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Book

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Time-Varying Effects of Extreme Weather Shocks on Output Growth of the United States

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Abstract

This study investigates the impact of a structural shock to a metric of extreme weather, identified using sign restrictions, on output growth (and inflation) in the United States (US) from 1961 to 2022, using a time-varying parameter vector autoregressive (TVP-VAR) model. Our results show that severe weather shocks adversely affect output growth (and inflation) over the forecast horizon of one- to twelve-quarter-ahead. More importantly, we find that the effect of extreme weather on the US macroeconomic variables is indeed time-varying, with the impacts becoming smaller in recent times, possibly due to improved adaptation to climate change.

Keywords: Severe weather, Endogenous TVP-VAR, Growth, Inflation

JEL Codes: C32, E31, E32, Q54

1. Introduction

Climate change is, perhaps, the most important of challenges currently, with the potential to impact the health and welfare of every person on the planet by imposing a large aggregate risk to the economy (Giglio et al., 2021). Not surprisingly, there exists a burgeoning literature analysing the impact of (severe) weather shocks on the macroeconomy, and economic growth in particular[1] (see, Alessandri and Mumtaz (2022), Kim et al. (2022), Huber et al. (2023), and Kim et al. (forthcoming) for detailed reviews of this literature).[2]

Theoretically speaking, based on the modifications to the models of rare disaster risks (see, Rietz (1988) and Barro (2006)), extreme weather conditions can adversely impact growth by undermining labour productivity and capital quality, as well as through dampening effects on

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[1] Cepni et al. (2023) showed that climate risks can also be utilized to predict business cycle turning points, i.e., have high-frequency macroeconomic effects as well.

[2] While the extant literature primarily focusses on post World War II data, studies like Gupta et al., (2023), and Marfatia et al. (2023), have analysed the impact of climate change on economic growth spanning multiple centuries.

research and development (R&D) expenditure, i.e., the patent obsolescence channel (Sheng et al., 2022a). At the same time, climate risks have been shown to enhance persistence in the process of uncertainty (Sheng et al., 2022b). Since uncertainty causes economic agents to postpone consumption and investment decisions, the real economy is likely to be negatively affected (Bloom, 2009). Thus, there is a possibility that the detrimental effects of climate risks on macroeconomic growth can emanate from both the demand and supply sides of the economy. We aim to extend this line of empirical research by analysing the time-varying impact of climate risks,[3] with a recently developed meteorological time series (the Actuaries Climate Index (ACI)) for severe weather, on growth (and inflation) of the United States (US) over the quarterly period of 1961 to 2022. To conduct our econometric analysis, we utilise a new class of time-varying parameter vector autoregression (TVP-VAR) model, as developed by Leiva-Leon and Uzeda (2023). In this model, the identified (sign-restriction(s)-based) structural innovation(s) is (are) allowed to influence the dynamics of the coefficients in the model, unlike in traditional TVP-VARs, wherein the underlying cause(s) of parameter variations remain unknown. Relying on a time-varying framework is important, not only because the underlying distribution of the shocks to weather is changing over time as a result of climate change but also because economic agents are likely adapting to climate-related risks by undertaking weather-resilient investments in infrastructure and production technologies. Put alternatively, our analysis explicitly allows for the parameters that govern the distribution, as well as the economic effects of weather shocks, to be time-varying. Hence, we can convincingly draw inferences about the effects of climate change on US macroeconomic variables in the presence of (possible) adaptation.

To the best of our knowledge, this is the first paper to analyse the impact of severe weather shocks on output growth (and inflation) in the US by using the VAR model characterised by endogenous time variation of the parameters.[4] While the focus is on the US, we also provide results for Canada (in the Appendix), for which the ACI is also available, over the same sample

[3] The risks associated with climate change can be typically categorised into two groups. The first group comprises physical risks arising due to, for example, rising temperatures, higher sea levels, more destructive storms, and floods or wildfires. The second group comprises the so-called transition risks. Transition risks result from the gradual switchover to a low-carbon economy and include risks due to climate-policy changes, the emergence of competitive green technologies, and shifts in consumer preferences. Understandably, we consider only the physical component of climate change in this paper.
[4] The only other related study is the (working) paper of Kim et al. (2022), These authors used a smooth transition vector autoregressive (ST-VAR) model to show that a shock to ACI index, when it is at its lower-regime, had a statistically insignificant effect on the growth rate of industrial production, but led to a significant negative effect in the state defined by its higher values on average.

period. The remainder of the paper is organised as follows: Section 2 outlines the data and the basics of the methodology, while Section 3 presents results derived from the sign-restriction-based identification of the extreme weather shock. Finally, Section 4 concludes the paper, and draws policy implications of our findings.

