our knowledge of monetary transmission channels in the euro area in the context of unprecedented shocks, multiple ongoing structural changes and the extension of the monetary policy toolkit over the last decade and a half as well as the recent steep inflation wave and its reversal. More information is provided on its website.

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FORWARD GUIDANCE IN CLIMATE POLICY

by Riccardo Degasperi*, Tara Hamadi†, Filippo Natoli‡, Valerio Nispi Landi§
and Kevin Pallara¶

Abstract

We examine the macroeconomic implications of the green transition, focusing on the role of carbon policy. Using high-frequency surprises around regulatory events in the EU Emissions Trading System and a Proxy-SVAR framework, we identify two distinct shocks: one to the current policy stance (current stance shocks) and another to the expected path of the green transition (expected path shocks). Both types of shocks reduce greenhouse gas emissions and economic activity, but differ in their inflationary effects. Current stance shocks raise inflation, while expected path shocks are deflationary. A structural scenario analysis shows that monetary policy easing following a path shock substantially mitigates output losses and moderates the decline in inflation. Moreover, path shocks lower expected growth, depress economic sentiment and increase uncertainty, while also encouraging a reallocation towards greener assets and reducing climate-related risks. These findings align with the predictions of an environmental New Keynesian model. Our results highlight the importance of forward guidance in climate policy, emphasizing its role in shaping macroeconomic expectations and accelerating the transition to a low-carbon economy.

JEL Classification: C3, E3, H23, Q58.

Keywords: climate policy, forward guidance, inflation, green transition.

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1 Introduction[1]

Our understanding of the macroeconomic implications of the transition to a low-carbon economy remains incomplete. This partly reflects the difficulty of measuring progress in the green transition, which is inherently linked to the evolution of climate policies. In the literature, studies on climate policy have either focused on surges in attention to climate change around major international policy milestones (Engle et al., 2020; Ardia et al., 2023; Meinerding et al., 2023) or on changes in current regulation within individual jurisdictions or regions (Känzig, 2023; Konradt and Weder di Mauro, 2023; Känzig and Konradt, 2024). While useful for examining the immediate effects of policy announcements, these approaches may not adequately capture key dimensions of the green transition. In the first case, focusing exclusively on the direction established by international agreements overlooks the effects of their actual implementation. In the second case, regulatory changes may occur without affecting the pace of decarbonization or reshaping expectations about the future trajectory of carbon policy – both of which are central to the green transition process.

This work aims to assess the macroeconomic effects of progress in the decarbonization process. Key policy questions include whether green transition policies effectively reduce CO_2 emissions, what economic costs they entail in terms of reduced activity, and whether they are likely to have inflationary or deflationary effects. For central banks, a critical question is whether carbon policies will exacerbate the trade-off between price stability and output stabilization going forward. This paper argues that the answers to these questions depend on which specific dimension of carbon policy is involved.

The event-study literature typically treats green transition policies as unidimensional, but their intended timing can vary significantly. Some policies – such as adjustments

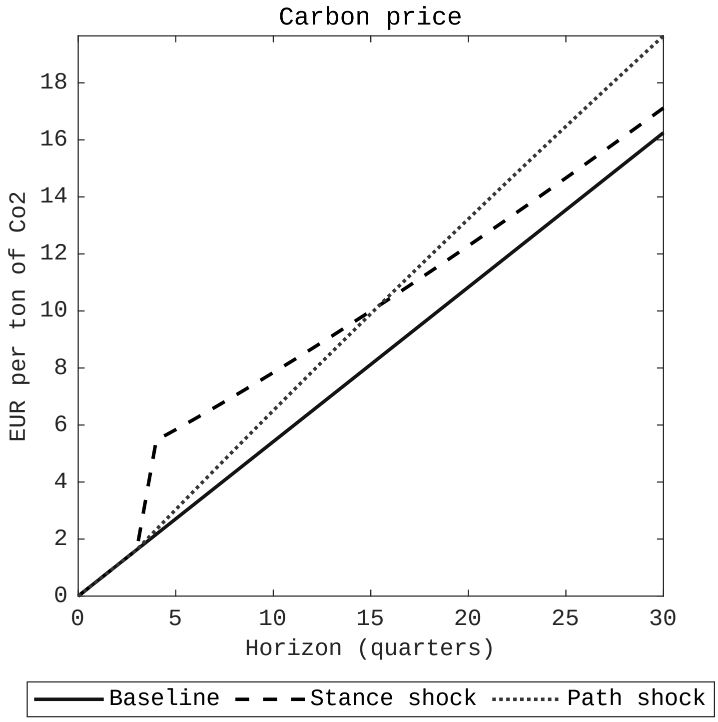
[1]This paper has benefited from presentations at the 2023 Bank of Italy 'Energy and Climate Change Workshop', the 2024 IAAE Annual Conference, the 2024 Bank of Italy 'Economic Implications of Climate Change' workshop, the European Central Bank, the 2025 ESCB ChaMP Workshop, the 2025 IAAE Annual Conference, and feedback from Piergiorgio Alessandri, Adrien Bilal, Martin Bodenstein, Luisa Carpinelli, Ambrogio Cesa-Bianchi, Mark Egan, Andrea Fabiani, Marco Flaccadoro, Andrea Gazzani, Refet Gürkaynak, Giacomo Mangiante, Evi Pappa, Nicola Pavanini, Jean-Paul Renne, Esteban Rossi-Hansberg, Sergio Santoro, Daniele Siena, Paolo Surico, and Fabrizio Venditti. Special thanks to Diego Känzig for sharing his carbon policy shock series and the series used in his paper. A previous draft has circulated under the title 'The Macroeconomic Effects of the Green Transition'. The last version of the work has been published in the European Economic Review. All errors are our own. The views expressed in this paper do not necessarily reflect those of the Bank of Italy.

to carbon emission allowances – can affect carbon prices in the very short run. Others, like setting deadlines for phasing out internal combustion engines, may have more delayed effects, for example, by influencing the future prices of critical metals. In this paper, we quantify the effects of changes in the future trajectory, or *path*, of carbon policy, distinguishing them from changes in its *current stance*. Figure 1 illustrates the effect on the equilibrium trajectory of the carbon price of two types of transitory policy changes, assuming a predetermined schedule of progressively increasing carbon tax rates (solid line). A transitory change in the current stance (dashed line) temporarily raises the *level* of the carbon tax rate, while a transitory change in the path (dotted line) temporarily increases its *slope*, causing the tax rate to reach the long-run target earlier. As such, the latter can be interpreted as a policy change affecting the expected pace of future decarbonization – essentially, a form of forward guidance in climate policy.[2]

We investigate the macroeconomic effects of such distinct climate policy changes empirically, with a focus on the European Union (EU), by exploiting unanticipated regulatory changes to the EU Emissions Trading System (ETS). Specifically, we adopt a high-frequency identification strategy that leverages the differential response of various asset prices to the two dimensions of policy change. To this end, we extend the dataset of EU ETS regulatory events compiled by Känzig (2023), covering ETS announcements through June 2023, thus also including Phase III and Phase IV of the ETS. Regulatory developments within the EU ETS stem from various institutional sources, including decisions by the European Commission, legislative votes in the European Parliament, and rulings by European courts. Following Känzig (2023), we focus on regulatory announcements that influence the supply side of emission allowances. These include changes to the total emissions cap, adjustments in the allocation of free permits, changes to auctioning procedures, and revisions concerning the eligibility of international credits. The rationale for exploiting variation in asset prices around regulatory events is that, on event days, the observed variation is plausibly attributable to the event itself. If the window is narrow enough, the price surprises are likely to capture only the market

[2]Over the longer term (not shown in Figure 1), the solid and dotted lines become parallel again, while the solid and dashed lines converge to the same level. Under the path shock, the carbon price reaches its upper bound – consistent with zero emissions – earlier than under the baseline and the current stance shock.

Figure 1: Changes to the current stance vs. changes to the path



Note: The solid line shows the carbon price in a transition to a zero-emission economy, driven by an emission tax. The dashed line shows the current stance shock. The dotted line shows the path shock.

reaction to the released news.

Based on our argument that different policy dimensions differentially affect expected carbon prices at different points in time, we leverage variation around regulatory announcements in a variety of asset prices that span the term structure of carbon futures and the futures of a set of metals that are critical for green transition technologies. Specifically, we obtain daily surprises around regulatory events not only in the price of the nearest-term carbon futures, but also in the term structure of quoted contracts expiring in the short to medium run. We focus on European Union Allowance (EUA) futures from 1 to 5 quarters ahead since, for longer-maturity contracts, the sample is substantially shorter and liquidity may be limited. Importantly, we also obtain surprises in the full term structure of futures of critical metals – zinc, copper, and nickel – as different policy dimensions differentially affect expected demand for climate-friendly technologies, which rely on these metals for their development and commercialization.

Employing these surprises in the price of critical metals is key, as the term structure of EUA futures alone would mostly reflect information about the term structure of interest rates, since the cost of carry for EUA contracts is essentially just the cost of money (Bredin and Parsons, 2016).

Without additional identifying restrictions, the surprises reflect a combination of the different dimensions of carbon policy. To disentangle shocks to the current stance from those to the expected path of carbon policy, we extract the first two principal components from the surprises in all asset prices and rotate them such that the first factor primarily affects the short end of the carbon futures term structure, while the second factor loads on the longer end. This approach is similar in spirit to the identification of the target and path factors of monetary policy proposed by Gürkaynak et al. (2005). In addition, we drop events in which the rotated principal components co-move positively with stock prices to remove residual endogenous variation from the surprises.

Having obtained measures of shocks to the current stance and the path of carbon policy, we quantify their macroeconomic effects. We estimate a baseline structural VAR model of the European economy, augmented – across different exercises – to capture different transmission channels. Identification of the shocks in our baseline specification is achieved using the Proxy-SVAR methodology, with the two rotated principal components serving as proxies for the shocks. As a robustness check, we show that the results are virtually identical when using an alternative identification strategy that imposes sign restrictions on the comovement of the high-frequency surprises (Jarociński and Karadi, 2020). The idea behind this alternative identification is that, within the event window, the stance shock moves the short end of the term structure of critical materials more than the long end, while the opposite holds for the path shock. Moreover, both shocks depress stock prices. Finally, we interpret our empirical findings through the lens of an environmental New Keynesian DSGE model developed by Ferrari and Nispi Landi (2025). The framework features a green sector and a brown sector, the latter being polluting and subject to an emission tax. We model the baseline green transition as a gradual increase in the emission tax. We then study the transmission of our current stance and path shocks through the lens of this model.

Three results stand out from our analysis. First and foremost, we find that while both shocks lead to a contraction in greenhouse gas (GHG) emissions and economic activity, a current stance shock is inflationary, whereas a path shock is deflationary. The decline in inflation following a path shock suggests that the upward pressure on firms' marginal costs is more than offset by the negative pressure on aggregate demand. In contrast, following a stance shock, the supply effect dominates. We interpret these differences with the help of our theoretical model. A path shock leads to a contraction in both aggregate supply and demand. Supply decreases because the carbon tax directly raises firms' marginal costs, all else equal. Demand falls as households, anticipating a permanent loss in income, reduce current consumption. We show analytically that the demand effect dominates, and inflation declines. In contrast, a stance shock implies a temporary rise in carbon taxation, so households expect higher future disposable income as the tax burden gradually declines. Consequently, a negative demand effect is absent, leading consumer price inflation to rise in line with the empirical findings. Simulations of the effects of the two shocks obtained using the theoretical model, calibrated following Coenen et al. (2018), are consistent with our empirical responses.

Second, since the path shock simultaneously reduces both prices and economic activity, the monetary authority does not face a trade-off between price and output stabilization and responds with an easing, which helps attenuate the shock's negative effects. To assess the extent of this attenuation, we conduct a counterfactual exercise – a structural scenario analysis designed to isolate the monetary policy channel. The analysis shows that, in the absence of a monetary policy easing, the impact on headline inflation and emissions would be roughly three times stronger, while the effects on industrial production and unemployment would be approximately twice as large.

Third, the VAR analysis shows that a path shock has negative effects on expected growth and inflation, validating the intuition coming from model simulations. It leads to a contraction in economic sentiment and employment expectations, a downward revision in professional forecasters' projections for growth and inflation for the year ahead, and it causes an increase in financial uncertainty. At the same time, the shock leads to a reallocation toward greener financial assets, which goes hand-in-hand with a decline in uncertainty surrounding the future of the energy transition. Relatedly, the shock also causes a decline in various measures of perceived climate-related risks (both physical and transition risks).

This paper contributes to the literature and offers policymakers important insights by introducing a method to measure the macro-financial effects of a change in the pace of the green transition. The connection between carbon futures and the prices of key commodities essential to the transition – largely overlooked in previous analyses – is central to identifying shocks to this forward-looking component of regulation. Overall, the empirical findings underscore the significant role of active guidance – or more precisely, *forward* guidance – by the climate regulator. Since such guidance can trigger immediate responses by firms both inside and outside the ETS (e.g., switching to cleaner energy sources), as well as by financial investors (portfolio rebalancing), it proves to be an effective policy tool for shaping expectations and accelerating the low-carbon transition.

Structure of the paper. The remainder of the paper is organized as follows. Section 2 briefly reviews the related literature and highlights our contribution. Section 3 discusses the methodology, the data, and the identification strategies for the current stance and path shocks. Section 4 discusses the empirical results in detail and provides reduced-form evidence about the mechanisms. Section 5 presents the DSGE model we rely on to rationalize our empirical findings. Section 6 offers some final considerations.

2 Literature

This paper contributes to several strands of the economic literature. First, it speaks to the literature examining the macroeconomic effects of the green transition focusing on carbon regulation. In this strand of the literature, findings are mixed: on the one hand, some studies find that carbon taxes in Europe and British Columbia do not significantly depress gross domestic product (Metcalf and Stock, 2020) or increase inflation (Konradt and Weder di Mauro, 2023); on the other hand, unexpected regulatory changes in the European ETS market between 2005 and 2019 have been shown to transmit as negative supply shocks – reducing industrial production and raising consumer prices and short-term inflation expectations (Känzig, 2023; Hensel et al., 2023; Känzig and Konradt, 2024), with stronger effects observed in high-emission countries (Berthold et al., 2023; Ciccarelli and

Marotta, 2024). We argue that previous studies overlook the importance of distinguishing between the various dimensions of green transition policies – specifically, their timing. Shocks that alter the pace of the transition process, by shaping the expectations of firms and financial markets, have effects that go beyond those of adjustments to the current policy stance.

Second, since the shocks we construct rely on high-frequency surprises in commodity and stock markets, this paper connects to the growing finance literature on the impact of climate policies on asset prices (Hengge et al., 2023; Ren et al., 2023; Millischer et al., 2023; Bolton et al., 2023). These studies, which focus on the effects of carbon regulation on the stock market, find that climate policy has heterogeneous impacts across firms – impacts that may depend not only on the level of greenness, typically measured by carbon emission intensity (Bolton and Kacperczyk, 2023), but also, within the ETS, on the surplus or deficit of emission allowances (Bolton et al., 2023). We contribute to this literature by leveraging the relationship between changes in carbon futures and changes in the prices of key transition commodities, such as energy transition metals.

Third, this paper connects to studies that analyze the role of forward guidance, the informational content of announcements about long-run policies, and market reactions to such announcements. This literature is particularly well developed in the study of monetary policy (Gürkaynak et al., 2005; Jarociński and Karadi, 2020). We build on it to isolate the different dimensions of climate regulation. More broadly, this paper fits into the literature that studies the importance of news shocks for business cycle fluctuations.[3]

Fourth, this paper contributes to the body of research employing DSGE models to examine the effects of the green transition on the macroeconomy (Golosov et al., 2014; Carattini et al., 2023; Ferrari Minesso and Pagliari, 2023; Barrage and Nordhaus, 2023; Ferrari and Nispi Landi, 2023; Moro and Nispi Landi, 2024), with a particular focus on inflation and/or monetary policy (Nakov and Thomas, 2023; Olovsson and Vestin, 2023; Airaudo et al., 2023; Del Negro et al., 2023; Annicchiarico et al., 2024; Giovanardi and Kaldorf, 2024; Ferrari and Nispi Landi, 2025).

[3]On news-driven business cycles, see Beaudry and Portier (2004, 2006); Beaudry and Lucke (2010); Ramey (2011); Miranda-Agrippino et al. (2025), among others.

3 Data and methodology

In this section, we detail how we obtain surprises in a variety of asset prices computed around regulatory events and describe how these surprises are used to identify the shocks of interest, following three alternative – and progressively more precise – approaches. Moreover, we present the empirical models and data employed, including the methodology used to assess the importance of the monetary policy channel in the transmission of the path shock to the economy.

3.1 Daily surprises in EUA Futures

Surprises in the prices of EUA and critical materials futures are obtained by computing the daily change in futures contract prices on the dates of regulatory events, as identified by Känzig (2023) and extended by us through June 2023. These events consist of regulatory updates such as decisions by the European Commission, votes by the European Parliament, or rulings from European courts. Particular emphasis is placed on regulatory developments related to the supply of emission allowances. Accordingly, our update of the surprise series focuses on news concerning the overall cap in the EU ETS, the free allocation of allowances, the auctioning of allowances, and the use of international credits.

The selection of announcement dates is based on a thorough review of both the Official Journal of the European Union and the European Commission's Climate Action news archive. In addition to the 126 events identified between 2005 and 2019 by Känzig (2023), we include 25 additional events spanning the period from 2020 to 2023. Thus, between April 2005 and June 2023, there are 151 carbon policy announcement days in total.[4] EUA contracts have been traded on the European Energy Exchange (EEX) in Leipzig and

[4]Notably, only a small number of events concern the establishment of the overall cap within the ETS system. In the initial two phases of the ETS, key announcements relate to decisions regarding the National Allocation Plans (NAPs) of individual member states. These include instances where the Commission either approved or rejected allocation plans, as well as court rulings addressing legal conflicts over the free allocation of allowances. As the system transitioned to auctioning as the default method for allocating allowances, regulatory news in Phase III predominantly focused on decisions concerning the timing and quantities of emission allowances to be auctioned. Starting in Phase II, a significant number of key announcements addressed the use and eligibility of international credits. A detailed account of these events is provided in Section A of the Online Appendix.

the Intercontinental Exchange (ICE) in London since April 2005. We use data from the ICE, which plays a dominant role in the price discovery process of the European carbon emissions market (Stefan and Wellenreuther, 2020). Our analysis focuses on contracts with maturities ranging from the front quarter to five quarters ahead, for which liquidity is high and price data are available since April 2005.[5] Among energy transition metals, we concentrate on three – zinc, copper, and nickel – which are considered essential for clean energy technologies and electric vehicles, according to the International Energy Agency, and for which long time series of price data are available. Futures contracts for these metals are traded on the London Metal Exchange (LME). We consider maturities up to seventeen months, which are generally highly liquid and available since the start of our sample in 1999.

