

# Becoming Green: On the Aggregate and Firm-level Effects of Green Technology News Shocks

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## Abstract

We empirically explore the macroeconomic and firm-level implications of anticipations about future technological advancements in the green sector. Utilizing the economic value of green patents granted to publicly listed companies in the U.S., we identify green technology news shocks via a convenient and meaningful rotation of the innovations from a Bayesian Vector Autorregresion Model (BVAR). These shocks are decomposed into two orthogonal components: *i*) a common technological component shared by both green and non-green innovation, that reproduces response patterns akin to those expected from a technology news shock with long-run impacts on productivity; and *ii*) an idiosyncratic component to green innovation inducing inflationary pressures and stock price reductions. The responses to the orthogonal component suggest the existence of a green transition news content that can be related to expectations of more rigorous carbon policies or stricter environmental standards in the future. Our focus on green innovation deepens our understanding about the effect of technology-specific news shocks and provides information of practical importance for macroeconomic and environmental policies.

**Keywords:** *Green innovation; Green transition; Technology news; Patents; Impulse-response*

**JEL Classification:** *E32, O31, O44*

# 1 Introduction

Green innovation is key in the fight against climate change. By making new low-carbon technologies (LCTs) available, green innovation is a powerful tool in curbing emissions and helping firms and households to adapt to the adverse impact of climate change. The macroeconomic implications of the development of new technologies is an under-explored topic in the empirical literature. From a path-dependency argument (Acemoglu, Akcigit, Hanley, & Kerr, 2016; Aghion, Dechezleprêtre, Hémous, Martin, & Van Reenen, 2016), green innovation disrupts existing carbon-intensive economic systems by rendering current production processes obsolete. It can reduce potential productivity benefits in the short and medium run. Conversely, Ambec and Lanoie (2008) argues that green innovation can boost investment and gradually enhance productivity by improving energy efficiency and reducing energy costs. Green innovation can also generate broader knowledge spillovers than its carbon-intensive counterparts, thus fostering overall innovation (Antoine Dechezlepretre, 2017; Fried, 2018). Yet the empirical evidence on what of these effects dominate is inconclusive.

In this paper, we empirically explore the macroeconomic and firm-level implications of anticipations about future technological advancements in the green sector. Following the idea of Cascaldi-García and Vukotic (2022) and Miranda-Agrippino, Hacıoglu-Hoke, and Bluwstein (2022), we explode the informational content about future technology contained in the patent data. Utilizing the economic value of green patents granted to publicly listed companies in the U.S., we identify green technology news shocks via a convenient and meaningful rotation of the innovations from a Bayesian Vector Autorregresion Model (BVAR). These shocks are decomposed into two orthogonal components: *i*) a common technological component shared by both green and non-green innovation, that reproduces response patterns akin to those expected from a technology news shock with long-run impacts on productivity; and *ii*) an idiosyncratic component to green innovation inducing inflationary pressures and stock price reductions.

The responses of key macroeconomic variables to either component reveal interesting insights. A unit increase in the common component of the green technology news generate macroeconomic responses similar to those obtained for non-green innovation described in Cascaldi-García and Vukotic (2022). Concretely, the impact response of utilization-adjusted TFP is zero, while a significant positive effect is first obtained seven to eight quarters after the shock, and remains persistent throughout the examined horizon. In line with Barsky and Sims (2011), the delay between occurrence of the shock and its actual positive effect on productivity is indicative of the identified component as containing relevant information on future, rather than present, aggregate productivity levels. A positive impact response in output, consumption, investment, and worked hours is obtained with an effect that is short-lasting. Regarding the impulse responses of the macroeconomic variables to a unitary increase in the idiosyncratic content of green technology news, the most salient outcomes are the significant and persistent increase in the consumer price index and the persistent reduction in stock prices. This finding can be rationalized if the idiosyncratic

component is interpreted as containing relevant information regarding the green transition in the form of future more stringent climate policy. The response of firms to both components are also studied in variables as profits, sales, or liquidity.

This paper is related to two strands of literature. First, the empirical literature on the identification of technology news shocks and their macroeconomic impacts. While existing literature predominantly focuses on aggregate technology news, our focus on green technology-specific news offers a deeper understanding on the impacts depending on the nature of the shocks and provides relevant information for policy decisions. Second, the literature on the economic benefits and costs associated with the green transition. Most of the evidence stems from simulation results derived from large-scale, general equilibrium models. Our contribution enhances the discussion by providing empirical estimates that complement previous works as G. Metcalf (2019), G. E. Metcalf and Stock (2023), or Känzig (2023). A related work is the study by Hasna, Jaumotte, Kim, Pienknagura, and Schwerhoff (2023) at the IMF who also studied the macroeconomic and firm level impacts of green innovation. The main difference is that we do not conceive patents fillings as indicator of actual innovation but rather as news about future technological developments in the sense of Beaudry and Portier (2006). Moreover, the decomposition of the shocks into information regarding technological developments and information about the green transition is innovative in this literature.

The rest of the paper is organized as follows. Section 2 describes the related literature and the contribution of our paper. Section 3 presents the patents data sources and the construction of patent-based innovation indexes, as well as the macroeconomic and firm level data sources. Section 4 introduces the methodology and the identification and decomposition of structural shocks in the context of a BVAR model. Empirical results, both aggregated and at the firm level, are described in Section 5. Finally, Section 6 concludes.

## 2 Related Literature

Our paper is related to the empirical literature on the identification of technology news shocks and their macroeconomic impacts. Beginning with the seminal work of Beaudry and Portier (2006), a substantial body of research have explored the role of advanced information about technological improvements for business cycle fluctuations. Of practical importance are the identification assumptions. Traditional strategies, motivated by economic theory, often combine zero restrictions on the immediate response of TFP with assumptions about the drivers of productivity in the long-run. Beaudry and Portier (2006), for instance, identify technology news shocks as an innovation to the stock market index that is orthogonal to the current TFP levels. Barsky and Sims (2011), on the other hand, assume that technology news shocks are orthogonal to current TFP levels but maximize its forecast error variance at all horizons between zero and forty quarters. A similar idea is proposed by Francis, Owyang, Roush, and DiCecio (2014) who impose a zero restriction on the immediate response of TFP but assumes that the news shocks maximize the forecast error variance of TFP at a forty-quarter horizon. Kurmann and Sims (2021) adopt the methodol-

ogy of Francis et al. (2014) but without the zero impact restriction. In all cases, the pattern of response of the TFP to the news shocks is an imposition rather than an independent result.

In a pair of recent studies, Cascaldi-García and Vukotic (2022) and Miranda-Agrippino et al. (2022) implement alternative identification strategies that do not impose particular dynamics on the TFP response. Both contributions are based on the premise that patents constitute a relevant source of information on inventive activity and signal potential future technological advancements. Miranda-Agrippino et al. (2022) constructs a proxy for technological news shocks built from the number of quarterly-patent applications filed at the USPTO. Cascaldi-García and Vukotic (2022) adds to the literature by exploiting the stock market valuations of patents granted to publicly listed firm, as captured by the innovation index proposed by Kogan, Papanikolaou, Seru, and Stoffman (2017). Despite not being explicitly assumed, both papers obtain a shape for the TFP response that aligns with the conceptualization of Beaudry and Portier (2006). Our study extends the methodology of Cascaldi-García and Vukotic (2022) by exploring the identification of technology-specific news shocks. While existing literature predominantly focuses on aggregate technology news, our focus on green technology-specific news offers a deeper understanding on the impacts depending on the nature of the shocks and provides relevant information for policy decisions.