2. Data and Methodology

As indicated in the introduction, we rely on the TVP-VARs model of Leiva-Leon and Uzeda (2023) for our analysis, with the framework allowing for the dynamics of coefficients to be driven by the identified (discussed below) severe climate risk shock within the model. Formally, we have:

$$Y_t = X_t \phi_t + A e_t \tag{1}$$

$$\phi_t = \phi_{t-1} + H_{c,\lambda} e_t + H_{L,\lambda} e_{t-1} + v_t \tag{2}$$

where Y_t is a vector of endogenous variables that include the extreme weather metric, output growth and inflation. More specifically, the seasonally-adjusted ACI is used to capture the severe climate events, while the year-on-year growth rates in percentage of the seasonally-adjusted real Gross Domestic Product (GDP) and Consumer Price Index (CPI) correspond to measures of output growth and inflation. The macro variables are sourced from the FRED database of the Federal Reserve Bank of St. Louis, while the ACI (developed by actuary associations in Canada and the US) is available for download from: https://actuariesclimateindex.org/data/. Note that the ACI is actually available monthly, which we convert to quarterly data using a three-month average, and is an aggregate indicator of the frequency of severe weather (high and low temperatures, heavy rainfall, drought (consecutive dry days), and high wind, with all based on gridded data at the resolution of 2.5 by 2.5 degrees latitude and longitude), and the extent of sea level rise (using tidal gauge station data). Based on the latest data availability at the time of writing this paper, we cover the period of 1961:Q1 to 2022:Q3.

The dynamic relationships of these variables are driven by the vector of time-varying coefficients ϕ_t. The constant terms and regressors involving two lags are collected in $X_t = I \otimes (1, Y'_{t-1}, Y'_{t-2})$, where I is an identity matrix, and the symbol $\otimes$ represents the Kronecker product. e_t is the vector of structural shocks that have unit variance and are mutually uncorrelated. A is the impact matrix that captures contemporaneous relationships amongst reduced-form errors. The model specified in Equation (2) allows the vector of time-varying coefficients ϕ_t driven by its one-period lag and by both contemporaneous and lagged structural shocks e_t and e_{t-1}, respectively.

We are interested in analyzing the time-varying effect of extreme weather shocks on growth (and inflation), and hence need to identify the ACI innovation. It is noteworthy that the methodology of Leiva-Leon and Uzeda (2023) does not require us to identify all the structural shocks in the system. In other words, for our context, we impose partial sign restrictions on the impact matrix A, whereby we assume that a positive severe weather shock will contemporaneously lead to a reduction in output growth and a rise in inflation.

3. Empirical Findings

Though our primary objective is to obtain time-varying impulse responses of GDP growth (and inflation) to the extreme weather shock in the US, to get an overall sense of the impact, we present the result derived from a constant parameter sign-restricted VAR in Figure 1, as outlined in Uhlig (2005). Based on the same identification scheme discussed above for the TVP-VAR, we observe a statistically significant negative (positive) effect on growth (inflation), with a delayed maximum effect of about 4.0 (2.3) percentage points, over one- to twelve-quarter-ahead horizon (one- to eight-quarter-ahead horizon), following a one-unit shock to the ACI.[5]

[INSERT FIGURE 1]

Next, we turn our attention to the primary focus of our paper, which is analysing the impulse response of quarterly GDP growth (and inflation) of the US following an extreme weather shock, not only over forecast horizons of one- to twelve quarter-ahead, but also over time using the endogenous TVP-VAR model of Leiva-Leon and Uzeda (2023), outlined in the previous section.[6]

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[5] With the underlying data on the ACI, year-on-year real GDP growth, and CPI inflation derived from the same sources as that of the US, results for Canada from the constant parameter sign-restricted VAR are presented in Figure A1 in the Appendix. The results are qualitatively similar to that of the US, but the growth now initially declines slightly more by about 6.0 percentage points. Interestingly, the effects on year-on-year industrial production growth, as well as year-on-year CPI inflation, based on monthly data for both US and Canada are way smaller in terms of the magnitude of the impact, when compared to the quarterly results. These results have been reported in Figures A2 and A3 in the Appendix of the paper. Note, the monthly data were derived from the same sources as the quarterly ones. Additionally, we must point out that due to computational capabilities on our side, we were not able to conduct the time-varying analysis of the monthly data.