3.2 Current stance and path shocks

We decompose the variation in the high-frequency surprises related to changes in the current policy stance from the variation related to the path of carbon policy by leveraging information contained in the surprises in the term structure of EUA and critical materials futures. We implement this decomposition in three different ways, using different methodologies.

Surprises in the term structure of EUA futures. The first methodology is based on the intuition that the prices of EUA contracts with different maturities may respond differently to changes in distinct dimensions of carbon emission policies. We take the surprises in EUA futures at different maturities around regulatory announcements and estimate the principal components needed to explain the bulk of their variation. These components can be thought of as capturing different aspects of carbon policy (Gürkaynak et al., 2005). We find that the first principal component of surprises in the first six EUA contracts explains 93% of the variance, while the second accounts for approximately 6%. Together, they explain over 99% of the variation in the surprises.

[5]Price data for EUA contracts with maturities between six and fifteen quarters ahead are available only from April 2008, while data for maturities sixteen and seventeen quarters ahead are available only from August 2010.

To facilitate a structural interpretation, the factors are rotated so that one loads on the short end and one on the long end of the EUA term structure. Components that load on different segments of the term structure capture policy changes with different temporal horizons. The resulting factors can then be used as external instruments in a Proxy-SVAR to identify the causal effects of two distinct dimensions of carbon emission policy: a shock to the current policy stance and a shock to the policy trajectory (the path shock). Before being used as instruments, the factors are aggregated from announcement frequency to monthly frequency to match the frequency of the data used in the VAR analysis. In months with more than one announcement, the monthly surprise is defined as the sum of the daily surprises. In months with no announcements, the monthly surprise is set to zero.

This methodology represents the minimal deviation from Känzig (2023) that allows us to obtain our results and is included for comparability. Indeed, when exploring how the shock identified under this identification strategy propagates, we use the same data, the same sample, and the same lag length. The only difference lies in the proxies.

Sign restrictions on the prices of critical minerals. The second methodology consists of imposing sign restrictions on how high-frequency surprises in the prices of various assets respond to the shocks of interest (Jarociński and Karadi, 2020; Cieslak and Schrimpf, 2019). In contrast to the previous methodology, we also leverage surprises in the prices of critical materials and stock market indices for identification. Specifically, we include three sets of surprises in the VAR: surprises in the price of the front-quarter EUA contract, surprises in the STOXX Europe 600, and surprises in the slope of the term structure of critical materials – defined as the first principal component of the differences between the prices of the five-month-ahead and front-month contracts for copper, zinc, and nickel.[6] We leverage these surprises to identify three shocks: the current stance shock, the path shock, and a residual shock that captures some endogenous variation in the surprises, effectively controlling for it.

Importantly, by including the high-frequency surprises in the set of endogenous

[6] As a robustness exercise, we define the slope as the first principal component of the differences between the 17-month and front-month contracts for copper, zinc, and nickel, obtaining similar results. However, contracts at longer maturities may suffer from low liquidity in parts of the sample.

Table 1: Sign Restrictions

Shocks	Surp. EUA fq	Surp. ES 600	Surp. Slope CM 5m-fm	Other
Current stance	+	-	-	·
Path	+	-	+	·
Residual component	+	+	+	·

Notes: Restrictions on the contemporaneous responses of high-frequency surprises to the shocks. Dots indicate unrestricted variables. The column 'Other' includes all endogenous variables in the system beyond the high-frequency surprises.

variables in the VAR, this methodology avoids relying on the assumptions of instrument reliability and exogeneity that are required in the previous strategy. Table 1 summarizes the sign restrictions that set-identify the three shocks.

The current stance shock is identified when a positive surprise in the price of the front-quarter EUA contract corresponds to a negative surprise in the STOXX Europe 600 and a negative surprise in the slope of the term structure of critical materials. The underlying assumption is that the cost-push nature of the policy negatively affects stock prices and causes a larger increase in the prices of near-maturity contracts for critical materials compared to those with longer maturities.[7]

The path shock is identified when a positive surprise in the price of the front-quarter EUA contract is associated with a negative surprise in the STOXX Europe 600 and a positive surprise in the slope of the term structure of critical materials. Unlike the stance shock, the effect of the path shock is tilted toward contracts for critical materials with longer maturities.

The residual shock is identified by a positive comovement of all three surprises. This positive correlation is difficult to reconcile with the supply-side nature of shocks to carbon emission policy and suggests that the surprises might capture variation unrelated to the shocks of interest. For many regulatory events, we observe a positive correlation between surprises in EUA futures and revisions in stock market prices within the event window (Figure B.1).

One potential explanation is that shocks other than the current stance or path shocks

[7] Or, equivalently, it leads to a larger drop in the prices of near-maturity contracts relative to longer-dated ones. Figure B.2 provides a graphical illustration of the sign restrictions on the slope of the term structure of critical materials.

are being captured within the daily event window. Another possibility is that the announcements act as aggregators of sparse information about the state of the economy by revealing the current level of carbon emissions in the atmosphere, which strongly correlates with economic activity and has been used as a timely measure of production during periods of high uncertainty. During 2020, policymakers, analysts, and researchers used real-time CO_2 emissions data to track economic slowdowns and recoveries when official GDP or industrial production data were lagging (Liu et al., 2020). This explanation is akin to the signaling channel of monetary policy (Melosi, 2017). Alternatively, this correlation might arise from balance sheet revaluation effects. The balance sheets of companies under the ETS with a surplus of emission allowances may improve when the European Commission reduces the supply of allowances. Either way, accounting for this variation sharpens the identification of the shocks of interest.

Term structures of EUA and critical minerals futures. The third methodology combines insights from the first two. Like the first approach, it constructs exogenous instruments to identify carbon policy shocks, but it also leverages the intuition underlying the sign restrictions of the second methodology. To maximize the informational content of the instruments, we estimate the principal components that capture carbon policy shocks from surprises in both EUA and critical materials futures contracts.

The set of contracts includes EUA futures (with maturities ranging from one to five quarters) and futures for nickel, copper, and zinc (with maturities from six to seventeen months). We exclude the EUA front-quarter contract since, during the transition from Phase I to Phase II of the ETS, its price drops to zero due to technical reasons. The first principal component explains 56% of the total variance in the surprises, while the second accounts for an additional 20%. The factors are rotated so that the first loads primarily on the short end of the EUA futures term structure, while the second loads on the long end and is not influenced by movements in the short end of the curve. To further purify the shocks, we remove the residual endogenous component by setting to zero the values on announcement days when the surprises comove positively with those in the STOXX Europe Oil & Gas price index.[8] The clean factors are then aggregated from

[8] We use the STOXX Europe Oil & Gas index because, following regulatory shocks, its comovement

announcement frequency to monthly frequency.

This methodology provides two robust instruments that can be used to identify the shocks of interest in a Proxy-SVAR framework. The instruments are displayed in Figure 2: the orange line represents the instrument for the stance shock, while the blue line corresponds to the instrument for the path shock. Two key takeaways are worth highlighting. First, larger surprises do not necessarily coincide with larger movements in the price of front-quarter carbon futures, which are often driven by technical factors rather than changes in market equilibria. This suggests that shock identification is not driven by a few anomalous events. Second, surprises are evenly distributed over time, indicating that shocks are not concentrated in specific periods.

It is important to note that sharper identification does not necessarily translate into more precisely estimated impulse response functions. Although we exploit additional information to identify the shocks, we also discard a substantial number of observations in which the correlation between the rotated factors and stock prices in the oil and gas sector is positive, thereby reducing statistical power.

3.3 Empirical models

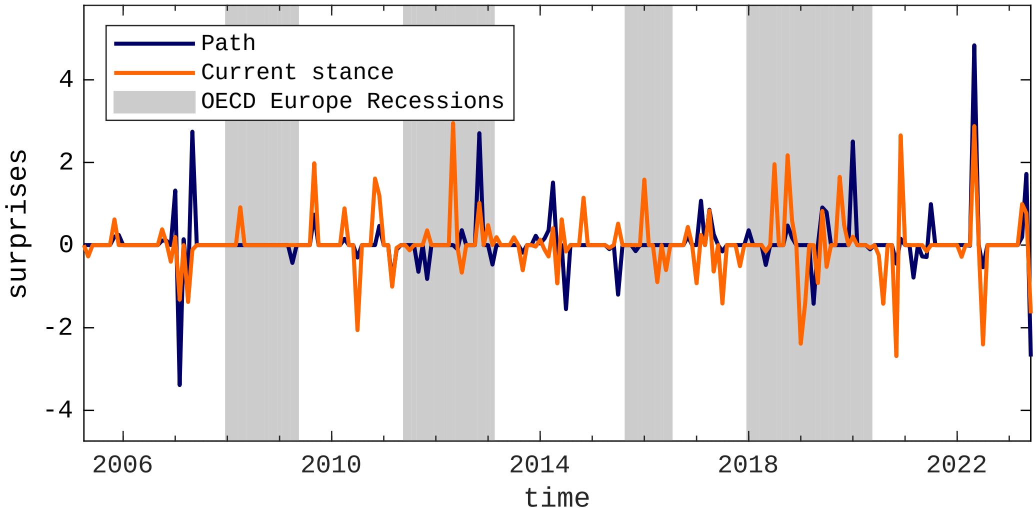
Gauging the differential macroeconomic effects of the current stance and path shocks requires an empirical specification that models both the European economy and the market for carbon emissions.

Our baseline VAR specification follows Känzig (2023) and includes eight variables: the energy component of the Harmonized Index of Consumer Prices (HICP); an index of total greenhouse gas (GHG) emissions for EU-27 countries (excluding land use, land-use change, and forestry, but including international aviation) sourced from Eurostat; headline HICP; industrial production (excluding the construction sector); either the three-month Euro interbank rate or the one-year Euro OIS rate; the unemployment rate; the STOXX Europe 50; and the real price of Brent crude oil.

A direct link between the macroeconomy and the carbon emissions market is provided by the energy component of the HICP, as an unanticipated surprise in the price of carbon

with EUA futures prices is expected to be unambiguously negative.

Figure 2: Instruments for current stance and path shocks



Note: Instruments for carbon policy path shocks (blue) and current stance shocks (orange) obtained by extracting the first two principal components from the surprises in EUA futures (1-quarter-ahead to 5-quarter-ahead) and critical materials futures (6-month-ahead to 17-month-ahead) at announcement frequency – rotated so that the first one loads on the short end of the term structure of EUA futures while the second loads on the long end – and by replacing with zeros those dates for which the correlation between the factors and the daily movement in the STOXX Europe Oil & Gas index is positive. Gray areas represent OECD peak-to-trough recession dates. Sample: April 2005 – June 2023.

emissions has an immediate impact on energy production costs. Since GHG emissions data are only available at an annual frequency, we interpolate them to a monthly frequency using a Chow–Lin temporal disaggregation procedure, with industrial production serving as the monthly indicator.[9] When employing the third identification strategy, we replace the three-month interbank rate with the one-year OIS rate, which better captures changes in the Euro Area monetary policy stance – particularly during the zero lower bound period.

The models include either 12 or 6 lags of the endogenous variables and are estimated using Bayesian methods – that efficiently deal with the high dimensionality of the systems – with standard macroeconomic priors, as described in Section B.1 of the Online Appendix. Shocks are identified using either external instruments or sign restrictions. A detailed description of the Proxy-SVAR methodology is provided in Section B.2 of the Online

[9]The same approach has been employed by Känzig (2023).

Appendix.

To evaluate the importance of various transmission channels, we select a set of indicators that capture economic sentiment, financial uncertainty, rebalancing toward green assets, and climate-related risk and uncertainty. We augment our baseline VAR by including these indicators – one by one – as additional variables.[10]

The indicators that we consider are twelve: the Economic Sentiment Indicator and the Employment Expectations Indicator produced by the European Commission DG ECFIN; the Consensus Forecasts one-year-ahead projections for GDP growth, private consumption, inflation, and unemployment rate; the VSTOXX Volatility Index; a measure of green excess returns, computed as the ratio between the Dow Jones BIC Europe Sustainability Index and the STOXX Europe 600; the global, equally weighted, Energy Uncertainty Index by Dang et al. (2023); the Transition Risk and Physical Risk Indices by Bua et al. (2024); and the Media Climate Change Concerns (MCCC) Index by Ardia et al. (2023).[11]

The estimation sample varies across exercises. When employing the first identification strategy, the sample runs from January 1999 to December 2018, matching the sample period used in Känzig (2023). When using sign restrictions (the second identification strategy), the sample starts in May 2005 – constrained by the limited historical availability of EUA surprises – and ends in June 2023. For the third identification strategy, the sample extends from January 1999 to June 2023. The sample period also varies across the augmented VAR specifications, depending on the data availability of the selected indicator. Table A.6 reports the specific sample period for each case.

To assess the role of Euro Area monetary policy in shaping the transmission of the carbon path shock, we conduct a counterfactual exercise: a structural scenario analysis designed to isolate the monetary policy channel. This analysis uses the methodology

[10] To be precise, we adopt the specification used in Figure 3, augmented with the selected indicator and removing the unemployment rate.

[11] Regarding the MCCC Index, concerns are defined as 'the perception of risk and related negative consequences associated with this risk'. Based on this definition, Ardia et al. (2023) design a score that measures concerns using the informational content of news articles. Their methodology relies on two lexicons: (i) a risk lexicon, which identifies the level of discussion about (future) risk events, and (ii) a sentiment lexicon, which captures increases in the perceived severity of those risks. We use a monthly version of their daily aggregate index, which reflects changes in climate change concerns by aggregating article-level concern scores.

developed by Antolin-Diaz et al. (2021).[12] The exercise enables us to evaluate the significance of the monetary policy channel by contrasting a scenario in which variables respond endogenously to a carbon policy path shock with one in which the response of interest rates is offset by a counteracting sequence of Euro Area monetary policy shocks, keeping rates at their steady-state level.[13]

4 Empirical results

In this section, we show that changes to different dimensions of climate policy can have substantially different macroeconomic effects. First, we discuss the results obtained using our third – and most precise – identification strategy, which leverages information from the term structures of EUA futures and critical materials, while also accounting for residual endogenous variation in the surprises. We find that a carbon policy path shock – which can be thought of as a climate policy forward guidance shock – is deflationary, whereas a current stance shock is inflationary. Second, we quantify the role of the endogenous response of monetary policy in shaping the transmission of the path shock, showing that, in the absence of policy easing, the contractionary effects would be amplified. Third, we examine how the shock propagates across a variety of indicators capturing different transmission channels. Fourth, we demonstrate that an alternative identification strategy based on sign restrictions yields similar results. Finally, we show that the term structure of EUA futures – even when excluding very long maturities – contains sufficient information to identify the effects of a path shock, using the same data, sample, and specification as Känzig (2023) for comparability.

4.1 Carbon policy forward guidance shock

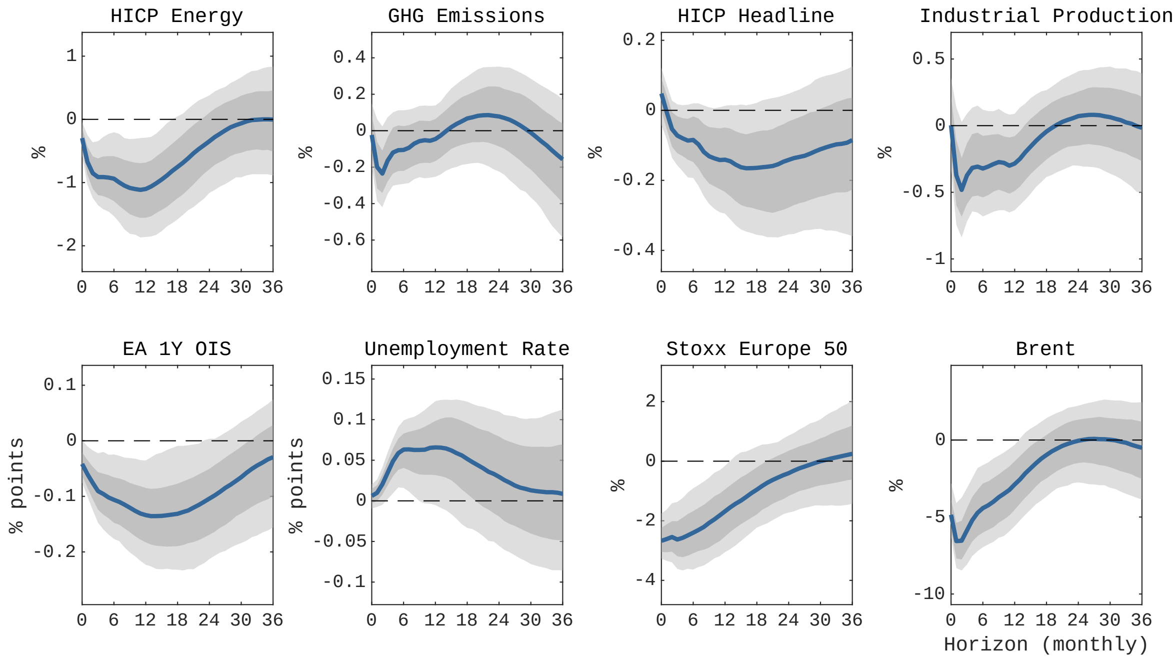
A carbon policy path shock propagates similarly to a negative demand shock, leading to a contraction in both quantities and prices (Figure 3).[14] Industrial production declines

[12] Breitenlechner et al. (2022) discuss how to adapt the Antolin-Diaz et al. (2021) framework to compare impulse responses across different scenarios.

[13] The sequence of monetary policy shocks is identified using the instrument based on high-frequency surprises around ECB announcements developed by Jarociński and Karadi (2020).