This paper is also linked to the literature on the economic benefits and costs associated with the green transition. In the long-run, the positive benefits of a cleaner economy in terms of mitigating climate change damages are widely recognized, see Acemoglu, Aghion, Bursztyn, and Hemous (2012). Nonetheless, the transition towards a green economy, prompted by carbon taxes and/or subsidies to green investments, involves a complex array of short- to medium-run economic implications of practical importance for macroeconomic and environmental policies. For instance, Goulder and Hafstead (2018) models the economic impact of carbon taxation and estimates that that implementing a carbon tax of 40 dollars per ton starting in 2020 and rising at 5 percent real annually, would result in an output reduction of just over 1 percent by 2035 compared to a scenario without such a tax.

Other group of authors have used New Keynesian frameworks to explore the monetary impacts of transition policies. Ferrari and Nispi Landi (2022), for instance, finds that a current increase in a carbon tax exerts inflationary pressures, whereas anticipated future increases dampen demand. Expectations play a crucial role in determining the prevailing effect. Airaud, Pappa, and Seoane (2024), in a model for a small open economy, observe that increases in brown energy taxation lead to a rise in firms' marginal costs, with inflationary effects and persistent output losses. Green public investment or subsidies would induce a transition with no inflationary or output costs, albeit without a quick improvement in energy efficiency. Del Negro, di Giovanni, and Dogra (2023) point out that climate policies introduce an inflation-output trade-off, modulated by the relative price stickiness in the dirty and green sectors and whether the policies involve taxes or subsidies. Other

relevant references along this line include Bartocci, Notarpietro, and Pisani (2022) and Ferrari and Nispi Landi (2023).

Most of the evidence on the real and monetary consequences of the green transition stems from simulation results derived from large-scale, general equilibrium models. From an empirical perspective, recent contributions examine the macroeconomic effects of carbon taxation, albeit with conflicting findings. G. Metcalf (2019) and Bernard and Kichian (2021), despite adopting different methodological frameworks, conclude that the British Columbia carbon tax does not detrimentally affect output or employment. This view is further supported by G. E. Metcalf and Stock (2023) who find no significant adverse effects on employment or GDP growth of carbon taxation in various European countries. In contrast, Känzig (2023) documents that a carbon policy shock in Europe leads to higher energy prices, lower emissions and more green innovation, at the cost of a fall in economic activity.

Our analysis contributes to the empirical literature by examining a complementary and under-explored aspect of the green transition: the macroeconomic implications of anticipations about future technological advancements in the green sector. Various mechanisms through which expected and actual green innovation influences economic decisions have been proposed. From a path-dependency argument (Acemoglu et al., 2016; Aghion et al., 2016), green innovation disrupts existing carbon-intensive economic systems by rendering current production processes obsolete. In the short and medium run, potential productivity benefits are reduced. Conversely, Ambec and Lanoie (2008) suggest that green innovation can boost investment and gradually enhance productivity by improving energy efficiency and reducing energy costs. In the same direction, green innovation can generate broader knowledge spillovers than its carbon-intensive counterparts, thus fostering overall innovation (Antoine Dechezlepretre, 2017; Fried, 2018). Our empirical investigation, using U.S. data and a transparent strategy for identifying and decomposing green technology news shocks, addresses this topic.

A related work is the study by Hasna et al. (2023) at the IMF, which examines the macroeconomic and firm level impacts of green innovation in the short and medium run. Drawing on data on patent filings in OECD and BRICS countries from 1990 to 2020, these authors find that green patent filings stimulate output through increased investment, yet do not boost aggregate TFP. At the firm level, green patents increase revenue, albeit in a smaller magnitude compared to non-green patents.

Our study deviates from Hasna et al. (2023) in several aspects. First, we do not conceive patents filings as indicator of actual innovation but rather as news about future technological developments in the sense of Beaudry and Portier (2006). Second, we employ a transparent identification strategy that does not rely on the use of instrumental variables for addressing potential endogeneity issues.<sup>1</sup> Our strategy uses the market values of the granted patents—instead of patent filings—to construct the green and non-green innovation indexes in the spirit of Kogan et al. (2017). It provide our innovation indicator with

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<sup>1</sup>Patent applications may be prompted by current economic booms and/or past news.

an additional degree of exogeneity coming from the high frequency variation in the asset prices. Technology news shocks are identified within a VAR model assuming convenient meaningful rotations of the reduced-form innovations. Third, we decompose the shocks into information regarding technological developments and information about the green transition. To the best of our knowledge, this is the first paper proposing this type of decomposition.

### 3 Data

#### 3.1 Patent Data and Green Patent-Based-Innovation-Index (GPBII)

Data on patents is obtained from *Patents View*, a publicly accessible service maintained by the U.S. Patent and Trademark Office (USPTO). For each patent granted between 1960 and 2016, we collect information on the application and grant dates and the technology class indicated by the Cooperative Patent Classification (CPC) code. Based on the CPC code and following the classification system proposed by Haščič and Migotto (2015), we identify the green patents as all patents producing technologies related to climate change mitigation and adaptation, carbon capture and storage, renewable energy generation, pollution abatement, and waste management.

Quarterly data on patents grants is combined with firm-level data from the Centre for Research in Security Prices (CRSP) to construct the Green Patent-Based-Innovation-Index (GPBII) index, following the methodology of Kogan et al. (2017).<sup>2</sup> Shortly, the value of an individual green and non-green patent granted to a publicly listed firm is estimated by filtering the firm's stock price reaction around the patent grant announcement date from other unrelated news. Individual firm-level values are aggregated for to obtain the indexes presented in Figure 1.

Panel (a) in Figure 1 presents the levels of the GPBII (green) and NGPBII (brown). Both indices seem to evolve following a common trend. From 1990, both indices report a steeper increase that is interrupted at the beginning of the 2000s, with a more marked fall in the NGPBII. The value of the indices seems to follow times of speculation in the market, especially that of the dot-com bubble. In the mid-2000s, the GPBII appears to increase more steadily, but again a strong fall is observed around 2008, during the Great Recession. Even though the variability of both indices is similar—the correlation coefficient of the levels is above 0.83—the levels themselves are not. The ratio presented in Panel (b) shows that the GPBII is around 5% of the NGPBII. However, during the sample period, this ratio has varied significantly, experiencing periods of increase between 1960 and 1982 or 2000 to 2008, where the maximum peaks of the ratio were achieved. Panel (c) plots together the growth rates. The correlation of this measure is around 0.6.

<sup>2</sup>Codes and data files available at the GitHub repository <https://github.com/KPSS2017> were used.

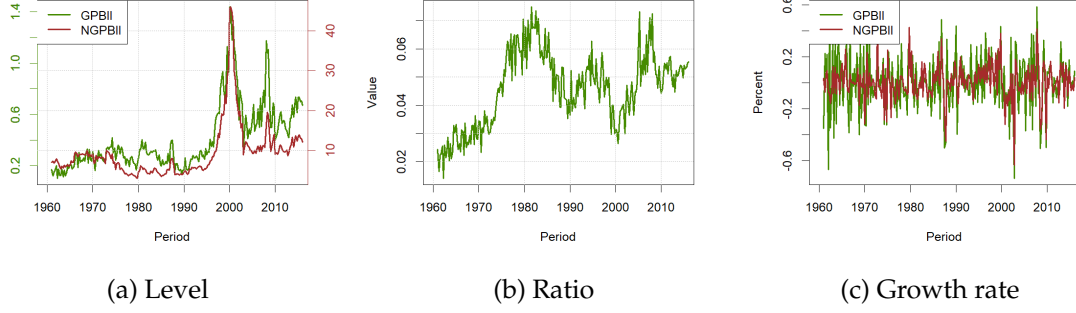


Figure 1: Green and non-green PBIIs.