[6] The reader is referred to Leiva-Leon and Uzeda (2023) for the technical details involving the computation of impulse responses.

In Figure 2, we present the time-varying impulses of GDP growth (and CPI inflation) over the period of 1980:Q1 to 2022:Q3, with the period 1961:Q1-1979:Q4 used to train the priors for initialising the time-varying coefficients, recalling that the model is estimated using a Bayesian strategy, based on independent priors for the blocks of model parameters, in line with the class of priors which is standard in TVP-VAR analyses, akin to Primiceri (2005).

Consistent with the results from the constant parameter sign-restricted VAR, we find that extreme weather shock tends to reduce output growth and raise inflation rates across the forecasting horizons. More importantly, the time-varying impulse responses indicate that the impact of climate change on output growth (and inflation) varies over time, with stronger effects felt from 1980 to 2000, especially as the forecast horizon increases. An impact of 3.9 percentage points on GDP growth (and 2.2 percentage points for CPI inflation) was observed in the early 1980s at the longest considered forecast horizon of twelve quarters due to a one-unit ACI shock. Interestingly, these numbers are similar to the highest impact in the sign-restricted constant parameter VAR observed at shorter forecast horizons. After the turn of the century, the effects are found to diminish, settling around 0.1 percentage points for both economic growth and inflation by the end of the sample, stabilizing over time across one to twelve-quarter-ahead predictions.[7]

[INSERT FIGURE 2]

Our time-varying findings seem to suggest that there has been a significant adaptation to increased severe weather over the years in our sample, at least at the macroeconomic level. To confirm this line of reasoning, we present the time path of the vulnerability and readiness scores associated with climate change in the US in Figure 3, obtained from the Notre Dame Global Adaptation Initiative (ND-GAIN).[8] Based on annual data available from 1995 to 2021, we can observe from the Figure that vulnerability scores began to decline steadily from around 2005, coinciding with a jump in readiness scores. Although the latter dipped slightly in 2014, the values thereafter remained higher compared to those from 1995-2004, with the vulnerability scores showing a general downward trend.[9]

[7] Though not as stark, the time-varying impulses for Canada, plotted in Figure A4 in the Appendix of the paper tells a qualitatively similar story, whereby the adverse impact of extreme weather shocks on GDP growth has tapered down in recent times from about 0.3 percentage points to virtually negligible adverse effects.

[8] The data is publicly available for download from: https://gain.nd.edu/our-work/country-index/download-data/.

[9] The time-varying results for Canada in Figure A4, also seem to be in line with the general opposite trends in the readiness and vulnerability scores reported in Figure A5 of the Appendix.

Overall, our findings underscore the dynamic interplay between climate shocks and the economy, emphasizing the need for targeted policies that not only mitigate immediate impacts but also bolster long-term resilience against future climate uncertainties.

[INSERT FIGURE 3]

4. Conclusion

In this paper, we use a TVP-VAR model to analyse the effect of extreme weather shocks on US GDP growth (and CPI inflation) from 1961 to 2022. Our results reveal that the adverse effects on the macroeconomy, characterized by lower growth and higher inflation, have decreased over time, possibly due to improved adaptation to climate change.

Despite our findings, policy measures to combat global warming must not be slowed down, given the ever-changing nature and frequency of climate-related disaster events. Moreover, in this paper, we consider only the physical risk component of climate change, overlooking the transition risk aspect, which has undoubtedly gained importance in recent times. A similar analysis involving transition risk is a direction we should explore in the future.

Beyond the issue of transition risk, while our focus was on the time-varying effect of extreme weather shocks on the growth of the US economy, it would also be intriguing to delve into the time-varying effects of climate risks on the components of CPI inflation, especially that of food,[10] considering the climate-agricultural production nexus. This is even though the overall effect on CPI inflation currently appears to be minimal. Given the Federal Reserve Bank's existing mandate to maintain inflation stability, our findings might carry significant monetary policy implications.