[14] Since the estimation sample spans the period from January 1999 to June 2023, it includes the pandemic and the related breaks in historical correlations. As a robustness check, we reduce the weight of

Figure 3: IRFs to carbon policy path shock – improved identification

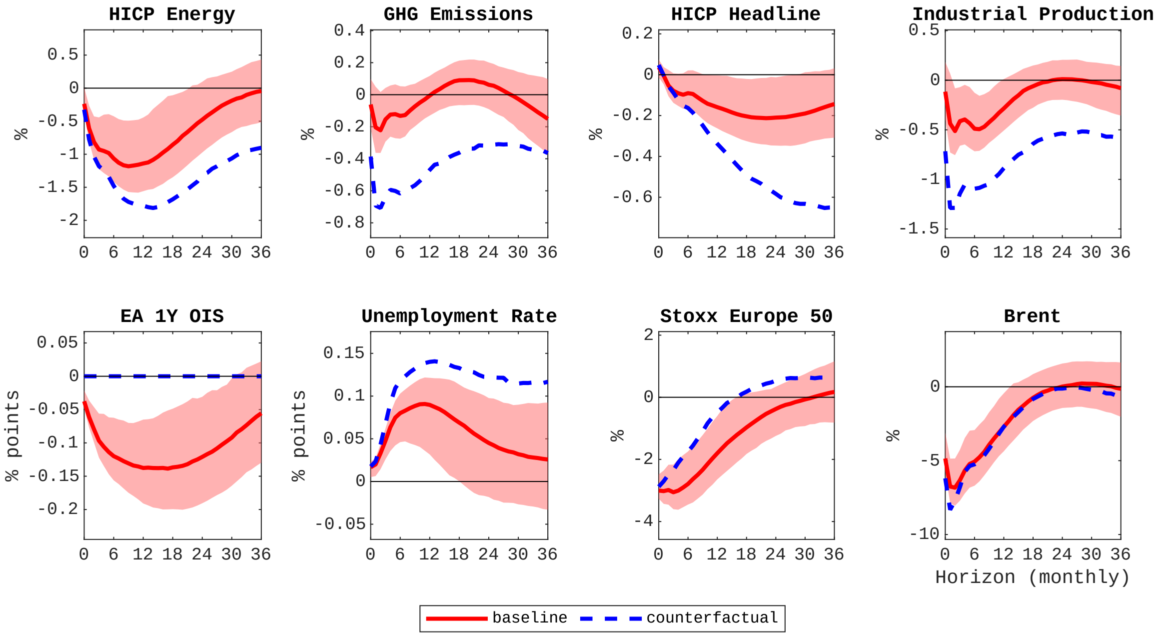


Note: Responses to a one-standard-deviation path carbon policy shock. Identification via external instruments using the second rotated factor in EUA and critical materials futures surprises, cleansed from the residual endogenous component. Bayesian VAR(12). Sample: 1999:1–2023:6. Results are virtually unchanged when controlling for the pandemic period (Figure C.4). Details on the series are reported in Table A.6. Gray bands denote 68% and 90% posterior credibility regions.

rapidly and persistently, quickly reaching a trough contraction of 0.5%, while the unemployment rate rises by 0.05 percentage points between six and twelve months after the shock. Greenhouse gas (GHG) emissions fall by approximately 0.2%. At the same time, consumer price inflation contracts, both in the overall index and in the energy component, declining by 0.2% and 1%, respectively. The stock market also falls sharply and persistently – by nearly 3% on impact – while the price of Brent crude oil drops by 5%, recovering only after two years. Most firms in the STOXX 50 are part of the "brown" economy. News signaling an acceleration of the green transition may thus lead to a decline in their stock valuations. Similarly, the drop in Brent prices is consistent with the path shock reducing demand for fossil fuels in favor of greener alternatives.

the pandemic period in the estimation of the reduced-form coefficients by applying pandemic priors (Cascaldi-Garcia, 2022). The results remain robust (Figure C.4).

Figure 4: Transmission without monetary policy intervention



Note: Responses to a one-standard-deviation path carbon policy shock, leaving all other shocks restricted to zero at all horizons (solid red); responses to a one-standard-deviation path carbon policy shock when a sequence of counteracting Euro Area monetary policy shocks offsets the response of the Euro Area 1Y OIS rate (dashed blue). Shocks are jointly (partially) identified via external instruments and one additional orthogonality restriction: carbon path shock identified using the second rotated factor in EUA and critical materials futures surprises, cleansed from the residual endogenous component; Euro Area monetary policy shock identified using as instrument the monetary policy shock corresponding to the median rotation of the sign restrictions provided by Jarociński and Karadi (2020). The IRFs to the monetary policy counteracting shock are reported in Figure C.6. Sample: 1999:1–2023:6. Bayesian VAR(6). Darker bands denote 68% posterior credibility regions. Details on the series are reported in Table A.6.

Facing no trade-off between price and output stabilization, the ECB unambiguously eases its policy stance, countering the recessionary effect. This monetary easing mitigates the contraction in industrial production and, consequently, the decline in emissions. It also helps support prices. To properly assess the efficacy of carbon policy and its macroeconomic implications, it is crucial to evaluate the effect of the policy in the absence of monetary policy intervention. To this end, we conduct a counterfactual exercise that isolates the transmission of the path shock through the monetary policy channel.

Absent the endogenous monetary policy response, the contractionary effects of the path shock are amplified: the impacts on headline inflation and emissions would be roughly three times stronger and more persistent, while the effects on industrial production and unemployment would be approximately twice as large (Figure 4).[15] On the one hand, this highlights the effectiveness of monetary policy in mitigating the adverse macroeconomic effects of the shock. On the other hand, it underscores that such easing comes at the cost of a smaller reduction in emissions.

The current stance shock leads to a sharp increase in prices, while industrial production and emissions decline (Figure C.3). This result is broadly consistent with Känzig (2023), although some differences emerge – possibly due to the different sample period, the use of the one-year OIS rate instead of the three-month interbank rate, or variations in data vintages. Overall, our results highlight a stark contrast in the propagation of shocks to the current policy stance versus those affecting the forward trajectory of carbon policy. While a stance shock behaves like a cost-push shock – raising prices and exerting recessionary pressure on output – a shock to the speed of the green transition is deflationary. We proceed by investigating the mechanisms through which the path shock propagates.

4.2 Transmission mechanisms

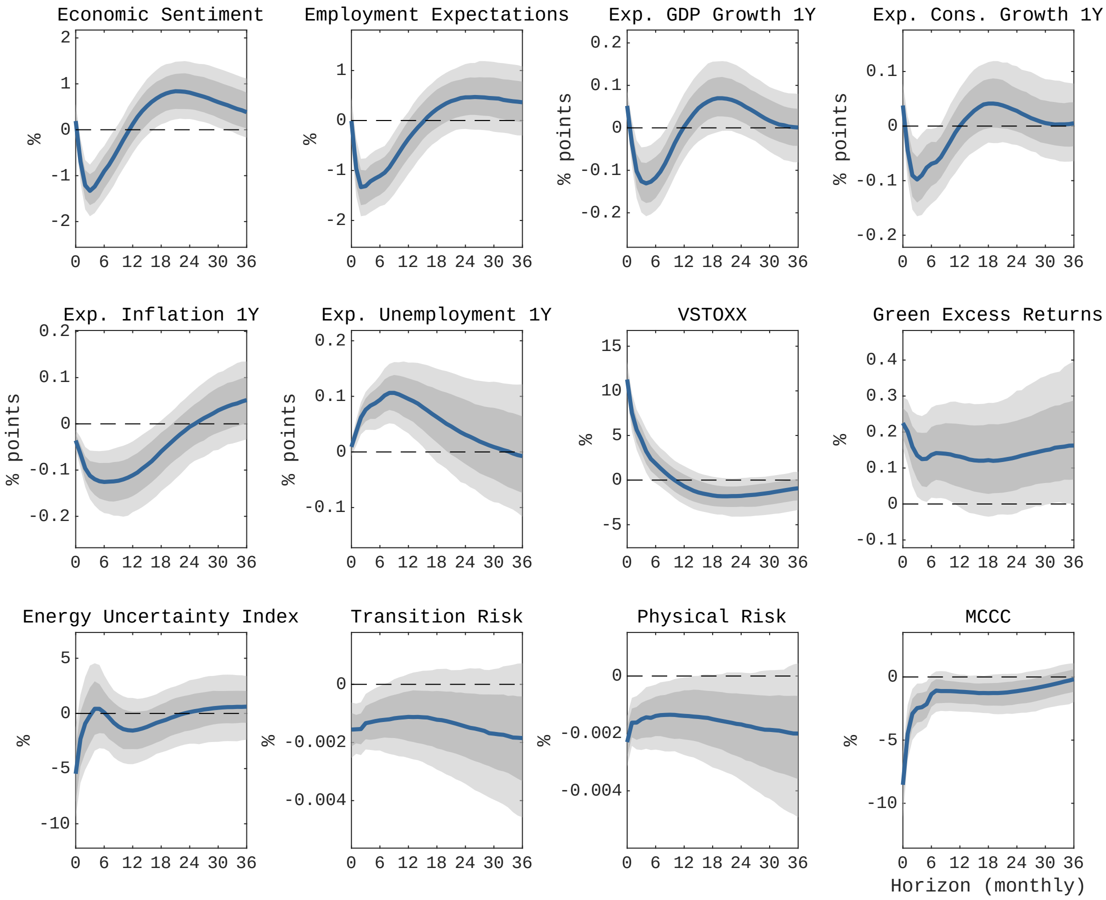
We study the transmission channels of the path shock by augmenting our baseline VAR with a variety of indicators, including them one at a time (Figure 5). We report only the responses of the selected indicators.

A one-standard-deviation path shock reduces economic sentiment and employment expectations by approximately 1%. Similarly, it leads to downward revisions of around 0.1 p.p. in expected growth, private consumption, and inflation, while expected unemployment is revised upward. The shock also increases financial uncertainty, with the VSTOXX index rising by 10% on impact, and triggers a rebalancing toward greener financial assets.

Importantly, the shock leads to a decline in measures of transition and physical risk developed by Bua et al. (2024), as well as in the energy uncertainty index proposed by

[15] Figure C.6 reports the impulse responses to the Euro Area monetary policy shock used as counteracting shock to offset the response of the interest rate to the carbon policy path shock. The credibility regions for the counterfactual scenario are shown in Figure C.8. Figure C.7 shows how the distribution of the monetary policy shock used to neutralize the monetary policy channel compares to its unconditional distribution. As expected, it shows that the sequence of shocks needed to stabilize the endogenous response of the interest rate to the path shock is composed predominantly of tightenings.

Figure 5: Propagation via variables important for the green transition



Note: Responses of selected indicators to a one-standard-deviation path carbon policy shock, obtained replacing the unemployment rate with the indicators of interest – one by one – in the specification used for Figure 3. Identification via external instruments using the second rotated factor in EUA and critical materials futures surprises, cleansed from the residual endogenous component. Bayesian VAR(6). The sample size depends on the availability of the indicators and is reported in Table A.6, together with details about the indicators. Gray bands denote 68% and 90% posterior credibility regions.

Dang et al. (2023). It also results in a contraction of the Media Climate Change Concerns (MCCC) Index constructed by Ardia et al. (2023), which drops by nearly 10% on impact. Such a decline suggests reduced apprehension about climate risks – both physical and transition – and may also reflect a decrease in uncertainty regarding the future evolution of climate policy.

A lower expected growth in consumption and output, weaker economic sentiment, and heightened uncertainty are key factors that may drive the deflationary effects of the shock. For example, if future consumption is expected to decline, households may reduce their current demand, exerting downward pressure on prices. Our theoretical analysis focuses on this channel.

4.3 Sign restrictions on high-frequency surprises

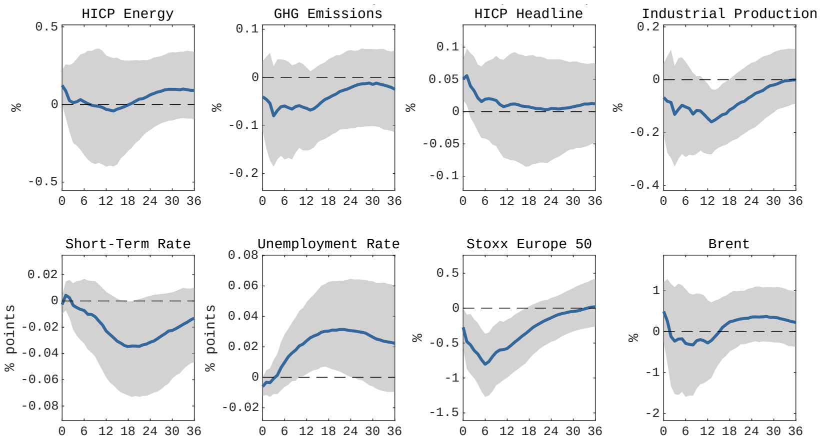
The results are virtually identical when using an alternative identification strategy that imposes sign restrictions on the comovement of high-frequency surprises in the prices of carbon futures, energy transition metals, and the European stock market index (Figure 6). The restrictions require that, within the event window, the stance shock affects the short end of the term structure of critical materials more than the long end, while the opposite holds for the path shock. Additionally, both shocks are assumed to depress stock prices.

A current stance shock is both inflationary and recessionary, consistent with the findings of Känzig (2023) and with our own results from the previous section (Panel 6a). Following a one-standard-deviation shock – corresponding to a 0.03% surprise in the price of EUA front-quarter futures – headline and energy HICP increase by 0.05% and 0.1%, respectively, while industrial production declines, unemployment rises, and the stock market contracts. GHG emissions decrease, while the monetary authority tends to ease the policy stance. No clear response pattern is observed for Brent crude prices.

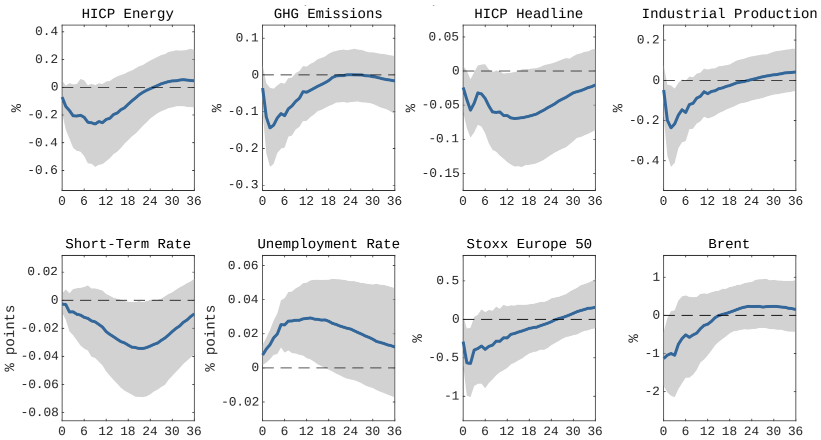
A path shock, by contrast, is deflationary (Panel 6b). Following a one-standard-deviation shock – corresponding to a 0.01% surprise in the price of EUA front-quarter futures – energy and headline HICP decrease by 0.3% and 0.05%, respectively. On the real side, the effects of the path shock are recessionary and similar in magnitude to those of the stance shock: industrial production declines, unemployment rises, and the stock market contracts. GHG emissions fall by 0.1%, and notably, the price of Brent crude decreases by 1%. Once again, the monetary authority responds by easing the policy stance, mitigating part of the shock's negative impact.

Panel 6c presents the impulse responses to a shock identified using the residual variation in the surprises. A one-standard-deviation shock – corresponding to a 0.03% surprise in the price of EUA front-quarter futures – propagates as a positive demand shock, leading to a significant increase in GHG emissions. Simultaneously, there is an

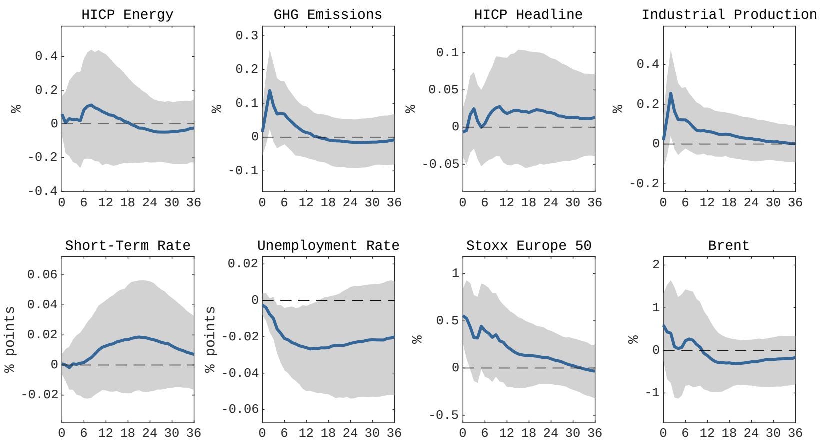
Figure 6: Alternative identification via sign restrictions



(a) Current stance shock



(b) Path shock



(c) Residual component

Note: Responses to one-standard-deviation current stance and path shocks (Panels 6a and 6b). Panel 6c reports the responses to a shock identified using the residual variation in the surprises as proxy. Identification via sign restrictions on the impact response of high-frequency surprises, as described in Table 1. Bayesian VAR(12). Sample: 2005:5–2023:6. Details on the series are reported in Table A.6. Gray bands denote 68% posterior credibility regions.

expansion in economic activity, as evidenced by rising industrial production and stock prices, and a decline in the unemployment rate. The shock also exerts upward pressure on both energy and headline inflation, interest rates, and the price of Brent crude.