### 3.2 Aggregate Macroeconomic Data

For the aggregate analysis, we use data on a range of variables related to technology, real macroeconomics, and forward looking indicators. The information set in our benchmark model includes the GPBII and NGPBII, utilization-adjusted TFP (Fernald, 2014), output, real consumption, real investment, hours worked, consumer price index, federal funds rates, consumer confidence, and stock prices. These variables are chosen as to encompass the set of variables used in the analysis of CG-V and Miranda-Agrippino et al. (2022), and to cover a wide spectrum of the macroeconomy. All variables are in log levels, following (Sims, Stock, & Watson, 1990), to account for possible cointegration. The data frequency is quarterly and covers the period from 1960:Q1 to 2016:Q4, which is the time window with more reliable data on patents. In the Appendix, we provide more details about the data sources and transformations.

### 3.3 Firm-level Data

We use quarterly data from Compustat covering the period from 1990 to 2016. Compustat serves as a comprehensive repository of publicly listed U.S. firms, meeting three important criteria outlined by Ottonello and Winberry (2020), essential for our analysis. Firstly, its quarterly frequency enables us to assess the impact of green technology news shocks at a relatively high frequency. Secondly, its extensive longitudinal scope allows us to leverage within-firm variation and control for unobserved firm-specific factors in our empirical framework. Thirdly, Compustat provides extensive balance-sheet data across several sectors of the economy. Our analysis primarily focuses on variables related to sales performance, financial health, and investment. We exclude data from the finance, insurance, real estate, and utilities sectors as in Cascaldi-García, Vukotic, and Zubairy (2023).

## 4 Methodology and Identification

### 4.1 Aggregate Analysis

We estimate a BVAR model with standard Normal-Inverse-Wishart (NIW) distribution priors. The choice of a BVAR is motivated by its ability to address the curse of dimensionality found in large VAR models, which is particularly relevant in our study. This is because we define a VAR system with more than 10 endogenous variables, an intercept, and four lags, and our data has a quarterly frequency. Initially, we identify the structural shocks of interest following the strategy in CGV. Specifically, we use a convenient lower triangular Cholesky decomposition, with the GPBII or the NGPBII ordered on top of the information set. The results are presented as median impulse responses to the identified structural shocks, with one-standard-deviation coverage bands provided for inference. Our empirical exercise is further refined by adopting a procedure that simultaneously utilizes both the GPBII and the NGPBII. This procedure involves a QR rotation to decompose the reduced-form residuals of the GPBII into common ( $\epsilon_{C,t}^G$ ) and idiosyncratic ( $\epsilon_{O,t}^G$ ) components with meaningful interpretation. The impulse responses of the macroeconomic variables to each of these components are obtained using Local Projections Jordà (2005). In the subsequent sections, we elaborate more on these procedures.

### 4.2 Firm-level Analysis

In the firm level analysis, we examine the effect of both the common and the idiosyncratic components of green technology news shocks on firm-level variables such as investment decisions, sales, profits, leverage, liquidity and R&D spending. Let  $s_t \in \{\epsilon_{C,t}^G, \epsilon_{O,t}^G\}$ . For each variable of interest and at each horizon  $h \geq 0$ , we estimate the following specification using panel Local Projections:

$$y_{it+h} - y_{i,t-1} = \alpha_{ih} + \alpha_{sth} + \beta_h s_t + \psi_h(L)x_t + \epsilon_{ith}, \quad (1)$$

where  $y_{it+h}$  is the dependent variable at time  $t + h$ ,  $\alpha_{ih}$  represents a fixed effect for firm  $i$ ,  $\alpha_{sth}$  denotes a fixed effect for sector  $s$  by quarter  $t$ , and  $s_t$  is either the common or the idiosyncratic component of the green technology news shock. Finally,  $x_t$  is a vector comprising aggregated-level variables, which include two lags of the macroeconomic variables described in Section 4.1. The coefficient  $\beta_h$  is our object of interest as it reflects the response of the dependent variable to the exogenous shock component. Following Ottonello and Winberry (2020), this specification can be extended to include firm-level and aggregate-level control variables in the right-hand-side to capture other important drivers behind firms' responses.



## 5 Empirical Results

### 5.1 Aggregate Effects

#### 5.1.1 Green technology news shocks independently identified

In an initial empirical exercise, green technology news shocks are identified following the approach of CGV. Concretely, we place the GPBII on top of the information set and achieve identification through a Cholesky rotation of the reduced-form residuals of the estimated BVAR model. Green curves in Figure 2 represent the implied dynamic responses of the macroeconomic variables to the identified shock over a twenty-quarter horizon, a duration deemed appropriate for future productivity forecasts. These responses are compared to the brown curves corresponding to the macroeconomic responses to a non green technology news shock. Brown responses are obtained in a similar process but replacing the GPBII by the NGPBII as the first variable in the system. The latter analysis closely replicates the findings in CGV.<sup>3</sup>

The pattern of responses in green and brown share interesting similarities. In both cases, a significant delay between the hit of the shock and its actual effect on TFP is obtained. Consistent with the expected responses to news about future technology improvements, we observe that the positive reactions of output, investment, and hours precede the significant impact on TFP. However, are not the similarities but the important differences between each type of responses what motivates our subsequent analyses. Notice that the real variable responses are less pronounced in the green-technology case. Whereas CGV reports a permanent TFP uplift of about 0.3%, our findings for the green-technology suggest a more modest long-term increase near 0.2%. This discrepancy can be attributed to the exclusive focus of GPBII on green innovations, which leaves out potentially more impactful non-green innovations. In addition, the response patterns in the price index, federal funds rate, consumer confidence and stock prices remarkably diverge from those in CGV. In the green case, the price index response is positive and significantly different from zero twenty quarters after the shock. Regarding stock prices, although an initial increase is observed on impact, the response turns permanently negative from the fifth quarter onwards.

From the previous comparison we infer that green and non-green technology news shocks identified in independent procedures share a common component driving the similar responses of TFP and real variables. In fact, the correlation between the two shock series is above 0.6. This observation is also consistent with the visual inspection of the levels and the growth rate of the GPBII and NGPBII presented in the previous section. While this commonality is relevant for policy analysis, we are also interested in the idiosyncratic component of the green technology news shocks that may explain the distinct responses of the monetary and forward looking variables. The idiosyncratic component cannot be independently identified and requires the simultaneous use of both the GPBII and NGPBII, and a transparent identification strategy as outlined in the next section.

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<sup>3</sup>CGV use the total PBII, obtained as the sum of the GPBII and the NGPBII. Provided that the NGPBII significantly contributes to the total PBII, a strong similarity in the outcomes of the analysis is expected.