[10] In Figure A6, we present the sign-restricted constant parameter VAR result of the effect of the ACI shock on quarterly food inflation (with the underlying data sourced from the FRED database), and as can be seen, the effect is indeed statistically significant.

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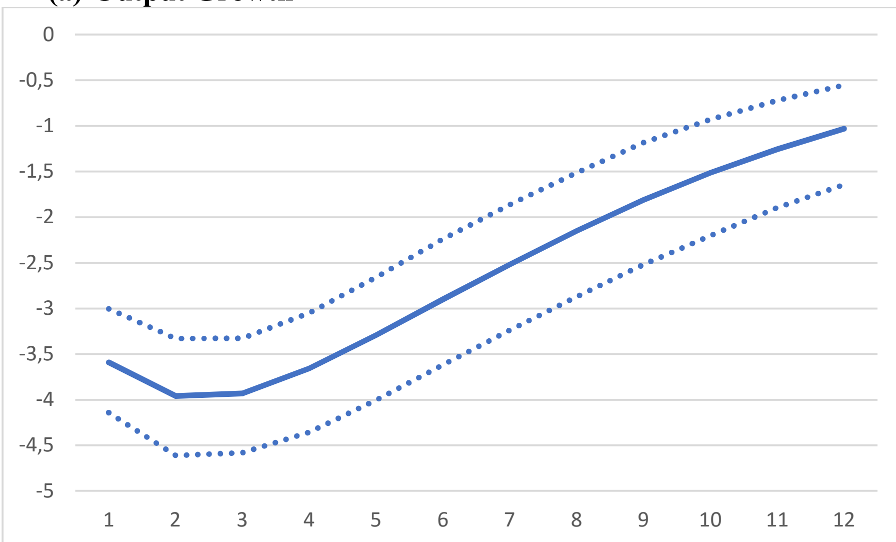
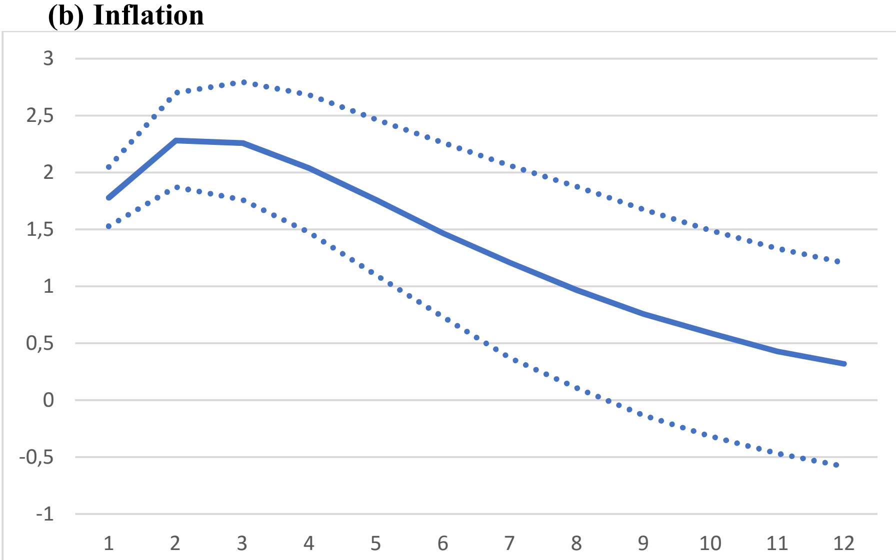
Figures:

Figure 1. The sign-restricted constant parameter VAR impulse responses of quarterly GDP growth and CPI inflation to the ACI shock in the US