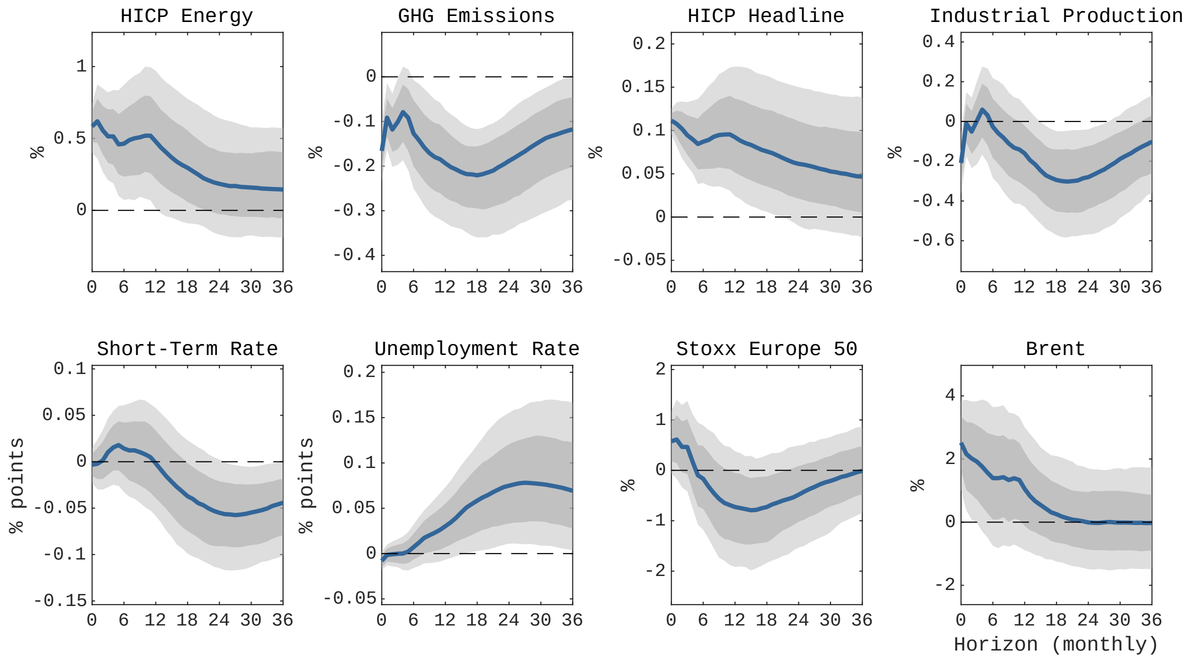
The results are robust to reducing the influence of the Covid-19 period in the estimation of the reduced-form parameters of the VAR. This is done by casting pandemic priors, in the form of dummy variables for the months between March and August 2020, following Cascaldi-Garcia (2022). Figure C.5 shows that the impulse responses are virtually identical to the baseline results. In another robustness exercise, we show that using longer maturity contracts to compute the surprises in the slope of the term structure of critical materials – which is used to cast the sign restrictions – returns similar results (Figure C.9). Specifically, we define the slope as the first principal component of the difference between surprises in the 17-month and front-month contracts of copper, zinc, and nickel.

4.4 Using the EUA term structure

Similar results are obtained even when relying solely on the informational content of the EUA futures term structure to distinguish between the two shocks. To enhance comparability, we adopt the same data, sample, and specification as Känzig (2023), and identify the stance and path shocks using external instruments constructed as rotated factors extracted from surprises in the EUA futures term structure.

A one-standard-deviation stance shock leads to a persistent inflationary effect, as higher costs for firms under the ETS are passed through to consumer prices (Figure 7). Simultaneously, industrial production declines and the unemployment rate rises. Emissions fall significantly, indicating that the current regulation effectively induces a short-run switch to less polluting fuels. Monetary policy – as reflected by the 3-month Euro interbank rate – does not adjust in the initial months following the shock due to rising inflationary pressure, but it eases in the medium term in response to the recessionary effects. Stock prices show no significant reaction to the shock, while Brent crude prices significantly increase on impact. Overall, the effects of a stance shock align closely with the findings of Känzig (2023).

Figure 7: IRFs to carbon policy current stance shock – EUA futures only

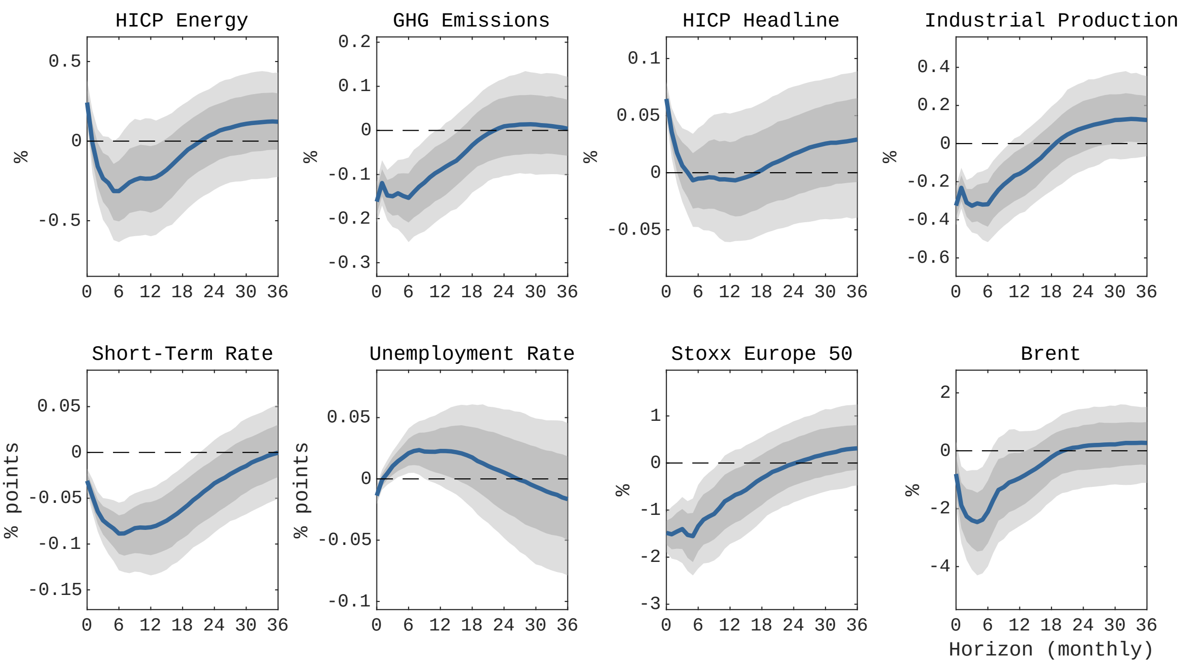


Note: Responses to a one-standard-deviation current stance carbon policy shock. Identification via external instruments using the first rotated factor in EUA futures (1-quarter-ahead to 5-quarter-ahead) surprises. Bayesian VAR(12). Sample: 1999:1–2018:12. For details on the series used, please refer to Känzig (2023). Gray bands denote 68% and 90% posterior credibility regions.

The effects of the path shock are qualitatively similar to those obtained under our preferred identification strategy, except for a transitory initial positive impact on consumer price inflation (Figure 8). After an initial uptick, inflation quickly turns negative for HICP energy and becomes insignificant for headline HICP. These dynamics may be driven by the strong monetary policy response sustaining prices, the inclusion of the residual component (which is not controlled for here), or the fact that information from the EUA term structure alone is insufficient to accurately isolate the two shocks. Similar to the stance shock, industrial production declines, unemployment rises, and GHG emissions plunge. Both stock prices and oil prices also fall sharply.

The impulse response functions reported in Figures 7 and 8 are estimated from VARs that include 12 lags of the endogenous variables. The robust first-stage F-statistics are 6.8 for the current stance shock and 85 for the path shock. Figures C.1 and C.2 in the Appendix demonstrate that the results remain consistent when using 6 lags, as in Känzig

Figure 8: IRFs to carbon policy path shock – EUA futures only



Note: Responses to a one-standard-deviation path carbon policy shock. Identification via external instruments using the second rotated factor in EUA futures (1-quarter-ahead to 5-quarter-ahead) surprises. Bayesian VAR(12). Sample: 1999:1–2018:12. For details on the series used, please refer to Känzig (2023). Gray bands denote 68% and 90% posterior credibility regions.

(2023). In that specification, the robust F-statistics increase to 18 for the current stance shock and 103 for the path shock.

5 An environmental DSGE model

We use the environmental DSGE model developed by Ferrari and Nispi Landi (2025) (FNL, henceforth) to simulate the current stance and the path shock. The model consists of five agents: a representative household, final-good firms, intermediate-good firms, the central bank, and the government.

The representative household chooses consumption, labor, investment in physical capital and in risk-free bonds in order to maximize her intertemporal utility function, which is increasing in consumption and decreasing in labor. Investment in capital is subject to adjustment costs. The representative final-good firm operates in perfect competition and produces the consumption and the investment good using as inputs a continuum of differentiated green and brown intermediate goods. Intermediate-good firms operate in monopolistic competition and produce an intermediate good using capital and labor, being subject to price adjustment costs, which give a role to monetary policy. In the brown sector, brown production of the intermediate good increases the flow of CO_2 emissions, which in turn fuel the stock of atmospheric carbon. A carbon tax per unit of emissions induces brown firms to reduce production and/or to spend on abatement activity to decrease emission intensity. Green firms do not pollute. Total factor productivity of both green and brown firms increases over time: this assumption implies that the flow and the stock of emissions would increase over time, without an appropriate carbon tax. The central bank sets the nominal interest rate using a Taylor rule targeting inflation. The government sets the carbon tax, rebating the revenues to households through lump-sum transfers.

The model is calibrated to the Euro Area, using the parameters of the ECB New Area Wide Model (Coenen et al., 2018). The interested reader may refer to FNL for the full list of equations and parameter values.

5.1 Model intuition

To better understand the intuition of the model, it is useful to consider a simplified version with no capital and only one sector. This model is not used for simulation, but only to fix ideas. Under these assumptions, FNL show that the model can be written as the 3-equation New Keynesian model:

$$y_t = \mathbb{E}_t y_{t+1} - \frac{1}{\sigma}\left(r_t - \mathbb{E}_t \pi_{t+1}\right) \tag{1}$$

$$\pi_t = \beta \mathbb{E}_t \pi_{t+1} + \kappa\left(y_t + \psi \tau_t\right) \tag{2}$$

$$r_t = \phi \pi_t \tag{3}$$

where y_t is output, π_t is inflation, r_t is the policy rate, τ_t is the carbon tax, and σ, β ,κ ,ψ, and ϕ are positive parameters. Assuming that the green transition implies a gradual increase in the carbon tax such that:

$$\tau_{t+1+j} = \bar{\tau} > \tau_t > 0 \;\; \forall j \geqslant 0, \tag{4}$$

it is easy to show that the simplified model reaches the long-run equilibrium in period $t+1$, where $y_{t+1} = \bar{y} = -\psi\bar{\tau}$ and $\pi_{t+1} = \bar{\pi} = 0$. We can then rewrite the system using an AD-AS representation:

$$y_t = -\psi\bar{\tau} - \frac{\phi}{\sigma}\pi_t \tag{5}$$

$$\pi_t = \kappa\left(y_t + \psi\tau_t\right). \tag{6}$$

Equation (5) is an aggregate demand curve – a negative relation between output and inflation. Equation (6) is an aggregate supply curve – a positive relation between output and inflation. It is immediate to see that the green transition negatively affects both demand and supply. Carbon taxes affect current demand by reducing future income.[16] They affect supply by increasing firms' marginal costs. FNL show that whenever the green transition is gradual ($\bar{\tau} > \tau_t$) the demand channel prevails and inflation goes down. Solving the system, we indeed get:

$$\pi_t = -\frac{\sigma\kappa\psi}{\sigma + \phi\kappa}\left(\bar{\tau} - \tau_t\right). \tag{7}$$

5.2 Scenarios

We consider a baseline scenario with a carbon tax starting from 0 and increasing linearly for 30 years, when it reaches a level such that all emissions are abated (corresponding to a price of carbon equal to 65 euro per ton of CO_2).[17] This is the scenario studied in FNL. Compared to FNL, we focus on a current stance shock and a path shock, to verify that they have an opposite impact on inflation, as shown in our empirical analysis. Both

[16]The fall in future household income is partially offset by the fact that the government rebates the revenues from the tax directly to households. Note that if the government gradually increased taxes on consumption, rather than on emissions, households would raise current demand, as future consumption would be more expensive.

[17]The price of carbon per ton of CO_2 is proportional to the carbon tax. See Ferrari and Nispi Landi (2023) for details.

shocks are modeled on top of the baseline scenario.

The stance shock is a further temporary and unanticipated increase in the *level* of the carbon tax by 200 basis points (i.e. around 3 euro per ton of CO_2) 4 quarters after the start of the transition. The shock dies out following an AR(1) process with parameter 0.95. The path shock is an unanticipated increase in the *slope* of the carbon price after 4 quarters. The slope starts decreasing from the higher level in the following quarter, until it comes back to the same slope as the baseline scenario, in quarter 60. Since then, the new path and the baseline path are parallel, until they reach the final level. The shock aims to capture exactly an acceleration of the green transition.

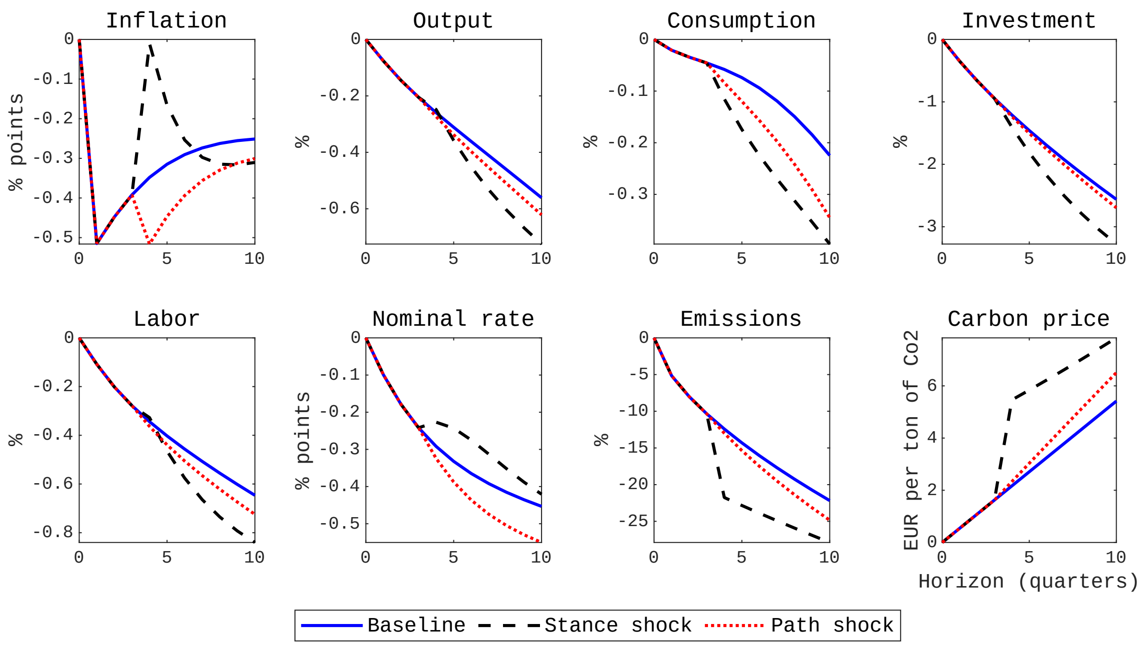
5.3 Results

The baseline scenario shows that the green transition is deflationary (Figure 9, blue solid line), consistent with the findings in FNL. Given that households expect a declining consumption path, through the Euler equation they demand fewer goods and more savings, putting downward pressure on the interest rate (as shown by the simplified model in equations 1 or 5). The reduction in demand more than offsets the decline in supply caused by the higher carbon tax, as reflected in the Phillips curve (equation 6 in the simplified model): inflation decreases in both the green sector and, to a lesser extent, the brown sector.

What happens when we add a current stance and a path shock? When the stance shock arrives, the carbon tax is relatively higher in the present than in the future, given the autoregressive nature of the process (Figure 9, black dashed line). This implies that the shock does not have a big effect on future income, dampening the negative demand effect of the Euler equation. The supply channel dominates and inflation goes up, compared to the baseline scenario shown in the blue solid line.

The path shock has opposite effects on inflation compared to the stance shock, consistent with our empirical findings (Figure 9, red dotted line). The shock increases both the current and future carbon tax, with the latter rising more: the simple model in equation (5)–(6) would predict deflationary effects and this is what we observe also in our simulations. The policy rate goes down, as found in the empirical section. Notice that

Figure 9: TRANSITION TO A GREEN ECONOMY



Note: The blue solid line shows the transition to a zero-emission economy, driven by an emission tax. The black dashed line shows the current stance shock. The red dotted line shows the path shock.

both shocks imply a larger recession, as the carbon tax is higher: output, consumption, investment, and labor fall below their baseline level.

In the Appendix we also perform some robustness checks on choices made in this section (Figures D.1–D.4): we consider a convex increase in the carbon tax rather than a linear increase; we double the value of the price of carbon necessary to abate the emissions; we analyze an incomplete transition where only half of emissions are abated in the new steady state; we consider a path shock where the slope comes back to the initial level after 30 quarters (as opposed to 60). Our main results are not qualitatively affected.

6 Concluding remarks

This paper advances the understanding of the macroeconomic implications of the green transition by distinguishing between shocks to the current stance – which temporarily increase the level of the carbon tax rate – and shocks to the future path of carbon policy – which increase the slope of the carbon tax schedule. In the latter case, regulation changes provide information on future policy moves: path shocks can be thought of as climate policy forward guidance shocks. By exploiting high-frequency regulatory surprises in the EU Emissions Trading System, computed on a set of financial asset prices that include the term structures of carbon emission allowances and critical materials futures, we identify how these two dimensions of carbon pricing differentially affect inflation, economic activity, and emissions.

Our findings demonstrate that while both shocks reduce greenhouse gas emissions and economic output, the current stance shock exerts upward inflation pressure, consistent with a cost-push effect. In contrast, the path shock is deflationary, driven by a dominant negative demand response. This insight challenges the often unidimensional treatment of green policies in the literature and underscores the importance of accounting for the timing and expectations embedded in climate regulation. Moreover, we show that the monetary authority's response is critical in shaping the macroeconomic outcomes of the green transition. Specifically, when a path shock occurs in isolation – without monetary policy easing – the contraction in output and emissions is substantially amplified.

A path shock negatively affects expectations of future growth and inflation. It reduces economic sentiment and employment outlook, and prompts professional forecasters to revise downward their projections for growth and inflation over the following year. At the same time, financial uncertainty rises. However, the shock also triggers a shift in investment toward greener financial assets and leads to a decline in several indicators of climate-related risk and uncertainty, suggesting reduced ambiguity about the future trajectory of the energy transition.

Our theoretical model shows that a path shock is deflationary. Anticipating higher future carbon taxes and a resulting decline in lifetime income, households reduce current consumption, triggering a contraction in demand. This demand-driven effect outweighs the supply-side impact of higher marginal costs for firms due to the tax. In contrast, the stance shock proves inflationary, consistent with our empirical results. Because it implies a temporary increase in carbon taxation, households foresee a future easing of the tax burden and an associated rise in expected disposable income, which offsets the negative demand effect. Simulations from the theoretical model closely replicate the impulse responses obtained from our empirical analysis, reinforcing the interpretation of the underlying transmission mechanisms.

We conduct a range of robustness exercises, including one that employs an alternative identification strategy based on sign restrictions and another that controls for the effects of the Covid-19 pandemic. Across these exercises, our results remain robust. Our findings emphasize the role of forward guidance by climate regulators as an effective tool to shape expectations and accelerate the transition. Taken together, these results offer important insights for policymakers seeking to design and implement climate policies that balance environmental goals with macroeconomic stability.