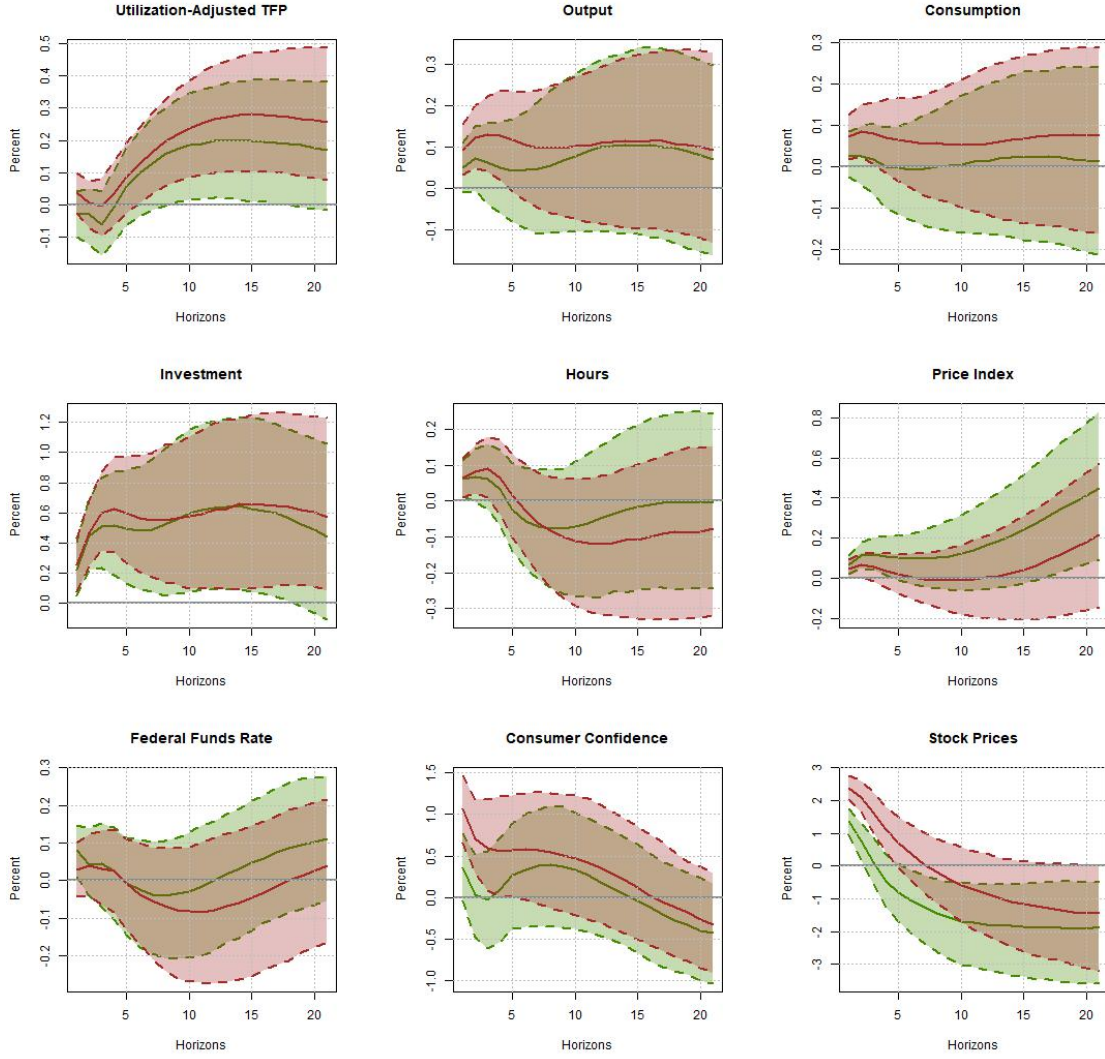


Figure 2: Dynamic responses to green (green curves) and non-green (brown curves) technology news shock identified in independent procedures

### 5.1.2 Orthogonal decomposition of green technology news shocks

Previous section motivates the identification of green technology news shocks in a joint procedure that incorporates both the NGPBII and the GPBII in the information set. We estimate the VAR model and obtain the reduced-form residuals,  $e_t^{NG}$  and  $e_t^G$ , associated to NGPBII and GPBII, respectively. Both residual series are correlated and, presumably, share a common component. Then,  $e_t^G$  is decomposed into two orthogonal elements using a QR decomposition. The first element, denoted as  $\epsilon_{C,t}^G$ , is obtained as the projection of  $e_t^G$  on the  $e_t^{NG}$  space and represents the common component of the green technology news. The second element,  $\epsilon_{O,t}^G$ , is obtained as the residual of the previous projection and represents the idiosyncratic component of the green technology news. Both components are orthogonal and satisfy  $e_t^G = \epsilon_{C,t}^G + \epsilon_{O,t}^G$ .<sup>4</sup>

<sup>4</sup>In Appendix XX we consider two alternatives to analyze the macroeconomic responses to the idiosyncratic component of the green technology news. The first approach is based in a Cholesky-rotation of  $e_t^G$  with respect

The dynamic responses of the macroeconomic variables to a unit increase in  $\epsilon_{C,t}^G$  and  $\epsilon_{O,t}^G$  are obtained using linear Local Projections Jordà (2005). Figures 3 and 4 plot those responses over an horizon of 20 quarters. Both types of shock components induce a significant increase of the GPBII on impact, yet their subsequent response patterns are completely different. Based on the results, we interpret  $\epsilon_{C,t}^G$  as representing a common technological content and  $\epsilon_{O,t}^G$  as indicative of the green transition content of the green technology news.

#### 5.1.2.1 Responses to the common technological content of green technology news

This section describes the responses of the macroeconomic variables to a unit increase in the common component of the green technology news,  $\epsilon_{C,t}^G$ .

Firstly, we examine the response of the utilization-adjusted TFP, a proxy for the technological advancement of the economy. Observe that, while the impact response of TFP is left unrestricted, the confidence intervals do not rule out a zero effect. A negative response is observed at horizon  $h = 3$  that may be related to the Schumpeter's idea of creative destruction. A significant positive effect is first obtained seven to eight quarters after the shock, and remains persistent throughout the examined horizon. In line with conceptualization of news shocks in Barsky and Sims (2011), the delay between occurrence of the shock and its actual positive effect on productivity is indicative of the identified component as containing relevant information on future, rather than present, aggregate productivity levels.

Regarding real variables, we note a positive impact response in output, consumption, investment, and worked hours, with an effect that is short-lasting. For instance, investment increases on impact and continues to rise for about 4 quarters before converging back to normal. Although the function is positive over the whole horizon, it is non-significant after quarter 6. Forward-looking indicators, as stock prices and consumer confidence, experience a positive strong initial increase that swiftly diminishes and turns non-significant by 4 quarter post-shock onwards. Notice that the positive responses of real variables and forward looking indicators precede the significant impact on TFP, a finding that clearly reveals the technological-information component contained in the green technology shock that prompt economic agents to act upon the realization of the shock. Consumer prices exhibits a weak rise on impact that can be explained by the demand increase induced by the movement in the real variables.

From the described responses, it is possible to relate the common component  $\epsilon_{C,t}^G$  to a technological content in the form of news about future technological development in the green sector. The macroeconomic implications are comparable to those described in in CGV and the related literature on technological news shocks.

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to  $e_t^{NG}$ . The second alternatives involve medium run restrictions and a QR rotation. Both alternatives lead us to similar results.