(a) Output Growth



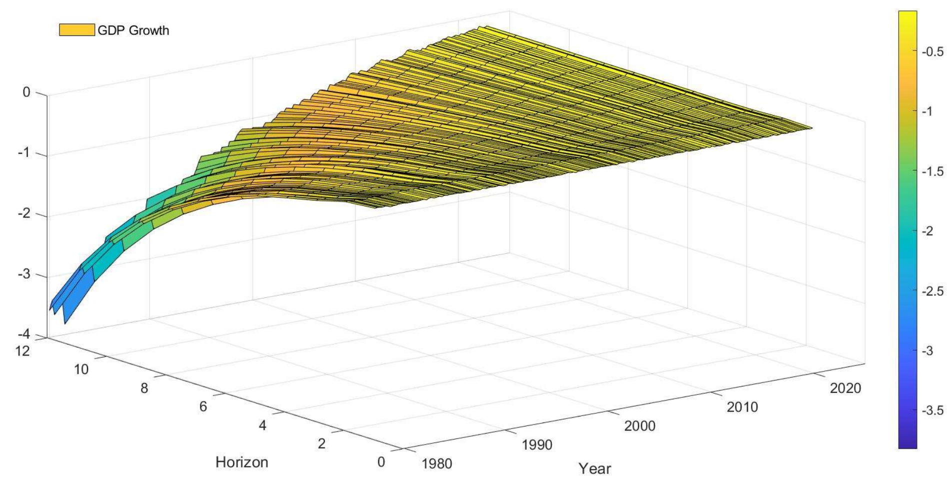
(b) Inflation



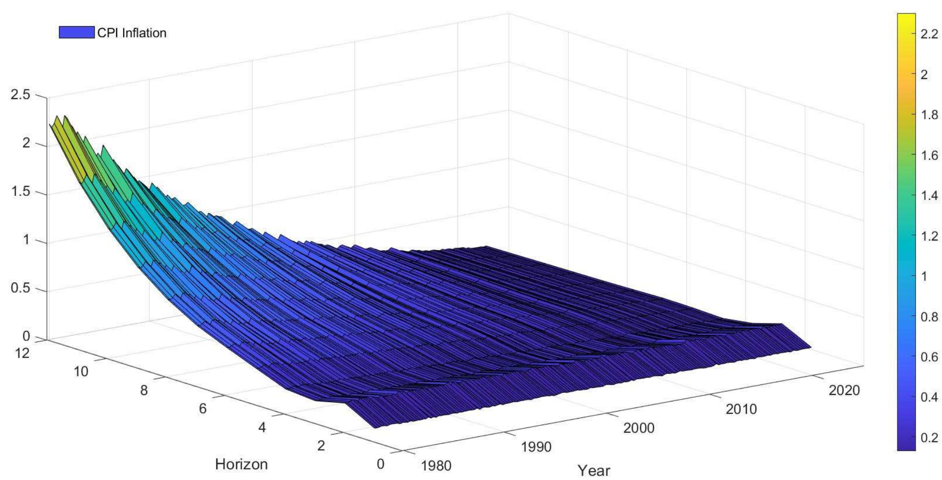
Note: The figure plots the median impulse responses of quarterly GDP growth and CPI inflation to a one unit shock to the ACI. The dotted lines represent 68% posterior bands.

Figure 2. The sign-restricted TVP-VAR impulse responses of quarterly GDP growth and CPI inflation to the ACI shock in the US

(a) Output Growth

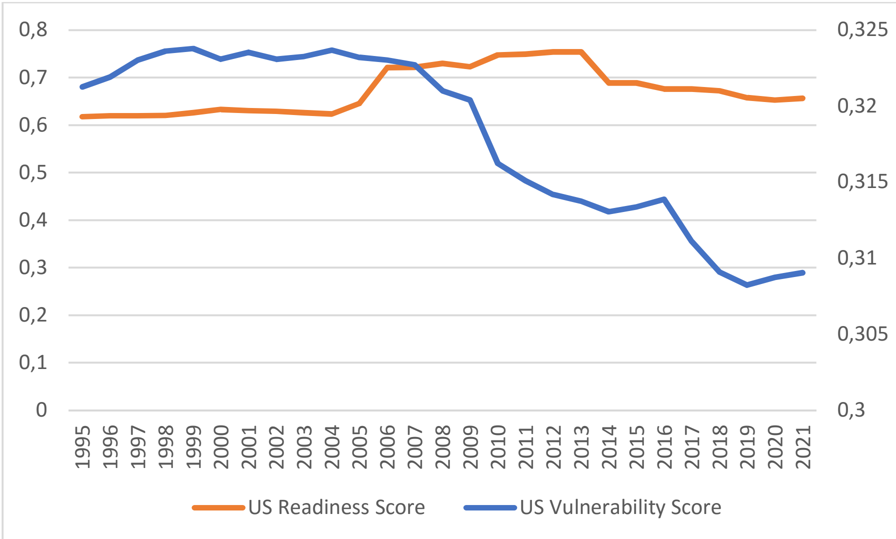


(b) CPI Inflation



Note: The figure plots the impulse responses of quarterly GDP growth and CPI inflation to a one unit shock to the ACI across time and horizons.