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Appendices

A Data

A.1 Regulatory events: announcement dates

Tables A.1 to A.4 list all the regulatory events used for the construction of surprises.

Table A.1: List of regulatory events

Date	ID	Event description
25/05/2005	1	Italian phase I NAP approved
20/06/2005	2	Greek phase I NAP approved
23/11/2005	3	Court judgement on proposed amendment to NAP, UK vs Commission
22/12/2005	4	Further guidance on allocation plans for the 2008–2012 trading period
22/02/2006	5	Final UK Phase I NAP approved
23/10/2006	6	Stavros Dimas delivered the signal to tighten the cap of phase II
13/11/2006	7	Decision avoiding double counting of emission reductions for projects under the Kyoto Protocol
29/11/2006	8	Commission decision on the NAP of several member states
14/12/2006	9	Decision determining the respective emission levels of the community and each member state
16/01/2007	10	Phase II NAPs of Belgium and the Netherlands approved
05/02/2007	11	Slovenia phase II NAP approved
26/02/2007	12	Spain phase II NAP approved
26/03/2007	13	Phase II NAPs of Poland, France and Czech Republic approved
02/04/2007	14	Austrian phase II NAP approved
16/04/2007	15	Hungarian phase II NAP approved
30/04/2007	16	Court order on German NAP, EnBW AG vs Commission
04/05/2007	17	Estonian phase II NAP approved
15/05/2007	18	Italian phase II NAP approved
07/11/2007	19	Court judgement on German NAP, Germany vs Commission
08/04/2008	20	Court order on German NAP, Saint-Gobain Glass GmbH vs Commission
23/04/2009	21	Directive 2009/29/EC amending Directive 2003/87/EC to improve and extend the EU ETS
23/09/2009	22	Court judgement on NAP, Poland vs Commission
24/12/2009	23	Decision determining sectors and subsectors which have a significant risk of carbon leakage
19/04/2010	24	Commission accepts Polish NAP for 2008-2012
09/07/2010	25	Commission takes first step toward determining cap on emission allowances for 2013
14/07/2010	26	Member states back Commission proposed rules for auctioning of allowances
22/10/2010	27	Cap on emission allowances for 2013 adopted
12/11/2010	28	Commission formally adopted the regulation on auctioning
25/11/2010	29	Commission presents a proposal to restrict the use of credits from industrial gas projects
15/12/2010	30	Climate Change Committee supported the proposal on how to allocate emissions rights
21/01/2011	31	Member states voted to support the ban on the use of certain industrial gas credits
15/03/2011	32	Commission proposed that 120 million allowances to be auctioned in 2012
22/03/2011	33	Court judgement on NAP, Latvia vs Commission
29/03/2011	34	Decision on transitional free allocation of allowances to the power sector
27/04/2011	35	Decision 2011/278/EU on transitional Union-wide rules for harmonized free allocation of allowances

Table A.2: List of regulatory events (cont'd)

Date	ID	Event description
29/04/2011	36	Commission rejects Estonia's revised NAP for 2008-2012
07/06/2011	37	Commission adopts ban on the use of industrial gas credits
13/07/2011	38	Member states agree to auction 120 million phase III allowances in 2012
26/09/2011	39	Commission sets the rules for allocation of free emissions allowances to airlines
14/11/2011	40	Clarification on the use of international credits in the third trading phase
23/11/2011	41	Regulation 1210/2011 determining the volume of allowances to be auctioned prior to 2013
25/11/2011	42	Update on preparatory steps for auctioning of phase 3 allowances
05/12/2011	43	Commission decision on revised Estonian NAP for 2008-2012
29/03/2012	44	Court judgments on NAPs for Estonia and Poland
02/05/2012	45	Commission publishes guidelines for review of GHG inventories in view of setting national limits for 2013-20
23/05/2012	46	Commission clears temporary free allowances for power plants in Cyprus, Estonia and Lithuania
05/06/2012	47	Commission publishes guidelines on State aid measures in the context of the post-2012 trading scheme
06/07/2012	48	Commission clears temporary free allowances for power plants in Bulgaria, Czech Republic and Romania
13/07/2012	49	Commission rules on temporary free allowances for power plants in Poland
25/07/2012	50	Commission proposed to backload certain allowances from 2013-2015 to the end of phase III
12/11/2012	51	Commission submits amendment to back-load 900 million allowances to the years 2019-2020
14/11/2012	52	Commission presents options to reform the ETS to address growing supply-demand imbalance
16/11/2012	53	Auctions for 2012 aviation allowances put on hold
30/11/2012	54	Commission rules on temporary free allowances for power plants in Hungary
25/01/2013	55	Update on free allocation of allowances in 2013
28/02/2013	56	Free allocation of 2013 aviation allowances postponed
25/03/2013	57	Auctions of aviation allowances not to resume before June
16/04/2013	58	The European Parliament voted against the Commission's back-loading proposal
05/06/2013	59	Commission submits proposal for international credit entitlements for 2013 to 2020
03/07/2013	60	The European Parliament voted for the carbon market back-loading proposal
10/07/2013	61	Member states approve addition of sectors to the carbon leakage list for 2014
30/07/2013	62	Update on industrial free allocation for phase III
05/09/2013	63	Commission finalized decision on industrial free allocation for phase three
26/09/2013	64	Update on number of aviation allowances to be auctioned in 2012
08/11/2013	65	Member states endorsed negotiations on the back-loading proposal
21/11/2013	66	Commission submitted non-paper on back-loading to the EU Climate Change Committee
10/12/2013	67	European Parliament voted for the back-loading proposal
11/12/2013	68	Climate Change Committee makes progress on implementation of the back-loading propsal
18/12/2013	69	Commission gives green light for a first set of member states to allocate allowances for calendar year 2013
08/01/2014	70	Climate Change Committee agrees back-loading
22/01/2014	71	Commission proposed to establish a market stability reserve for phase V
26/02/2014	72	Commission gives green light for free allocation by all member states
27/02/2014	73	Back-loading: 2014 auction volume reduced by 400 million allowances
13/03/2014	74	Commission approves first batch of international credit entitlement tables
28/03/2014	75	Commission approves second batch of international credit entitlement tables
04/04/2014	76	Update on approval of international credit entitlement tables
11/04/2014	77	Commission approves four more international credit entitlement tables
23/04/2014	78	Commission approves final international credit entitlement tables
02/05/2014	79	Commission published the number of international credits exchanged
05/05/2014	80	Commission submits proposed carbon leakage list for 2015-2019
04/06/2014	81	Auctioning of aviation allowances to restart in September
04/07/2014	82	Commission published the first update on the allocation of allowances from the New Entrants' Reserve
09/07/2014	83	Climate Change Committee agrees proposed carbon leakage list for the period 2015-2019
27/10/2014	84	Commission adopts the carbon leakage list for the period 2015-2019
04/11/2014	85	Updated information on exchange and international credit use
04/05/2015	86	Updated information on exchange and international credit use
15/07/2015	87	Proposal to revise the EU emissions trading system for the period after 2020
23/07/2015	88	Commission publishes status update for New Entrants' Reserve and allocation reductions
04/11/2015	89	Updated information on exchange and international credit use

Table A.3: List of regulatory events (cont'd)

Date	ID	Event description
15/01/2016	90	Commission publishes status update for New Entrants' Reserve
28/04/2016	91	Court judgment on free allocation in the EU ETS for the period 2013-2020
02/05/2016	92	Updated information on exchange and international credit use
23/06/2016	93	Following court judgement, commission to modify cross-sectoral correction factor for 2018-2020
15/07/2016	94	Commission published a status update on the allocation of allowances from the New Entrants' Reserve 2013-2020
08/09/2016	95	Court judgment on free allocation in the EU ETS for the period 2013-2020
04/11/2016	96	Updated information on exchange and international credit use
16/01/2017	97	Commission publishes status update for New Entrants' Reserve
24/01/2017	98	Commission adopts Decision to implement Court ruling on the cross-sectoral correction factor
15/02/2017	99	European Parliament voted in support of the revision of the ETS Directive for the period after 2021
27/04/2017	100	Climate Change Committee approves technical changes to auction rules
02/05/2017	101	Updated information on exchange and international credit use
12/05/2017	102	Commission publishes first surplus indicator for ETS Market Stability Reserve
17/07/2017	103	Commission publishes status update for New Entrants' Reserve
26/07/2017	104	Court judgment again confirms benchmarks for free allocation of ETS allowances for 2013-2020
06/11/2017	105	Updated information on exchange and international credit use
15/01/2018	106	Commission publishes status update for New Entrants' Reserve
04/05/2018	107	Updated information on exchange and international credit use
08/05/2018	108	Commission Notice on the preliminary carbon leakage list for phase IV (2021-2030)
15/05/2018	109	ETS Market Stability Reserve will start by reducing auction volume by almost 265 million allowances
16/07/2018	110	Commission publishes status update for New Entrants' Reserve
30/10/2018	111	Commission adopts amendment to ETS auctioning regulation
06/11/2018	112	Updated information on exchange and international credit use
05/12/2018	113	Poland's 2019 auctions to include some allowances not used for power sector modernization
04/01/2019	114	Amendment to the ETS auctioning regulation
15/01/2019	115	Commission publishes status update for New Entrants' Reserve
15/02/2019	116	Adoption of the Delegated Decision on the carbon leakage list for 2021-2030
23/04/2019	117	Iceland, Liechtenstein and Norway to start auctions on the common auction platform soon
15/05/2019	118	ETS Market Stability Reserve to reduce auction volume by almost 400 million allowances
16/05/2019	119	Revised 2019 auction calendars including EEA EFTA volumes published
12/06/2019	120	Poland's 2020 auction volume to include allowances not used for power sector modernisation
19/06/2019	121	Updated information on exchange and international credit use
11/07/2019	122	2020 and revised 2019 auction calendars of the common auction platform published
15/07/2019	123	Commission publishes status update for New Entrants' Reserve
28/08/2019	124	Commission amends ETS auctioning regulation for phase 4
31/10/2019	125	Commission adopts the Regulation on adjustments to free allocation due to activity level changes
08/11/2019	126	Auctioning regulation amendment for phase 4 of the EU ETS published and to enter into force
15/01/2020	127	Commission published the first update on the allocation of allowances from the New Entrants' Reserve
31/01/2020	128	Lifting the suspension of UK-related processes in the Union Registry of the EU ETS
21/02/2020	129	Auction calendar for the UK published
08/05/2020	130	ETS Market Stability Reserve to reduce auction volume by over 330 million allowances between September 2020 and August 2021 + Updated information on exchange and international credit use in the EU ETS
01/07/2020	131	2020 revised auction calendars published
05/08/2020	132	2020 calendar for transfers of allowances between the EU and Swiss emission trading registries
16/11/2020	133	Commission Decision (EU) 2020/1722 of 16 November 2020 on the Union-wide quantity of allowances to be issued under the EU ETS for 2021
17/11/2020	134	Start of phase 4 of the EU ETS in 2021: adoption of the cap and start of the auctions
27/11/2020	135	Timing of the distribution of free allowances in 2021 + 2021 calendar for transfers of allowances between the EU and Swiss emission trading registries
11/12/2020	136	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
17/12/2020	137	Commission Decision (EU) 2020/2166 of 17 December 2020 on the determination of the Member States' auction shares during the period 2021-2030 of the EU ETS
21/12/2020	138	2021 auction calendars published
12/03/2021	139	Commission Implementing Regulation (EU) 2021/447 of 12 March 2021 determining revised benchmark values for free allocation of emission allowances for the period from 2021 to 2025

Table A.4: List of regulatory events (cont'd)

Date	ID	Event description
12/05/2021	140	ETS Market Stability Reserve to reduce auction volume by over 378 million allowances between September 2021 and August 2022
25/05/2021	141	Updated information on exchange and international credits' use in the EU ETS
29/06/2021	142	Commission publishes the national allocation tables of Member States for EU ETS stationary installations eligible to receive free allocation in the period 2021-2025
22/07/2021	143	Revised 2021 and 2022 auction calendars published
16/02/2022	144	Revised 2022 auction calendar for general allowances published
05/04/2022	145	Amendments adopted by the European Parliament on 5 April 2022 on Decision (EU) 2015/1814 regarding the amount of allowances to be placed in the market stability reserve for the Union greenhouse gas ETS until 2030
12/05/2022	146	ETS Market Stability Reserve to reduce auction volume by over 347 million allowances between September 2022 and August 2023 (update)
19/05/2022	147	Revised 2022 auction calendar for general allowances published
28/07/2022	148	Revised 2022 and 2023 auction calendars published
19/04/2023	149	Decision (EU) 2023/852 amending Decision (EU) 2015/1814 as regards the number of allowances to be placed in the market stability reserve for the Union greenhouse gas ETS until 2030
25/05/2023	150	ETS Market Stability Reserve to reduce auction volume by over 272 million allowances between September 2023 and August 2024
21/06/2023	151	Revised 2023 auction calendar published

A.2 Macroeconomic and financial data

Table A.5 lists the futures contracts used in the construction of the instruments. Table A.6 provides details on the macroeconomic and financial data used in the paper including information on the data source, coverage, and transformations.

Table A.5: Futures used

Variable	Description	Source	Mnemonics	Sample
EUA futures	Itercontinental Exchange (ICE) ECX CFI, TRc1–TRc6 (settlement price)	Datastream	LEXC.01 – LEXC.06	Apr 2005 – Jun 2023
Zinc futures	London Metal Exchange (LME) - Zinc, TRc1–TRc18 (settlement price)	Datastream	LZZC.01 – LZZC.18	Jan 1999 – Jun 2023
Copper futures	London Metal Exchange (LME) - Copper, TRc1–TRc18 (settlement price)	Datastream	LCPC.01 – LCPC.18	Jan 1999 – Jun 2023
Nickel futures	London Metal Exchange (LME) - Nickel, TRc1–TRc18 (settlement price)	Datastream	LNIC.01 – LNIC.18	Jan 1999 – Jun 2023

Note: The table shows all futures contracts whose prices were used to construct the surprises.

Table A.6: Data description, sources, coverage, and transformations

Variable	Description	Source	Mnemonics	Sample	100·Logs	RW
HICP Energy	HICP Energy (EA-19), Index, 2015 = 100	Datastream	EKESCPENF	Jan 1999 – Jun 2023	•	•
GHG Emissions	Total GHG emissions exc. land use, land-use change and forestry and incl. int'l aviation	Eurostat/authors' calculations		Jan 1999 – Jun 2023	•	•
HICP Headline	HICP all items (EA-19), Index, 2015 = 100	Datastream	EKCPHARMF	Jan 1999 – Jun 2023	•	•
Industrial Production	Industrial production excl. construction (EA-19), WDA, SA, Index, 2021 = 100	Datastream	EKIPTOT.G	Jan 1999 – Jun 2023	•	•
Short-term rate	Euro interbank offered rate, 3-month, mean, eom	Datastream	EMINTER3	Jan 1999 – Jun 2023		
EA 1Y OIS	Euro 1 Year Overnight Index Swap, eom	Datastream	OIEUR1Y	Jan 1999 – Jun 2023		
Unemployment Rate	Unemployment rate (EA-19), SA	Datastream	EKESUNEMO	Jan 1999 – Jun 2023		
Stoxx Europe 50	STOXX Europe 50, eom	Datastream	DJSTO50	Jan 1999 – Jun 2023	•	•
Stoxx Europe 600	STOXX Europe 600, eom	Datastream	DJSTOXX	Jan 1999 – Jun 2023	•	•
Brent	Crude Oil Prices: Brent - Europe, $/bbl, NSA, eom	FRED	DCOILBRENTEU	Jan 1999 – Jun 2023	•	•
Economic Sentiment	Euro Zone, Economic Sentiment Indicator (ESI), Overall, SA	Datastream/European Commission	EKEUSESIG	Jan 1999 – Jun 2023	•	•
Employment Expectations	Euro Zone, Employment Expectations Indicator (EEI), Overall, SA	Datastream/European Commission	EKEUSEEIG	Jan 1999 – Jun 2023	•	•
Exp. GDP Growth 1Y	Consensus Forecasts, GDP growth, 1Y ahead, mean	Consensus Economics		Dec 2002 – Jun 2023		
Exp. Cons. Growth 1Y	Consensus Forecasts, private consumption growth, 1Y ahead, mean	Consensus Economics		Dec 2002 – Jun 2023		
Exp. Inflation 1Y	Consensus Forecasts, CPI inflation, 1Y ahead, mean	Consensus Economics		Dec 2002 – Jun 2023		
Exp. Unemployment 1Y	Consensus Forecasts, unemployment rate, 1Y ahead, mean	Consensus Economics		Dec 2002 – Jun 2023		
VSTOXX	VSTOXX Volatility Index	Datastream	VSTOXXI	Jan 1999 – Jun 2023	•	•
Green Excess Returns	Dow Jones BIC Europe Sustainability Index over STOXX Europe 600	Datastream	DJSEURE/DJSTOXX	Sep 2001 – Jun 2023	•	•
Energy Uncertainty Index	Energy Uncertainty Index	Dang et al. (2023)	global_EUI_equally_weighted	Jan 1999 – Oct 2022	•	•
Transition Risk	Transition Risk Index (TRI)	Bua et al. (2024)		Jan 2005 – Jun 2023	•	•
Physical Risk	Physical Risk Index (PRI)	Bua et al. (2024)		Jan 2005 – Jun 2023	•	•
MCCC	Media Climate Change Concerns Index	Ardia et al. (2023)		Jan 2003 – Aug 2022	•	•

Note: The table lists all variable used in the different models. The upper section lists all variables in the baseline specifications in Figures 3, 6, 7, and 8. The bottom section of the table lists the variables used to produce Figure 5. *100·Logs* indicates logarithmic transformations (and multiplication by 100). *RW* indicates assignment of a random walk prior vis-à-vis a white noise prior.