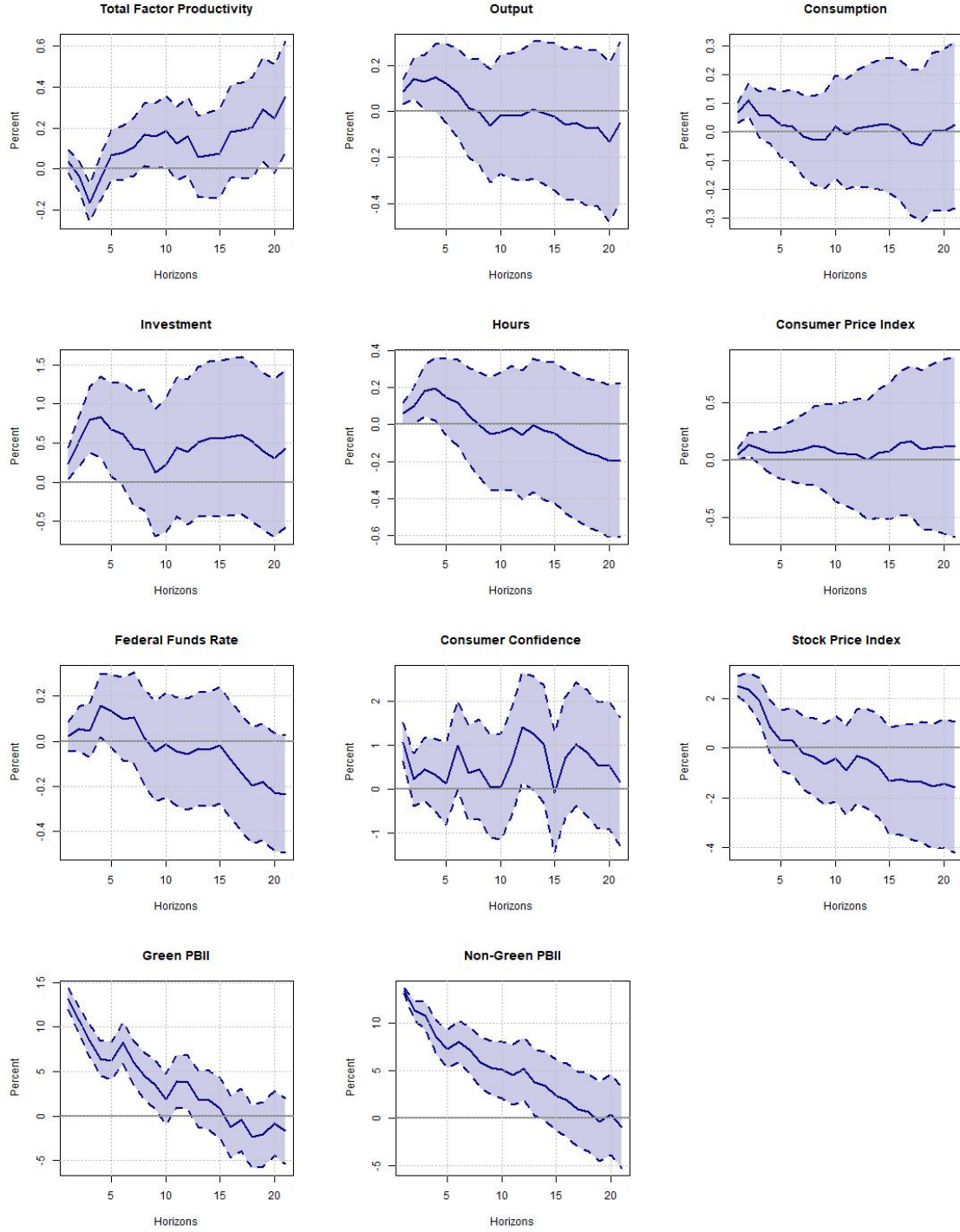


Figure 3: Dynamic responses to the common technological component of the green technology news shock

#### 5.1.2.2 Responses to the idiosyncratic transition content of green technology news

Now, we describe the impulse responses of the macroeconomic variables to a unitary increase in  $\epsilon_{O,t}^G$  that are plotted in Figure 4. Observe that such movement generates a significant immediate rise in the GPBII, whereas the NGPBII remains unchanged at any hori-

zon. This outcome is a consequence of the orthogonalization process, and implies that the responses of other variables in the model are driven by factors not correlated with fluctuations in the non-green innovation. Unlike the response to the technological component discussed in the previous section, the dynamics of the GPBII in the present case show an interesting pattern: after the initial rise, the response function swiftly declines, eventually stabilizing at a level approximately 5% above the starting point.

The most salient outcome in Figure 4 is the significant and persistent increase in the consumer price index. Although the immediate effect is mild, the impulse response function increases monotonically throughout the entire horizon. This finding can be rationalized by interpreting  $\epsilon_{O,t}^G$  as containing relevant information regarding the green transition. Concretely, green innovation potentially affects future paths for climate policy. If new technologies are developed today, regulators may adapt future taxes or standards to fully incorporate such technologies into the production process. Therefore, if unexpected news about future green technology are learned by economic agents, anticipated changes in future climate policy potentially affect present outcomes. The increasing response of inflation, for instance, is due to the expected increase in energy prices: dirty energy becomes relatively more expensive pushing up overall prices. This perspective may also explain the lasting impact of  $\epsilon_{O,t}^G$  on the level of green innovation if we account for the effects of climate policy on prompting green innovation, as documented in the literature.

The monetary policy stance exhibits a mild increase on impact, and its impulse response function shows an increasing behavior over the entire horizon, consistent with the rise in consumer prices. However, the point responses are barely significant, reflecting the policy trade-off introduced by the inflationary pressures. The weakly positive response aligns with the notion that the Central Bank adopts a monetary policy reaction function, placing positive weight on inflation and taking into account the economic consequences of the green transition. Regarding financial markets, it is observed that the stock market experiences a significant downturn following an increase in  $\epsilon_{O,t}^G$ . Stock prices reduce on impact and remain lower throughout the entire horizon, although the impulse response becomes statistically insignificant after 10 quarters post-shock. This pattern again can be explained by changes in expectations regarding a more stringent future climate policy. The responses of the real variables are not significant, although a U-shaped pattern is observable for output, consumption, investment, and hours worked, with the peak response occurring approximately 13 to 14 quarters after the shock. For the TFP, the peak response is observed at the 17th quarter and reaches statistical significance.