Figure 3: Time path of readiness and vulnerability scores for the US

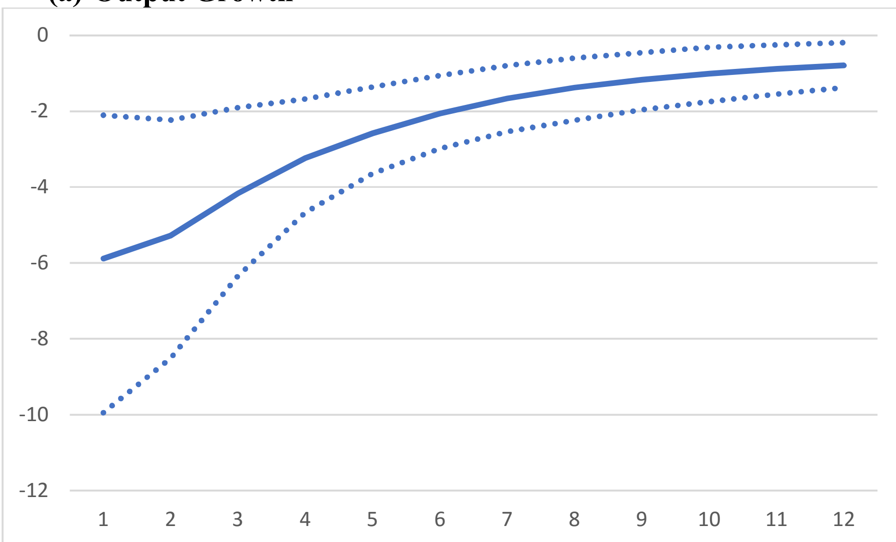


Note: Based on data sourced from the Notre Dame Global Adaptation Initiative (ND-GAIN).

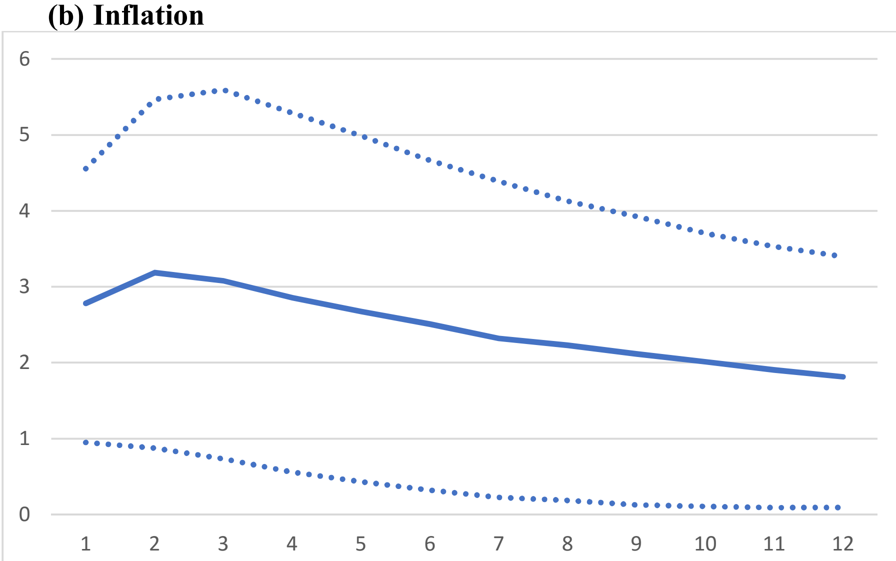
Appendix:

Figure A1. The sign-restricted constant parameter VAR impulse responses of quarterly GDP growth and CPI inflation to the ACI shock in Canada