B Methodology

B.1 Bayesian vector autoregressions

The prior adopted in the empirical analysis is a standard Normal-Inverse-Wishart (Litterman, 1986; Kadiyala and Karlsson, 1997). It formalises the view that an independent random-walk model for each variable in the system is a reasonable centre for the beliefs about their time series behaviour (Sims and Zha, 1998). The prior is imposed by setting the following moments for the prior distribution of the coefficients:

$$\mathbb{E}\left[(\mathbf{A}_\ell)_{ij}|\mathbf{\Sigma}\right] = \begin{cases} \delta_i & j = i,\ \ell = 1 \\ 0 & \text{otherwise} \end{cases}, \qquad \mathbb{V}\left[(\mathbf{A}_\ell)_{ij}|\mathbf{\Sigma}\right] = \begin{cases} \frac{\lambda^2}{\ell^2} & \text{for } j = i, \forall \ell \\ \frac{\lambda^2}{\ell^2}\frac{\sigma_i^2}{\sigma_j^2} & \text{for } j \neq i, \forall \ell \end{cases}, \tag{B.1}$$

where $(\mathbf{A}_\ell)_{ij}$ denotes the coefficient of variable j in equation i at lag ℓ and δ_i is either 1 for variables in levels or 0 for rates.[18] The prior assumes the coefficients $\mathbf{A}_1, \ldots, \mathbf{A}_p$ to be a priori independent and normally distributed. It also assumes that the most recent lags of a variable tend to be more informative than distant lags. This is represented by ℓ^2. The hyperparameters $\sigma_1^2, \ldots, \sigma_n^2$ are set using sample information and equal the variance of the residuals from a univariate autoregressive model of order 1 for each variable in the system. The term σ_i^2/σ_j^2 accounts for differences in the scales of variable j relative to variable i. The hyperparameter λ controls the overall tightness of the prior. The tightness is estimated using the optimal prior selection approach proposed by Giannone et al. (2015). The prior is cast by means of dummy observations (Bańbura et al., 2010).

B.2 Identification via external instruments

Identification of the structural shocks of interest is based on the Proxy SVAR/IV-SVAR approach (Stock and Watson, 2012; Mertens and Ravn, 2013; Stock and Watson, 2018). Consider the following reduced-form VAR(p) model,

$$\mathbf{Y}_t = \mathbf{c} + \sum_{\ell=1}^{p} \mathbf{A}_\ell \mathbf{Y}_{t-\ell} + \mathbf{e}_t, \tag{B.2}$$

[18] This reflects the idea that variables characterised by high mean reversion are best represented by a white noise process rather than a random walk.

where $\mathbf{Y}_t$ is a $n \times 1$ vector of endogenous variables, $\mathbf{A}_1, \dots, \mathbf{A}_p$ are $n \times n$ matrices collecting the autoregressive coefficients, $\mathbf{c}$ is a $n \times 1$ vector of intercepts, p is the lag order, and $\mathbf{e}_t \sim \mathcal{N}(\mathbf{0}, \mathbf{\Sigma})$ is a $n \times 1$ vector of mean-zero innovations with covariance matrix $\mathbf{\Sigma}$.

Assume that the innovations are linear combinations of the structural shocks such that the following condition holds,

$$\mathbf{e}_t = \mathbf{B}\mathbf{u}_t, \tag{B.3}$$

where $\mathbf{u}_t \sim \mathcal{N}(\mathbf{0}, \mathbf{\Omega})$ is a $n \times 1$ vector of structural shocks and $\mathbf{B}$ is a $n \times n$ matrix of impacts. The identification problem arises because the covariance matrix $\mathbf{\Sigma} = \mathbf{B}\mathbf{\Omega}\mathbf{B}'$ only provides $n(n+1)/2$ restrictions to identify the n^2 free parameters in $\mathbf{B}$.

For ease of exposition, assume that we are interested in identifying the impact of only one shock which, without loss of generality, is ordered first in the vector $\mathbf{u}_t$. Partition Eq. (B.3) as follows:

$$\begin{bmatrix} e_t^1 \\ \mathbf{e}_t^{2:n} \end{bmatrix} = \begin{bmatrix} \mathbf{b}_1 & \mathbf{B}_{2:n} \end{bmatrix} \begin{bmatrix} u_t^1 \\ \mathbf{u}_t^{2:n} \end{bmatrix},$$

where the notation $2:n$ indicates columns 2 to n of the underlying matrix, or element 2 to n of the underlying vector. The vector $\mathbf{b}_1$, which is the object that we want to identify, represents the $n \times 1$ impact vector for the shock of interest u_t^1. The Proxy SVAR/IV-SVAR identification strategy exploits external instruments to isolate exogenous variation in the innovations of the instrumented variable (in this application, the real price of oil) that is due to the structural shock of interest. A valid instrument needs to satisfy the two conditions of relevance and exogeneity. These conditions can be summarized as follows:

$$\mathbb{E}\left(z_t u_t^1\right) = \phi \neq 0, \tag{B.4}$$

$$\mathbb{E}\left(z_t \mathbf{u}_t^{2:n}\right) = \mathbf{0}. \tag{B.5}$$

If the conditions are satisfied, then the impact vector $\mathbf{b}_1$ is identified up to sign and scale, as shown in the following expression:

$$\mathbb{E}\left(z_t \boldsymbol{e}_t\right) = \mathbf{B}\mathbb{E}\left(z_t \mathbf{u}_t\right) = \begin{bmatrix} \mathbf{b}_1 & \mathbf{B}_{2:n} \end{bmatrix} \begin{bmatrix} \mathbb{E}\left(z_t u_t^1\right) \\ \mathbb{E}\left(z_t \mathbf{u}_t^{2:n}\right) \end{bmatrix} = \mathbf{b}_1 \phi \tag{B.6}$$

In practice, the impact vector $\mathbf{b}_1$ is then normalised so that a unitary impulse in u_t^1 induces a unitary response in the instrumented variable. Given the following partitioning,

$$\mathbb{E}\left(z_t \boldsymbol{e}_t\right) = \begin{bmatrix} \mathbb{E}\left(z_t e_t^1\right) \\ \mathbb{E}\left(z_t \boldsymbol{e}_t^{2:n}\right) \end{bmatrix} = \begin{bmatrix} b_{1,1}\phi \\ \mathbf{b}_{2:n,1}\phi \end{bmatrix}$$

one can immediately obtain

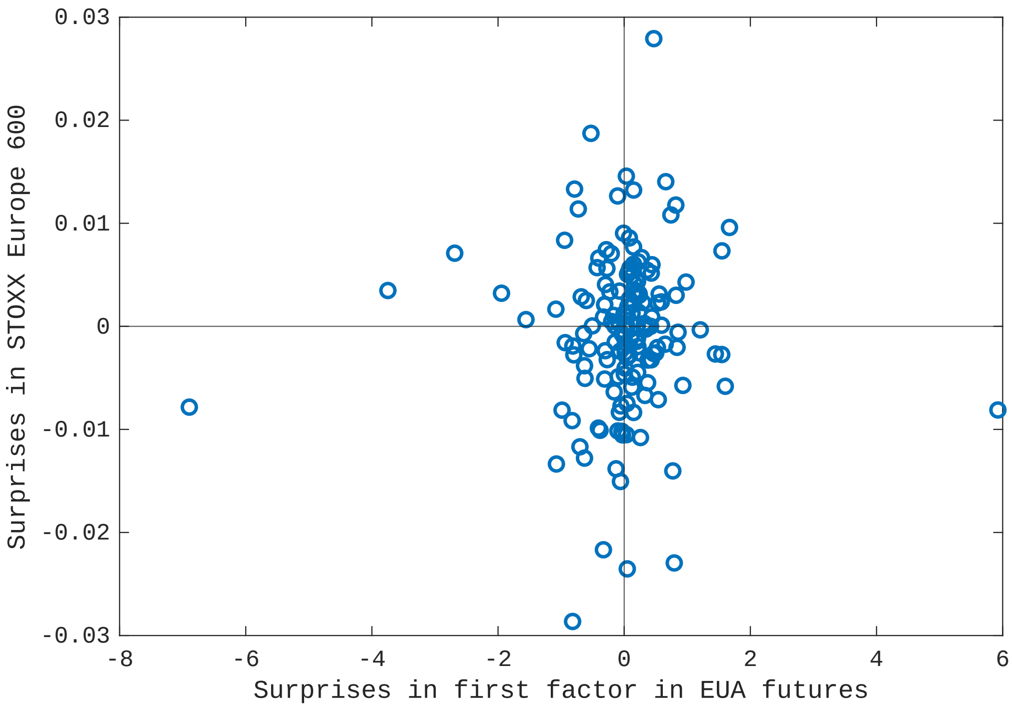
$$\mathbf{b}_{2:n,1} b_{1,1}^{-1} = \mathbb{E}\left(z_t \boldsymbol{e}_t^{2:n}\right) \mathbb{E}\left(z_t e_t^1\right)^{-1}$$

which identifies the impact vector $\mathbf{b}_1$ up to a scale.

B.3 Details on the identification via sign restrictions

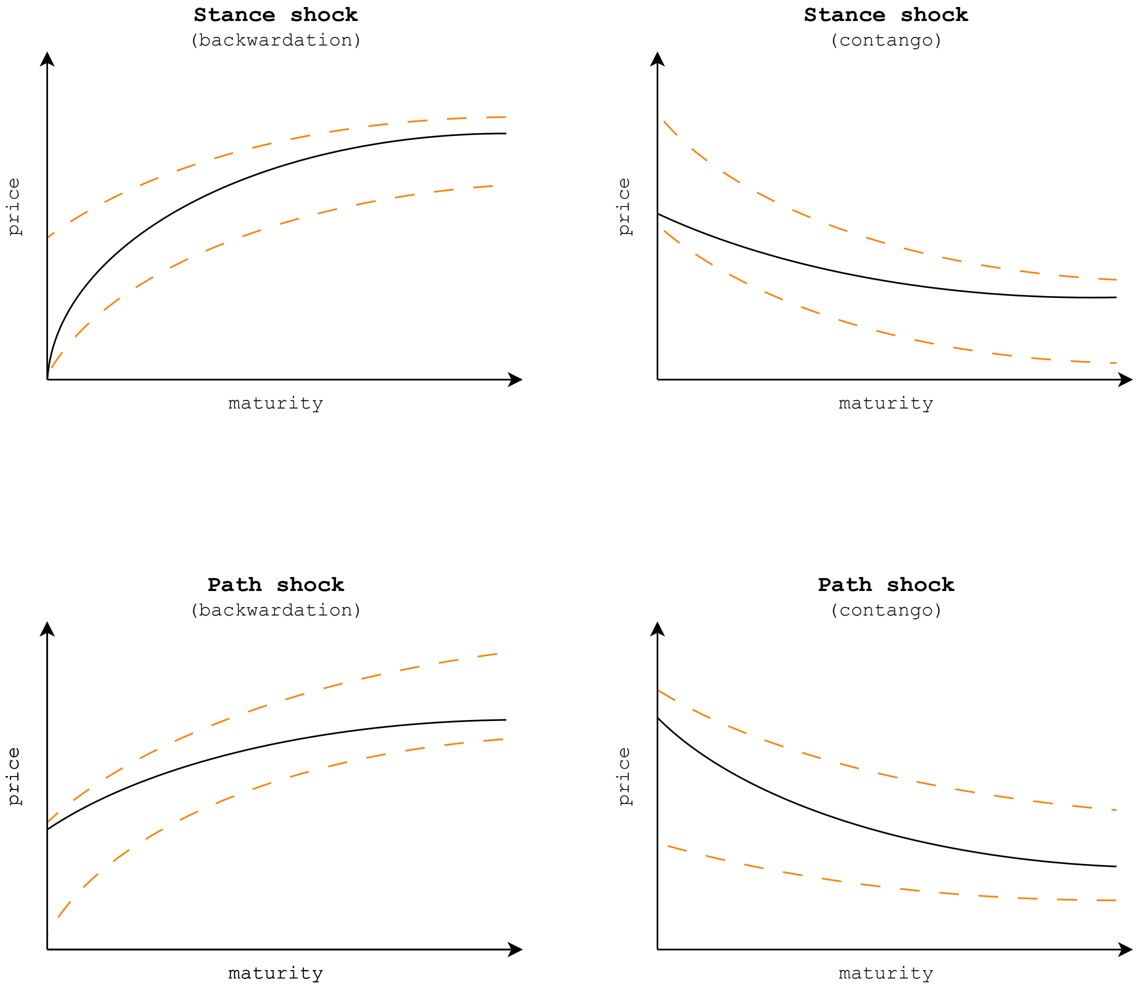
Figure B.1 shows the comovement, often times positive, between surprises in the price of carbon futures and surprises in the STOXX Europe 600. Figure B.2 illustrates, for each shock, the possible surprises to the term structure of critical materials that would be accepted under our sign restrictions.

Figure B.1: Comovement between EUA futures and stock prices



Note: Each dot represents the comovement between surprises in the first rotated principal component extracted from EUA futures surprises (front-quarter to 5-quarters-ahead) and surprises in the STOXX Europe 600 on the day of a specific regulatory event. The mass of dots in the upper-right and lower-left quadrants indicates that, for many regulatory events, a tightening of regulation corresponded within the day to stock market gains.

Figure B.2: Visualization of possible surprises to the slope of critical materials



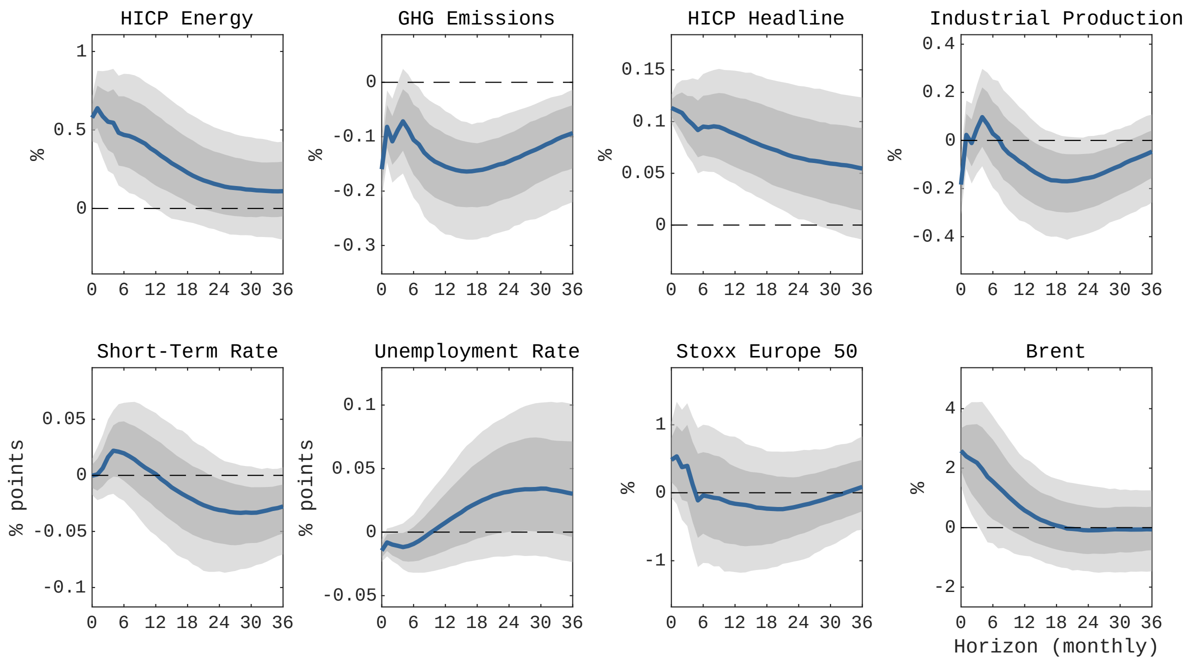
Note: the figure illustrates the surprises to the slope of the term structure of critical materials that would be considered valid under our sign restrictions. The black solid line depicts the term structure before the regulatory event. The orange lines depict shifts in the term structure that we would classify as valid to identify the shocks under our sign restrictions. The left panels illustrate the standard case in which the term structure is in backwardation, whereas the right panels are for the case of contango. The upper panels pertain to the current stance shock; the lower panels to the path shock. For instance, in the upper-left panel, we consider as valid shifts in the term structure that identify the stance shocks those cases in which the short end of the curve increases more than the long end and those cases in which the short end decreases by less than the long end.

C Robustness

C.1 Current stance and path shocks identified leveraging the EUA term structure

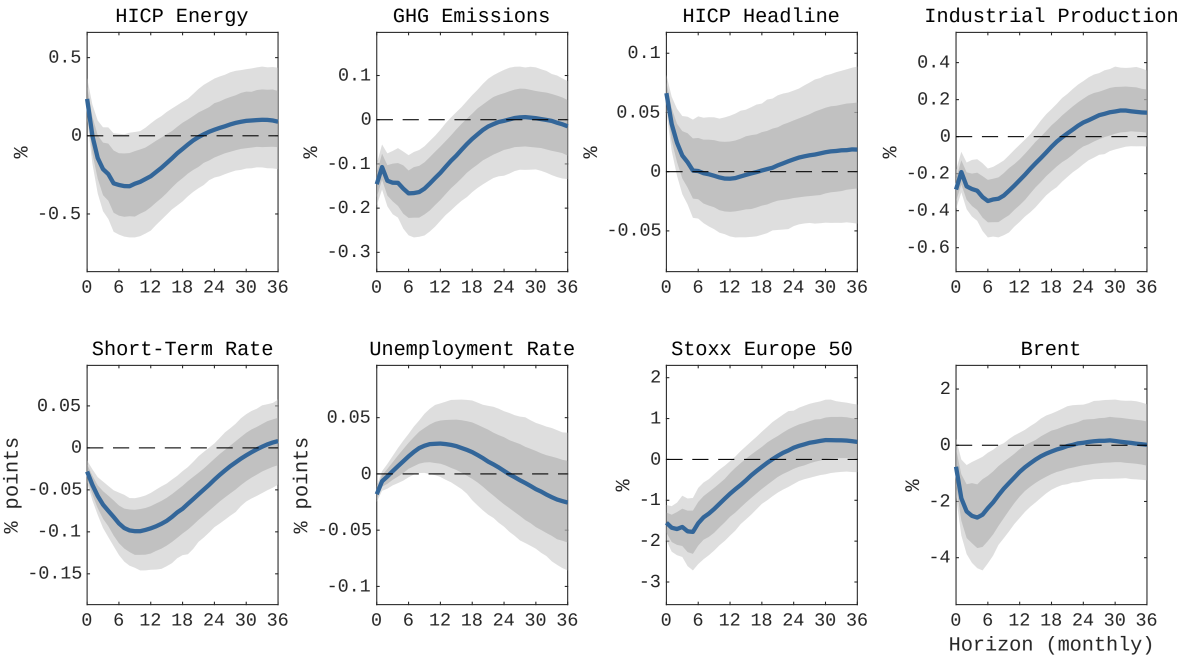
Using six instead of twelve lags of the endogenous variables in the VAR does not substantially alter the impulse response functions (Figures C.1 and C.2). However, the first-stage robust F-statistics are considerably higher with six lags.