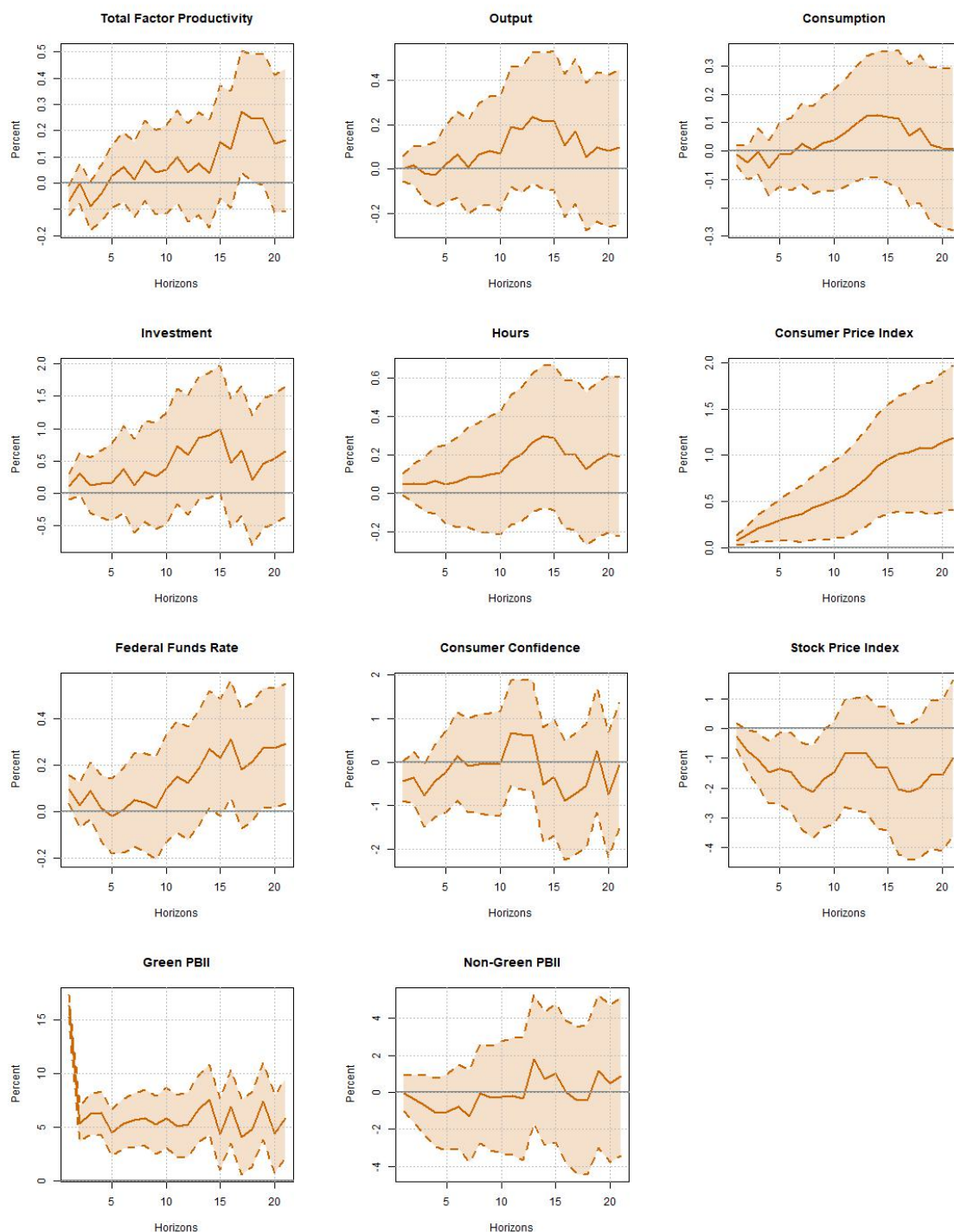


Figure 4: Dynamic responses to the idiosyncratic transition content of green technology news (Baseline)

*Consumer Prices.*—The idiosyncratic component of the green technology news shocks results in a strong and persistent increase in consumer prices. How are the responses of the energy prices and other specific price categories to this components? In Figure ?? we observe that the pattern response of energy prices mirrors that of the overall price index in magnitude and shape. In contrast, core consumer prices do not react in the short run



and a significant response is only observed around the 15th quarter following the shock. The responses obtained for the prices of durable goods and services closely resemble those of energy prices, indicating a substantial pass-through from energy inflation. Meanwhile, the price response of non-durable goods parallels that of core prices. These findings are consistent with theoretical expectations regarding the inflationary pressures induced by the green transition.

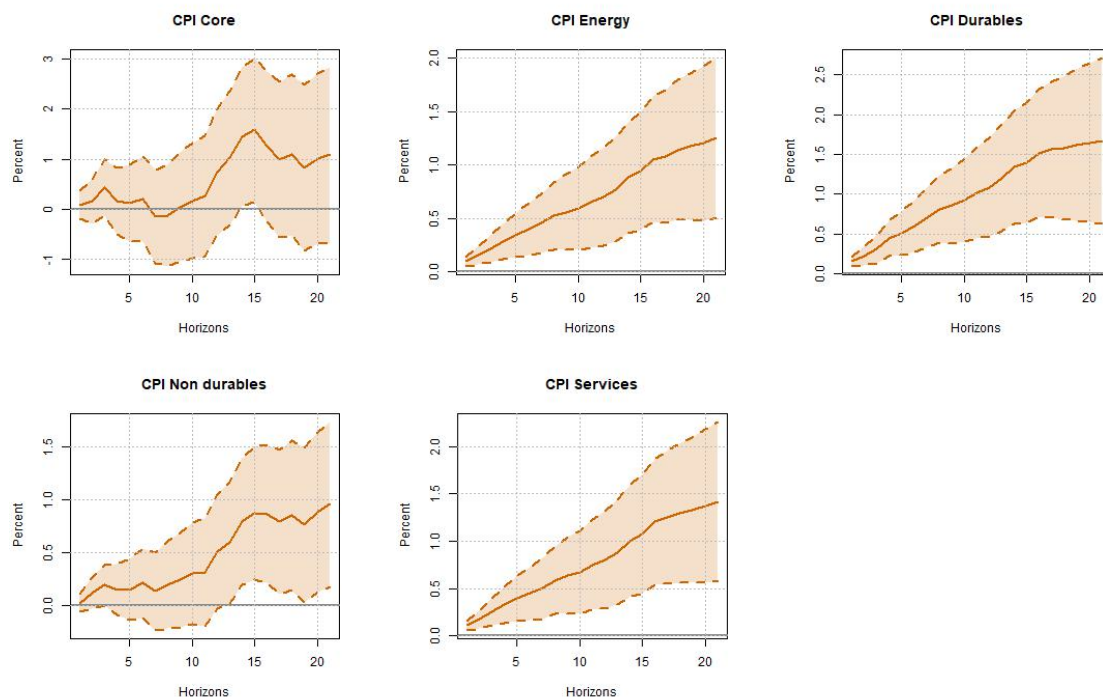


Figure 5: Dynamic responses to the idiosyncratic transition content of green technology news (CPI components)

*Stock Prices.*—To better understand the decline in aggregate stock prices, Figure 6 examines the stock price responses of selected industries potentially impacted by changes in environmental regulations. Except for the mining sector, all analyzed industries experience a reduction in their stock prices. For the oil and gas and automobile sectors, the reduction is transitory, with the response becoming non-significant from the 10th horizon onwards, mirroring the dynamics of the aggregated stock price index. In contrast, the electricity and retail sectors exhibit a more persistent fall in their stock prices. Observed responses align with the green technology news as containing a transition content, which carries implications of future changes in environmental regulations and the necessary investments required to adapt to upcoming technological scenarios.

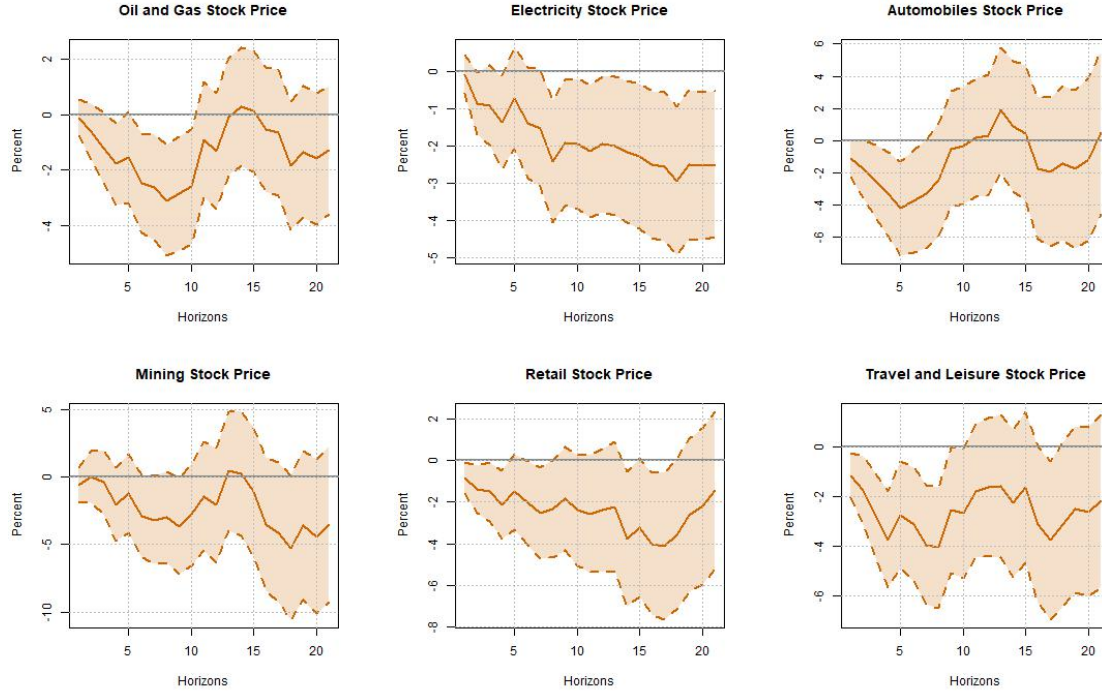


Figure 6: Dynamic responses to the idiosyncratic transition content of green technology news (Stock prices by industry)

## 5.2 Firm-level Effects

We begin our analysis on firms behavior by studying the reaction of firm-level variables to the common component of green news shocks. In order to understand the possible effects, we follow the specification of Cascaldi-García et al. (2023) in the panel local Projections in equation (1). We use bootstrap confidence intervals clustered by group, and work with a confidence level of 68.0%. Overall, the results show a favorable performance of the firm-level variables after a shock in the common component of the Green news technology variable, and unfavorable performance to idiosyncratic component shock. These broad results are in line with the aggregate results in the previous section. Nonetheless, the dynamic consequences of Green News shocks on firms' performance is still an object of study as there are some puzzling response.