(a) Output Growth



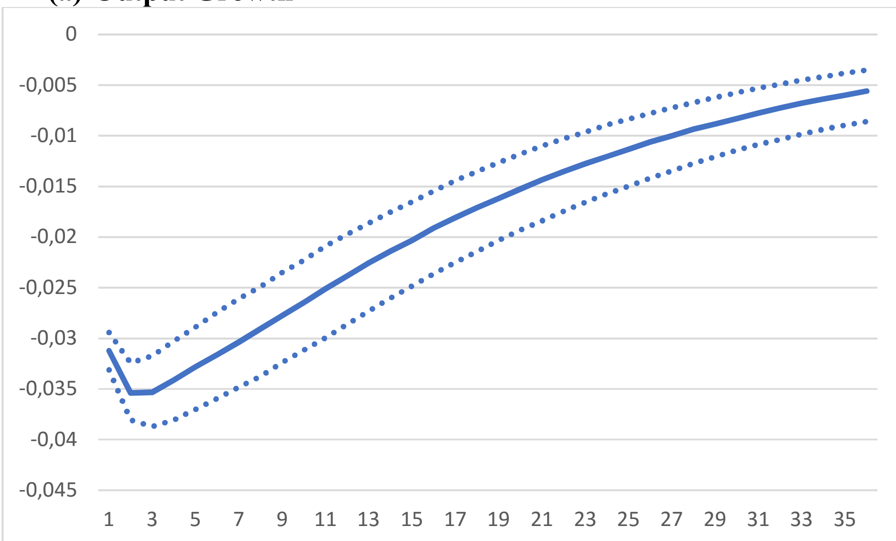
(b) Inflation



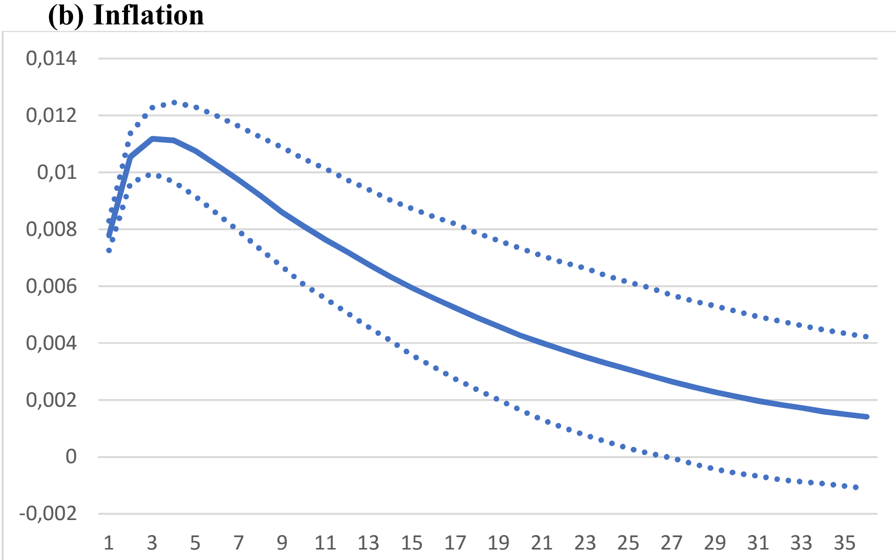
Note: See notes to Figure 1.

Figure A2. The sign-restricted constant parameter VAR impulse responses of monthly industrial production growth and CPI inflation to the ACI shock in the US