Figure C.1: IRFs to current stance shock – EUA futures only, 6 lags



Note: Responses to a one-standard-deviation current stance carbon policy shock. Identification via external instruments using the first rotated factor in EUA futures (1-quarter-ahead to 5-quarters-ahead) surprises. Bayesian VAR(6). Sample: 1999:1–2018:12. For details on the series used, please refer to Känzig (2023). Grey bands denote 68% and 90% posterior credibility regions. Robust F-stat = 18.4.

Figure C.2: IRFs TO PATH SHOCK – EUA FUTURES ONLY, 6 LAGS



Note: Responses to a one-standard-deviation path carbon policy shock. Identification via external instruments using the second rotated factor in EUA futures (1-quarter-ahead to 5-quarters-ahead) surprises. Bayesian VAR(6). Sample: 1999:1–2018:12. For details on the series used, please refer to Känzig (2023). Grey bands denote 68% and 90% posterior credibility regions. Robust F-stat = 103.5.

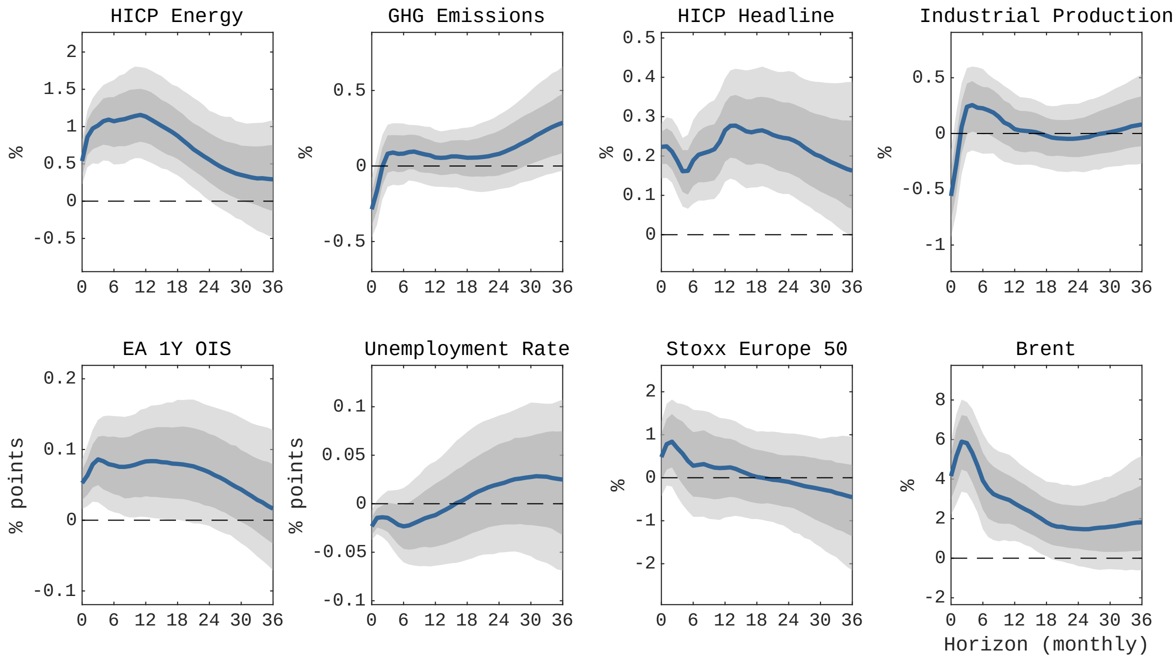
C.2 Current stance shock – improved identification

Figure C.3 shows that responses to a current stance carbon policy shock identified under our third – and most precise – identification strategy align with the responses obtained under the alternative two identification strategies and with the previous literature.

C.3 Controlling for the pandemic period

This robustness check is particularly relevant, given the significant structural breaks that Covid-19 introduced into the time series used in the analysis. Figures C.4 and C.5 show that the results obtained with our improved proxy and and with sign restrictions remain robust when the influence of the pandemic period on the estimation of the VAR's reduced-form parameters is downweighted by casting pandemic priors (Cascaldi-Garcia,

Figure C.3: IRFs to carbon policy current stance shock – improved identification



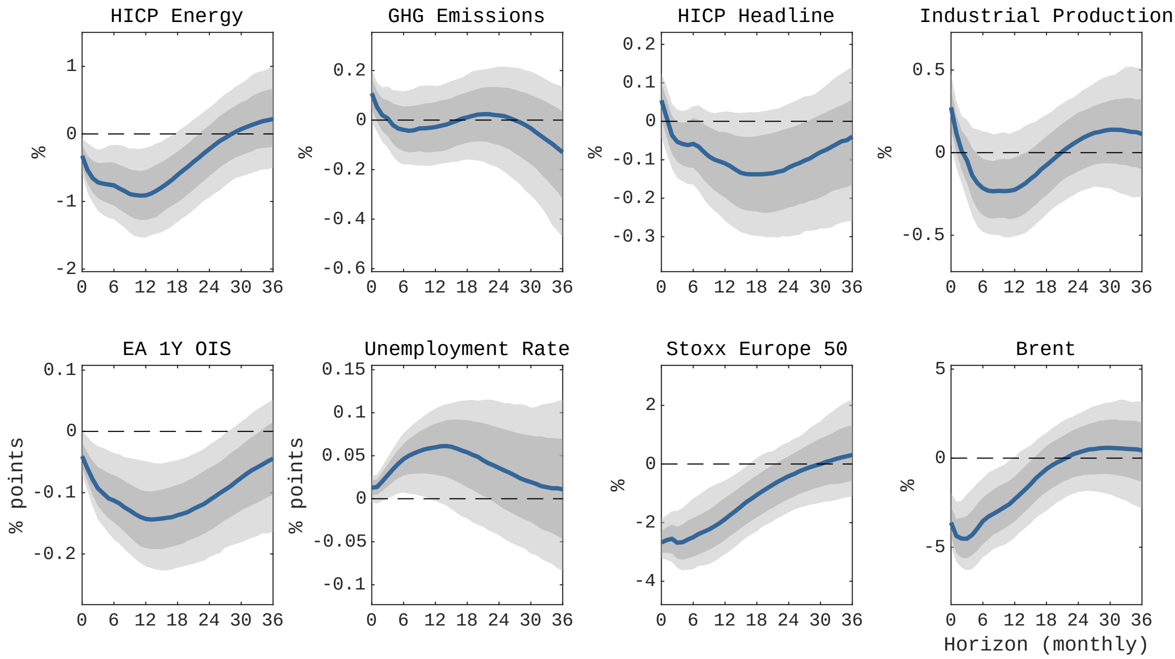
Note: Responses to a one-standard-deviation current stance carbon policy shock. Identification via external instruments using the first rotated factor in EUA and critical materials futures surprises, cleansed from the residual endogenous component. First-stage robust F-statistic = 15.6. Bayesian VAR(12). Sample: 1999:1–2023:6. Details on the series are reported in Table A.6. Grey bands denote 68% and 90% posterior credibility regions.

2022). In Figure C.4 the effect on emissions and industrial production appears more muted – due to credibility regions being larger. However, as we show in the structural scenario exercise, this is consistent with the monetary easing sustaining production, hence emissions.

C.4 Neutralizing the monetary policy channel

Figure C.6 shows the impulse response function to the counter-shock – a Euro Area monetary policy shock – used to neutralize the endogenous response of the interest rate to the path shock in Figure 4. The shock is identified using as an external instrument the monetary policy shock corresponding to the median rotation of the sign restrictions provided in Jarociński and Karadi (2020). Figure C.7 shows the distribution of the shocks under the structural scenario. The path shock has a degenerate distribution centred at one,

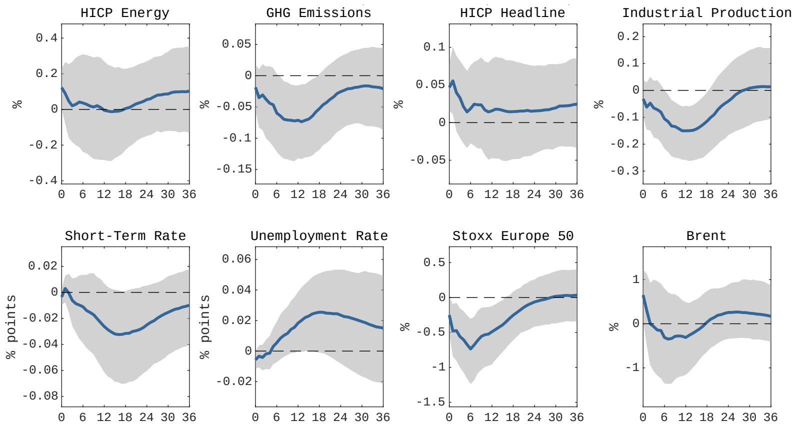
Figure C.4: IRFs to path shock – improved identification, excluding Covid-19



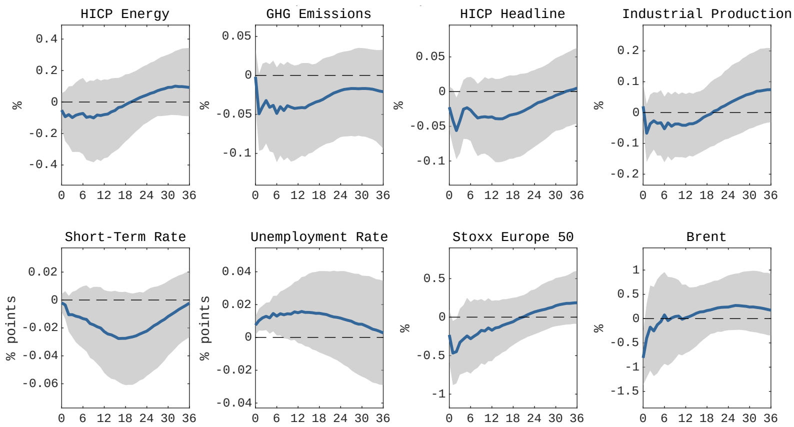
Note: Responses to a one-standard-deviation path carbon policy shock. Identification via external instruments using the second rotated factor in EUA and critical materials futures surprises, cleansed from the residual endogenous component. The informativeness of the pandemic period in the estimation of the reduced-form parameters of the VAR is reduced by including dummy variables for the months between March 2020 and August 2020 (Cascaldi-Garcia, 2022). Bayesian VAR(12). Sample: 1999:1–2023:6. Details on the series are reported in Table A.6. Grey bands denote 68% and 90% posterior credibility regions.

since it provides the initial impulse to the system. All other shocks – except the monetary policy one – are set to zero, hence their degenerate distributions. The distribution of the monetary policy shock – in the bottom-left panel – is shifted to the right, indicating that on average a sequence of monetary tightening shocks is needed to obtain the structural scenario. The mass of the distribution is concentrated within the support of a normal probability density function, indicating that the scenario is reasonably plausible (see Antolin-Diaz et al., 2021, for more details on scenario plausibility). Figure C.8 reports the impulse response functions to the path shock under the structural scenario, including 68% credibility regions.

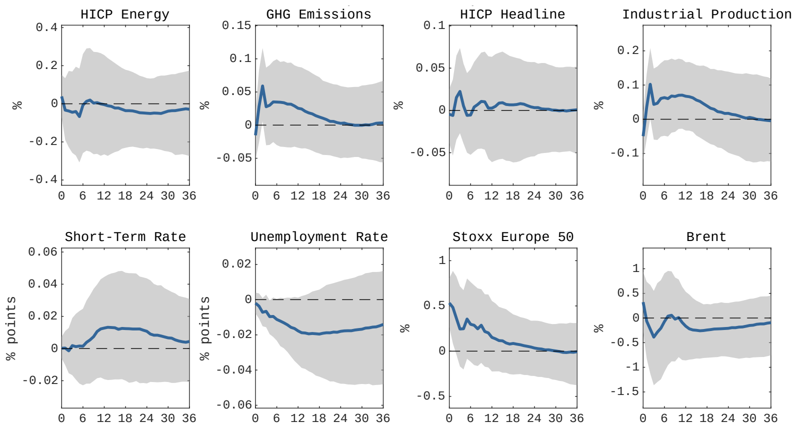
Figure C.5: Alternative identification via sign restrictions, excluding Covid-19



(a) Current stance shock



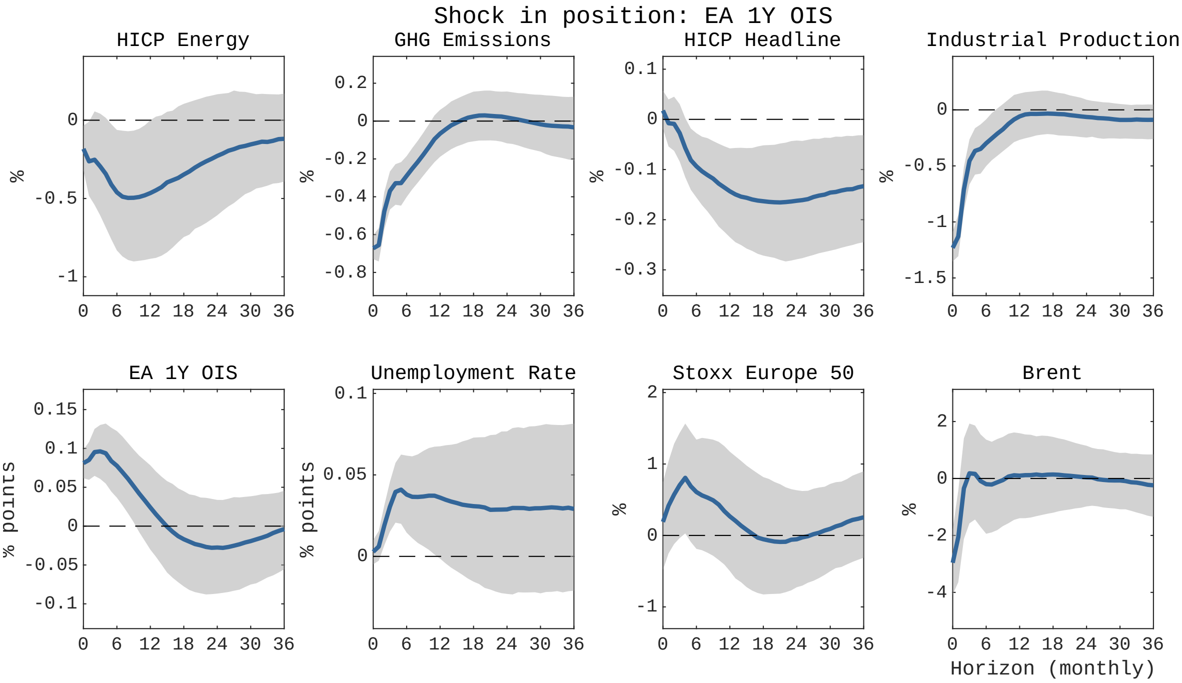
(b) Path shock



(c) Residual component

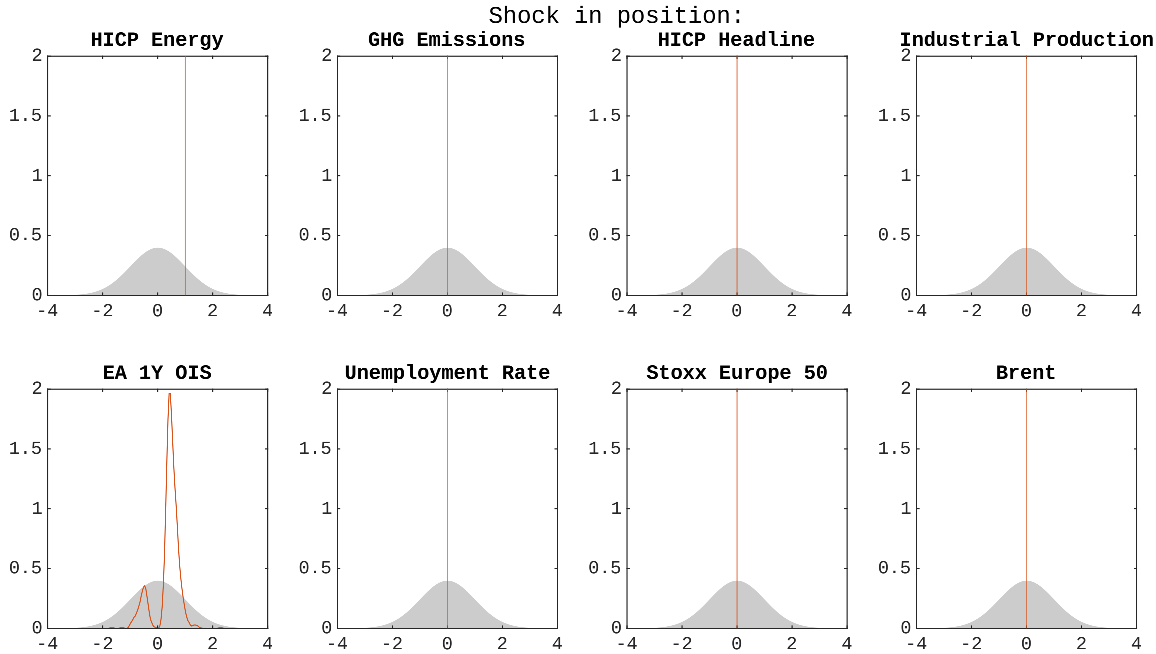
Note: Responses to one-standard-deviation current stance and path shocks (Panels C.5a and C.5b). Panel C.5c reports the responses to a shock identified using the residual variation in the surprises as proxy. Identification via sign restrictions on the impact response of high-frequency surprises, as described in Table 1. The informativeness of the pandemic period in the estimation of the reduced-form parameters of the VAR is reduced by including dummy variables for the months between March 2020 and August 2020 (Cascaldi-Garcia, 2022). Bayesian VAR(12). Sample: 2005:5–2023:6. Details on the series are reported in Table A.6. Grey bands denote 68% posterior credibility regions.