Figure 7 shows that the response of profits and sales variables suggest a presence of favorable effects on firm performance. However, these effects are not persistent, as both variables experience a decline one year after the shock. These fluctuations in performance seem not to be accompanied by changes in tangible capital investment as this variable is not significantly reacting to the shock. The results contrast with those of Cascaldi-García et al. (2023) where they find that, on average, there is a unequivocal positive effect of the news shocks on profits, sales, and investment in tangible capital.

In addition to income and investment variables, the average firms' financial health response is ambiguous. On one hand, there are no significant changes in the value of the leverage ratio (total debt over total assets), but the liquidity ratio (cash and short-term



investments over total assets) increases on impact and in the forthcoming quarters after the shock. This imply that even if firms do not increase the overall indebtedness as a percentage of total assets due to an increase in news technology shocks, there are increases in cash and liquid assets on average among the companies.

Lastly, there exists a positive increase in research and development expenditure although its response is not immediately after the impact. In fact, there is evidence that the increase in this variable reaches its peak two years after the innovation.

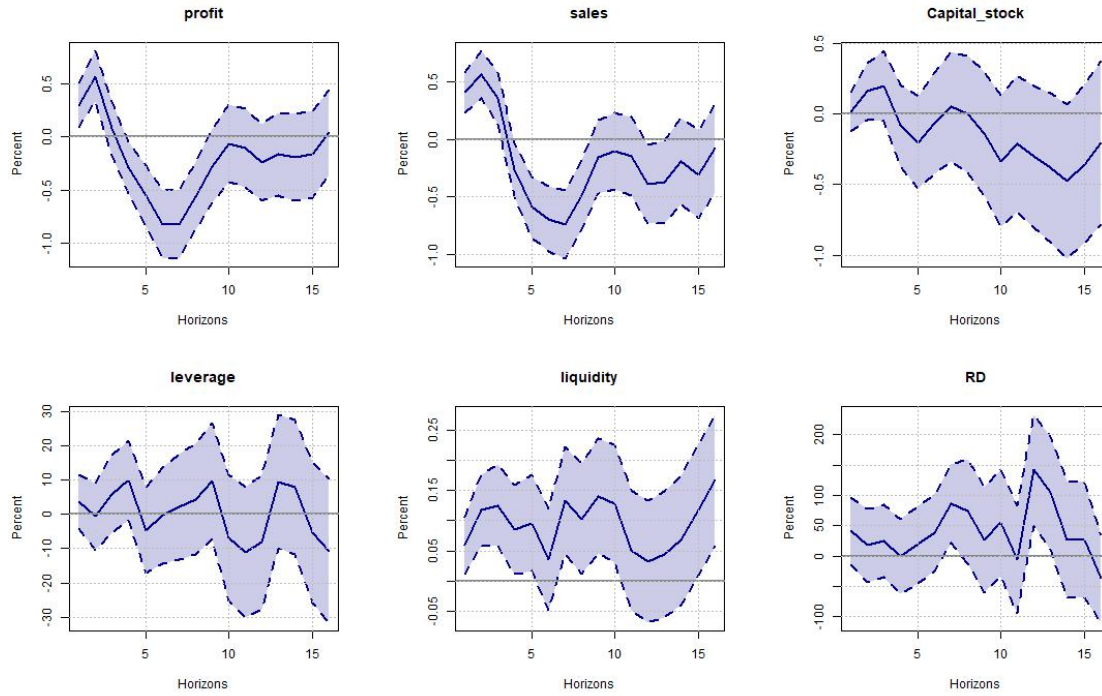


Figure 7: Dynamic responses of firm-level variables to common technological component of the green technology news shock)

Figure 8 shows the responses to a one-standard deviation shock in the idiosyncratic component of the green news shock. We observe an average reduction in both profits and sales. This reduction aligns with the decline in stock prices highlighted in the previous section; however, it does not suggest that the introduction of green patents necessarily leads to diminished firm profits and performance. Rather, it indicates that the segment of green technology innovation independent of technology in other sectors is initially associated with a decrease in the profits and sales of firms, on average, in the first few years after the shock. Nevertheless, profits and sales rebound thereafter, surpassing pre-shock levels. This suggests that while initial negative effects are present, the idiosyncratic green news shock may yield positive effects in the future. The anticipated upturn in sales and profits may spur increased investment in tangible capital on impact.

On the other hand, the financial health of firms shows and adverse response to the idiosyncratic component of the green news shock. This is evidenced by a decline in the liquidity ratio and an increase in the leverage ratio two years after the shock. The latter

indicates that despite potential medium-term profit and sales increases, firms intensify their levels of financial constraints.

Finally, expenditure on research and development exhibits a negative average response following an innovation in the idiosyncratic component green news shocks. This reduction is statistically significant during the first year after the shock with no changes thereafter.

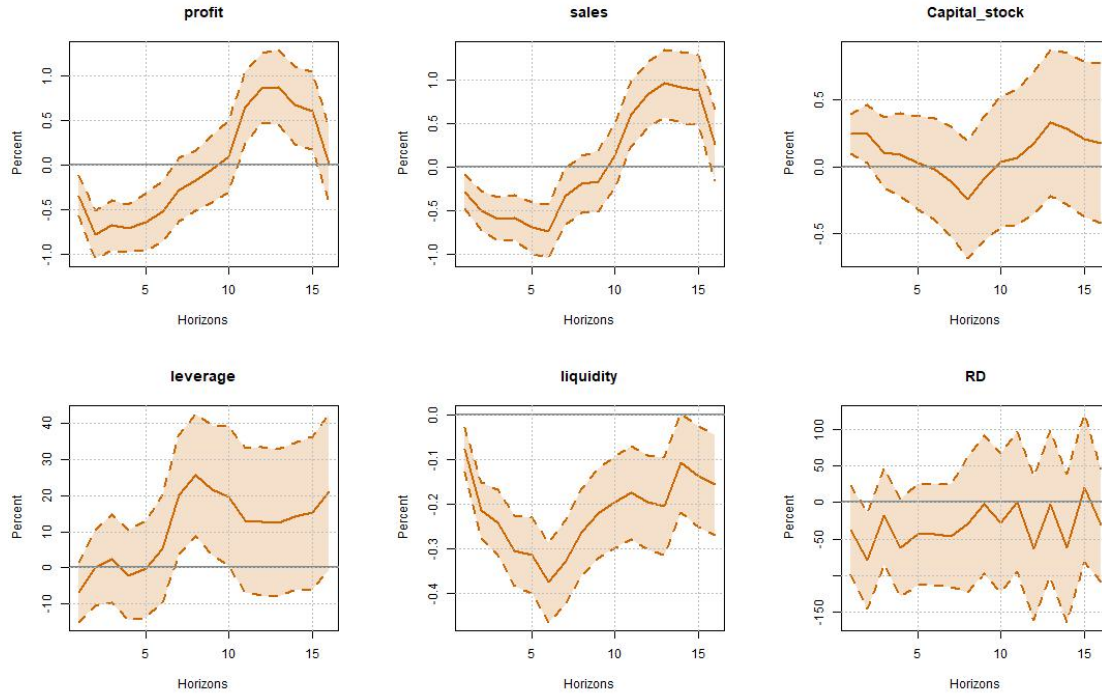


Figure 8: Dynamic responses of firm-level variables to idiosyncratic technological component of the green technology news shock)

## 6 Conclusion

This paper investigates how green technology news shocks propagate through the economy and provide aggregate and firm level evidence. The shocks are decomposed into two orthogonal components. The first component is related to the technological content in the form of news about future technological development in the green sector. The second component is interpreted as the transition component of the green technology news and generate macroeconomic responses consistent to anticipated changes in future climate policy that potentially affects the inflation path and stock prices. This research provides quantitative estimates of the economic consequences of the green transition in a mechanism that have been under explored in the literature, namely, the effects of green innovation. Our focus on green innovation deepens our understanding about the effect of technology-specific news shocks and provides information of practical importance for macroeconomic and environmental policies.