Figure C.6: Counter-shock for the structural scenario



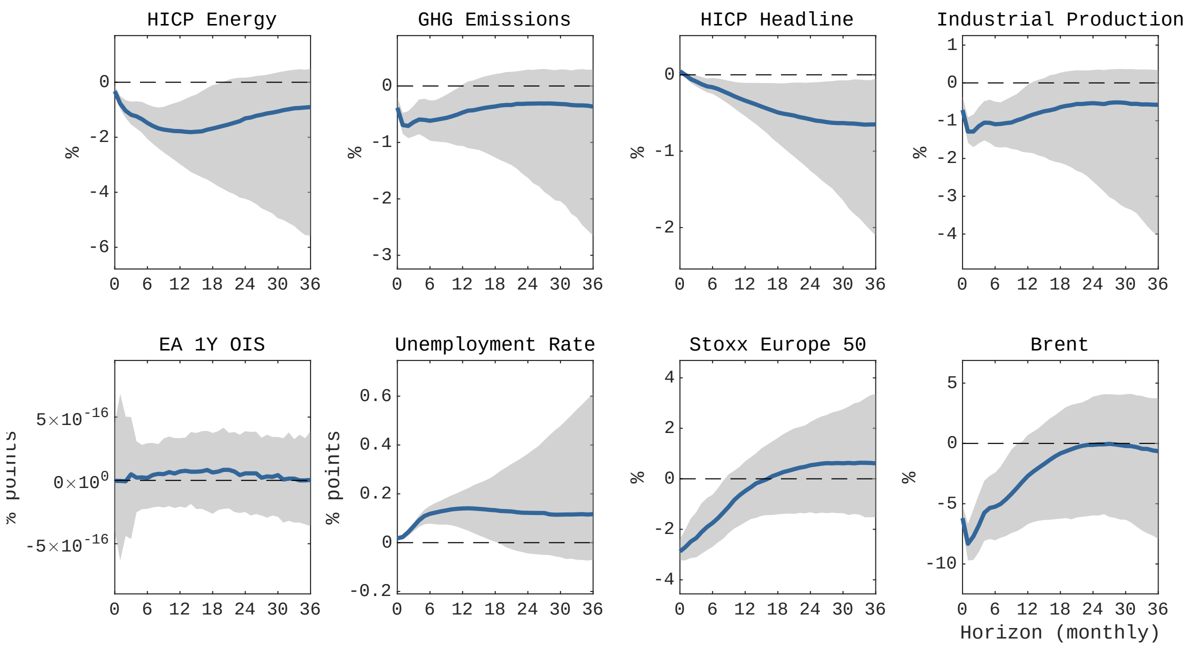
Note: Responses to a one-standard-deviation Euro Area monetary policy shock. The shock is jointly (partially) identified via external instruments and one additional orthogonality restriction together with a carbon path shock. The former is identified using as instrument the monetary policy shock corresponding to the median rotation of the sign restrictions provided by Jarociński and Karadi (2020); the latter using the second rotated factor in EUA and critical materials futures surprises, cleansed from the residual endogenous component. Bayesian VAR(6). Sample: 1999:1–2023:6. Darker bands denote 68% posterior credibility regions.

Figure C.7: Distribution of shocks under the scenario



Note: For each panel, the gray shaded area represents the probability density function (p.d.f.) of a standard normal distribution, whereas the orange line is the p.d.f. of the different shocks at horizon $h = 1$ under the structural scenario. The carbon policy path shock is displayed in the upper-leftmost panel. The Euro Area monetary policy shock is shown in the lower-leftmost panel. All other (unidentified) shocks are constrained at zero. On impact, the path shock is always equal to one, hence its distribution is degenerate and centered on one.

Figure C.8: FULL IRFS UNDER THE COUNTERFACTUAL SCENARIO

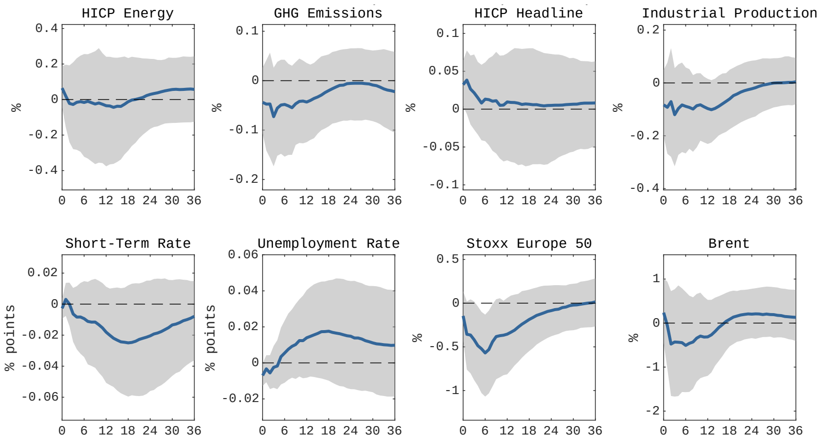


Note: Responses to a one-standard-deviation path carbon policy shock when a sequence of counteracting Euro Area monetary policy shocks offsets the response of the Euro Area 1Y OIS rate. Shocks are jointly (partially) identified via external instruments and one additional orthogonality restriction: carbon path shock identified using the second rotated factor in EUA and critical materials futures surprises, cleansed from the residual endogenous component; Euro Area monetary policy shock identified using as instrument the monetary policy shock corresponding to the median rotation of the sign restrictions provided by Jarociński and Karadi (2020). The IRFs to the monetary policy countershock are reported in Figure C.6. Sample: 1999:1–2023:6. Bayesian VAR(6). Darker bands denote 68% posterior credibility regions.

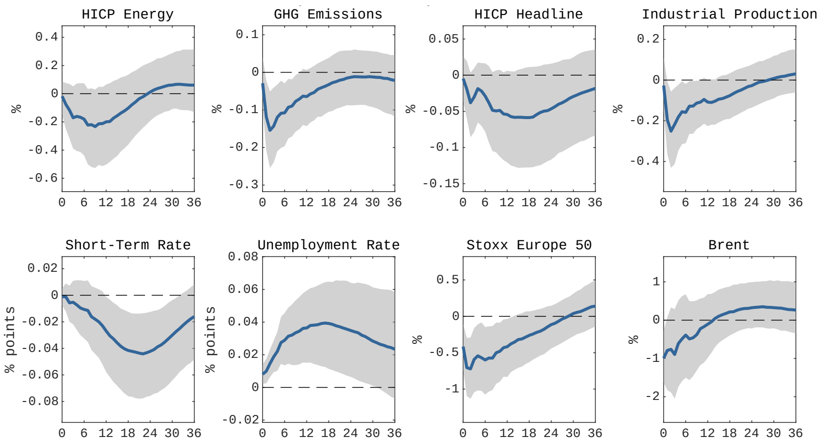
C.5 Sign restrictions using contracts at longer maturities

Figure C.9 shows that defining the slope of the term structure of critical materials as the difference between the surprises in the seventeen-month and front-month EUA contracts, instead of that between the five-month and front-month contracts – as done in the main text – does not change the results obtained with sign restrictions.

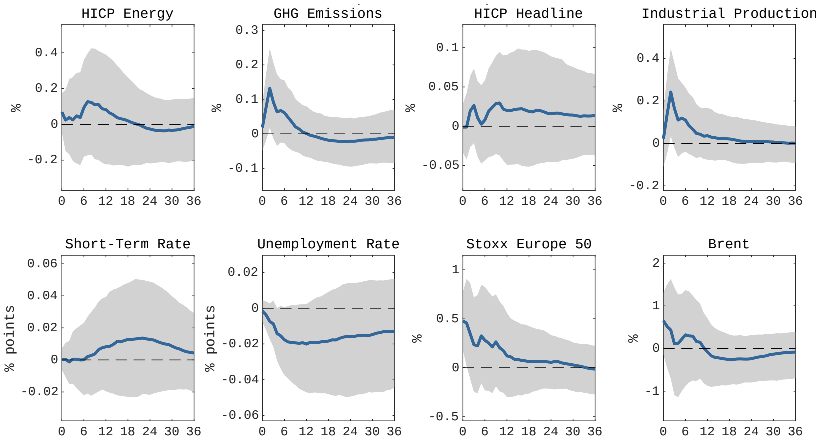
Figure C.9: Identification via sign restrictions – longer maturities



(a) Current stance shock



(b) Path shock



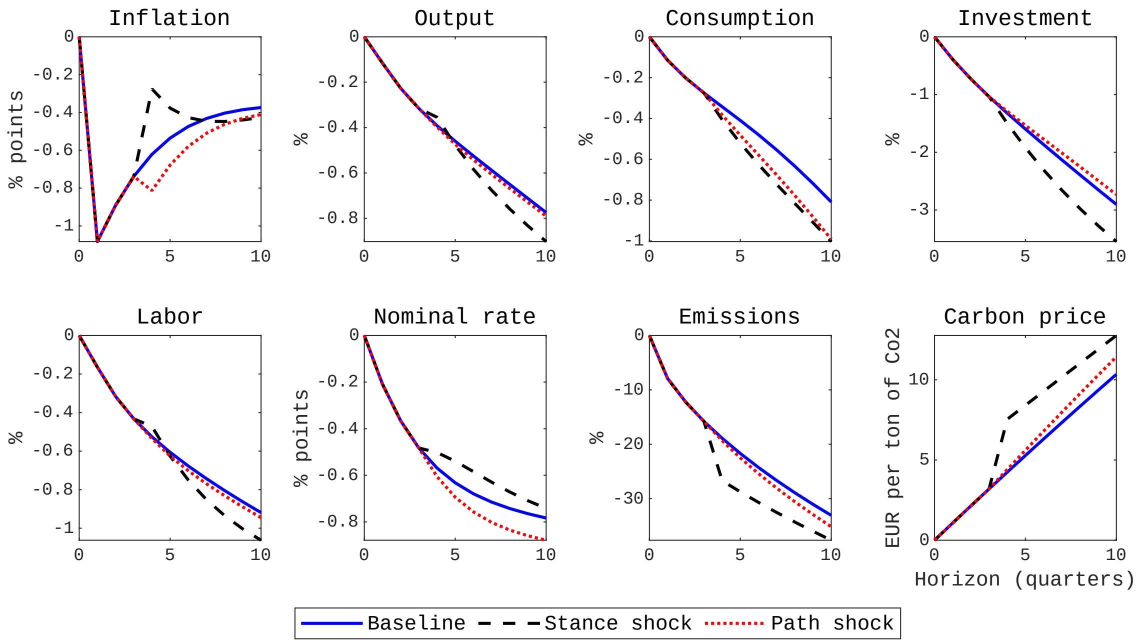
(c) Residual component

Note: Responses to one-standard-deviation current stance and path shocks (Panels C.9a and C.9b). Panel C.9c reports the responses to a shock identified using the residual variation in the surprises as proxy. Identification via sign restrictions on the impact response of high-frequency surprises, as described in Table 1, except the slope in the term structure of critical materials is computed as the difference between the surprise in the 17-month and front-month contracts. Bayesian VAR(12). Sample: 2005:5–2023:6. Details on the series are reported in Table A.6. Grey bands denote 68% posterior credibility regions.

D DSGE model

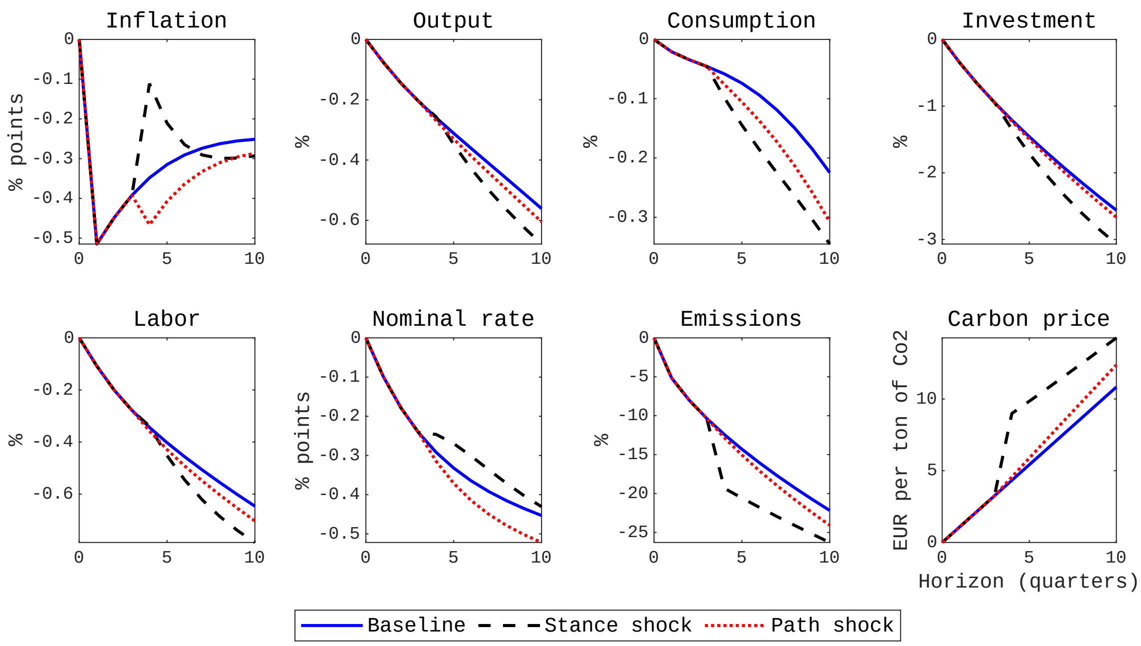
D.1 Additional figures

Figure D.1: Transition to a green economy: faster transition



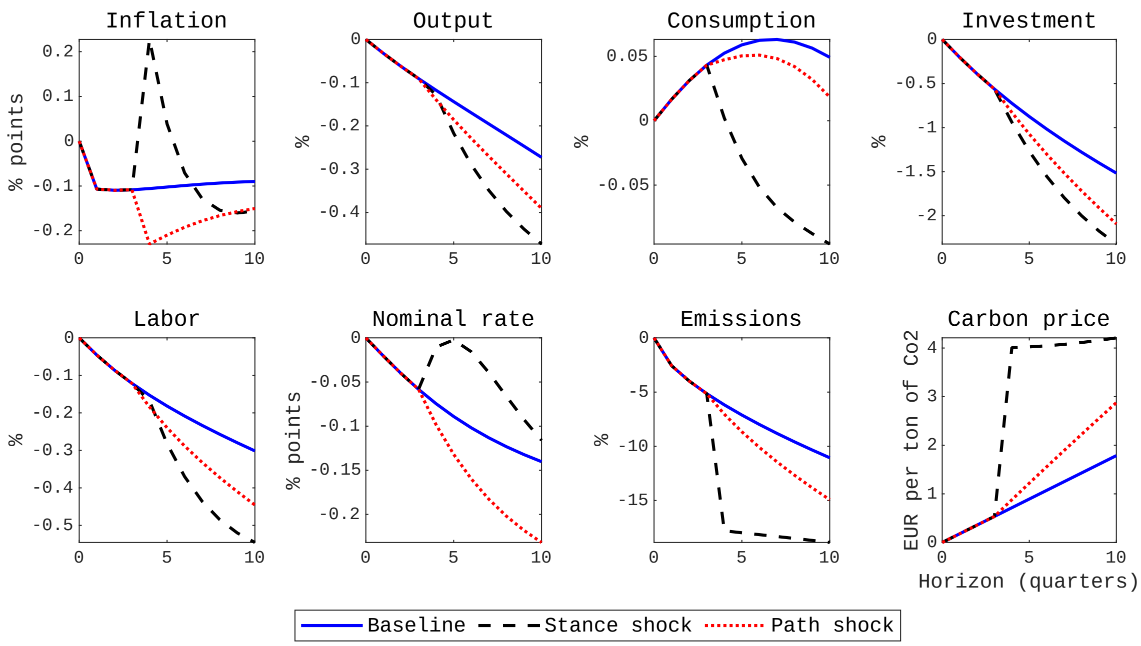
Note: The blue solid line shows the transition to a zero-emission economy, driven by an emission tax. The black dashed line shows the current stance shock. The red dotted line shows the path shock.

Figure D.2: TRANSITION TO A GREEN ECONOMY: HIGH CARBON PRICE



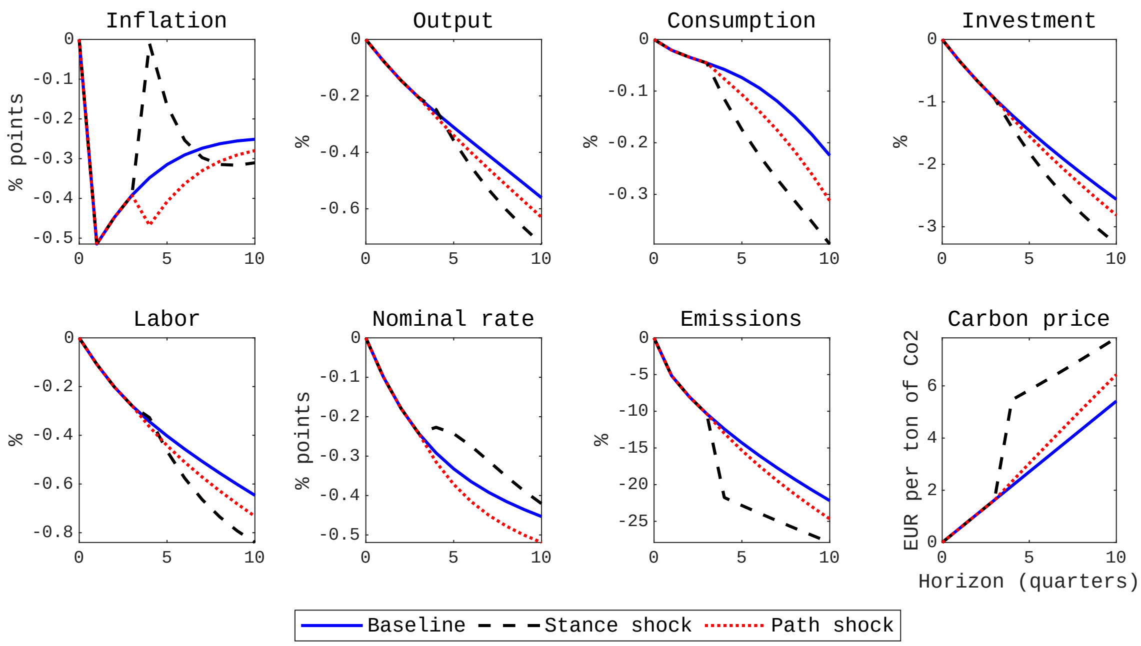
Note: The blue solid line shows the transition to a zero-emission economy, driven by an emission tax. The black dashed line shows the current stance shock. The red dotted line shows the path shock.

Figure D.3: Transition to a green economy: high final emissions



Note: The blue solid line shows the transition to a zero-emission economy, driven by an emission tax. The black dashed line shows the current stance shock. The red dotted line shows the path shock.

Figure D.4: Transition to a green economy: short path shock



Note: The blue solid line shows the transition to a zero-emission economy, driven by an emission tax. The black dashed line shows the current stance shock. The red dotted line shows the path shock.

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