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## A Appendix

### A.1 Aggregate and Firm-level Data Sources

This Appendix gives more details on the sources of the data used in the aggregate and firm level analyses.

Table A1: Data description and sources

Variable	Description	Source
<i>Aggregate Analysis:</i>		
GPBII and NGPBII	Green and Non-Green Patent Based Innovation index	Patents view + CRSP
TFP	Total Factor Productivity	Fernald (2014)
Output	U.S. Real Gross Domestic Product	FRED
Consumption	U.S. Real Consumption	FRED
Investment	U.S. Real Investment	FRED
Hours	Non-farm Business Sector: Hours Worked for All Workers	FRED
Consumer Price Index	Consumer Price Index for All Urban Consumers: All Items	FRED
Federal Funds Rate	Effective federal funds rate	FRED
Consumer Confidence	Consumer Confidence Index	Michigan Survey of Consumers
Stock Price Index	Standard and Poor's 500 Composite Stock Price Index	Robert Shiller's website
CPI Core	U.S. CPI for all urban consumers: all items less food and energy	FRED
CPI Energy	U.S. CPI for all urban consumers: energy	FRED
CPI Durables	U.S. CPI for all urban consumers: durables	FRED
CPI Non-durables	U.S. CPI for all urban consumers: non-durables	FRED
CPI Services	U.S. CPI for all urban consumers: services	FRED
Oil and Gas stock price	Average oil and gas sectoral stock price index	Datastream
Electricity Stock Price	Average electricity sectoral stock price index	Datastream
Automobiles Stock Price	Average automobiles sectoral stock price index	Datastream
Mining Stock Price	Average mining sectoral stock price index	Datastream
Retail Stock Price	Average retail sectoral stock price index	Datastream
Travel and Leisure Stock Price	Average travel and leisure sectoral stock price index	Datastream
<i>Firm-level Analysis:</i>		
Capital Stock	Property plan and equipment	Compustat
Sales	Sales divided by turnover	Compustat
Profit	Sales minus cost of goods sold	Compustat
Liquidity	Cash and short term investments over total assets	Compustat

### A.2 Identification Using a Choleski Rotation

The QR approach to decomposing the reduced-form residuals  $e_t^G$  is equivalent to a Choleski rotation in a system where NGPBII is ordered first and GPBII is ordered second within the information set. Identification is achieved by assuming that green technology news shocks, which induce movement in the GPBII, do not affect the NGPBII on impact. This assumption suggests a higher degree of exogeneity for the non-green innovation, which is plausible if we conceive green technology innovation as nested within non-green innovation. The impulse responses to a structural green technology news shock, identified under this ordering assumption, are identical to those in Figure 4 computed using local projections. For comparison, Figure A1 presents the impulse responses from the estimated VAR model that produce similar interpretations. The decision to maintain the QR results as baseline is motivated by the possibility to obtain responses to the common projected component.

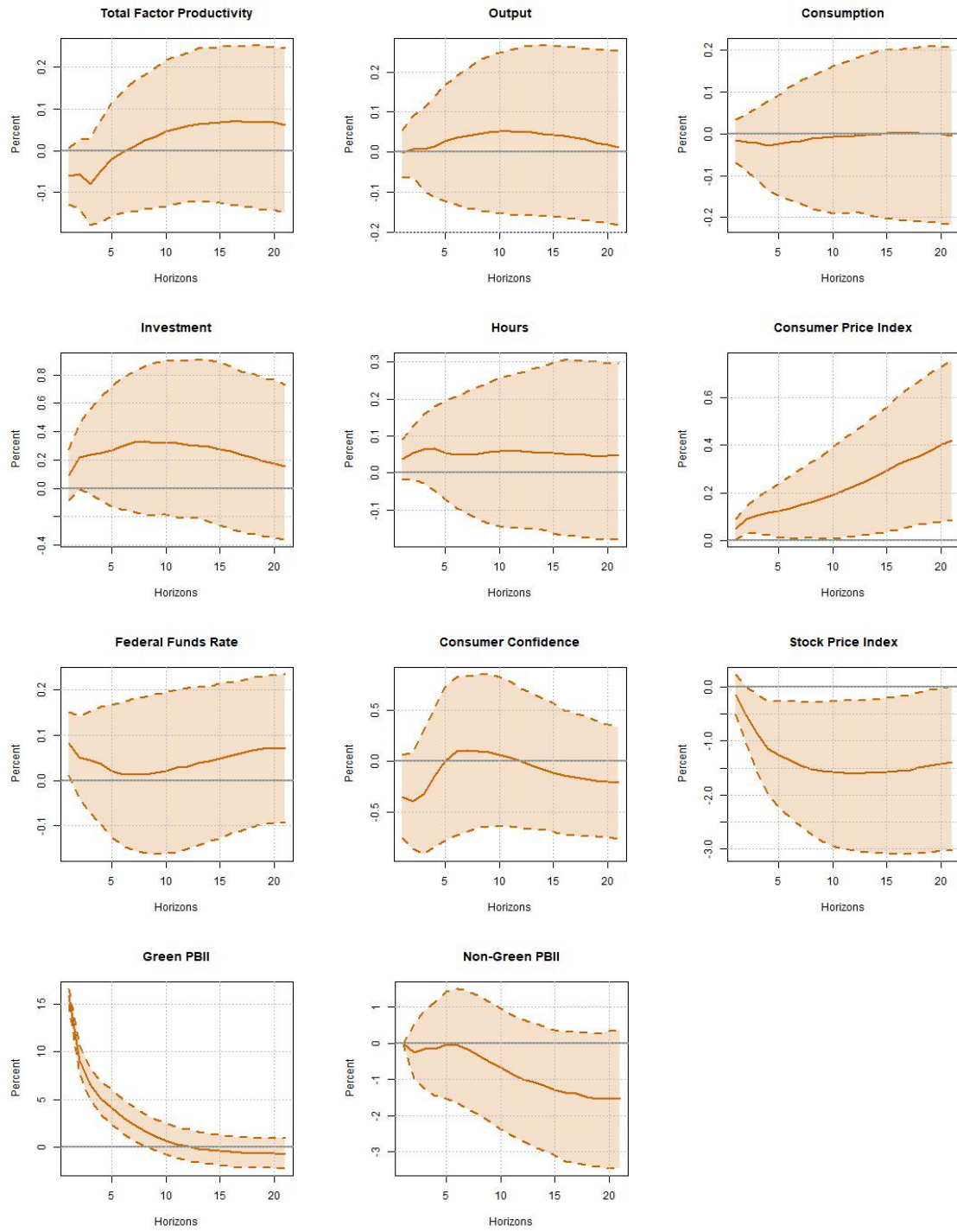


Figure A1: Dynamic responses to green technology news shocks identified using Choleski