(a) Output Growth



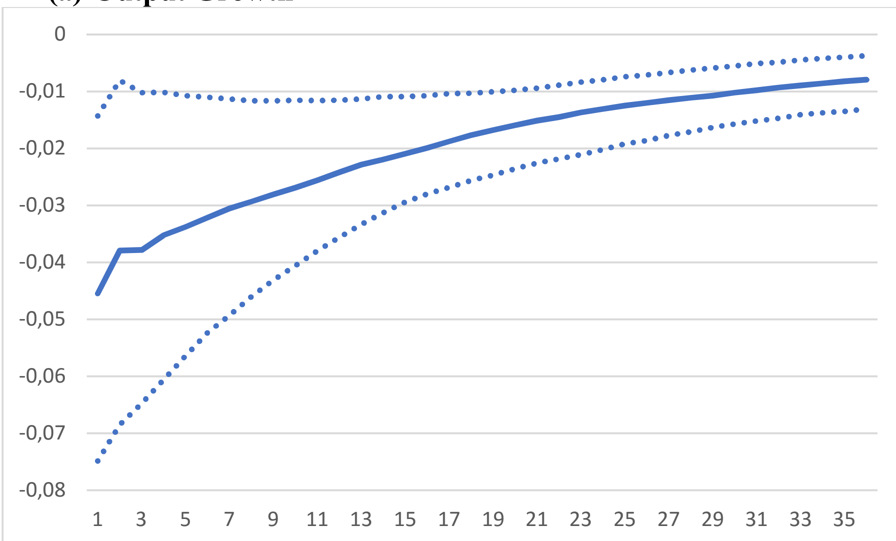
(b) Inflation



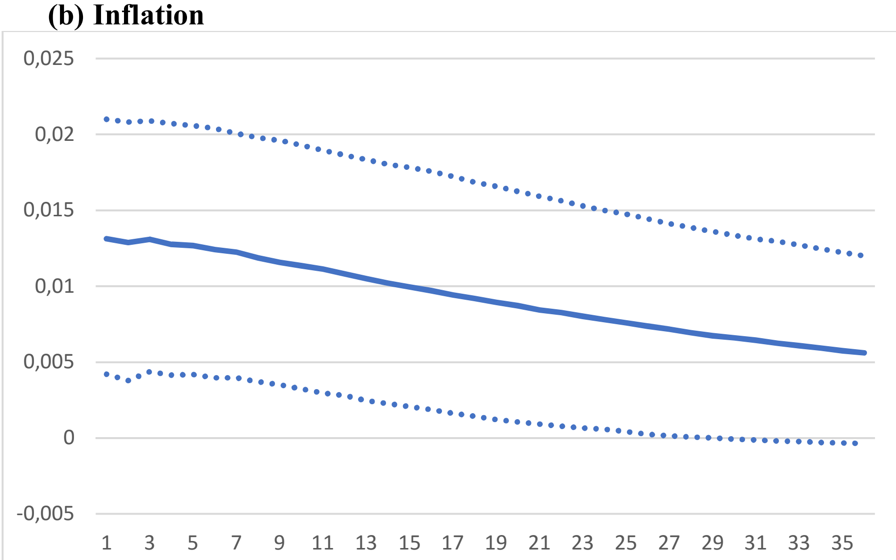
Note: See notes to Figure 1.

Figure A3. The sign-restricted constant parameter VAR impulse responses of monthly industrial production growth and CPI inflation to the ACI shock in Canada

(a) Output Growth



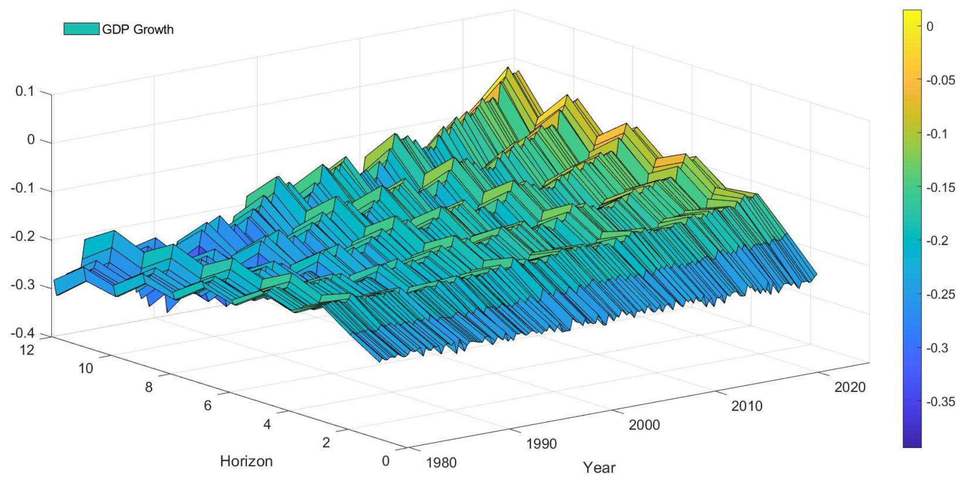
(b) Inflation



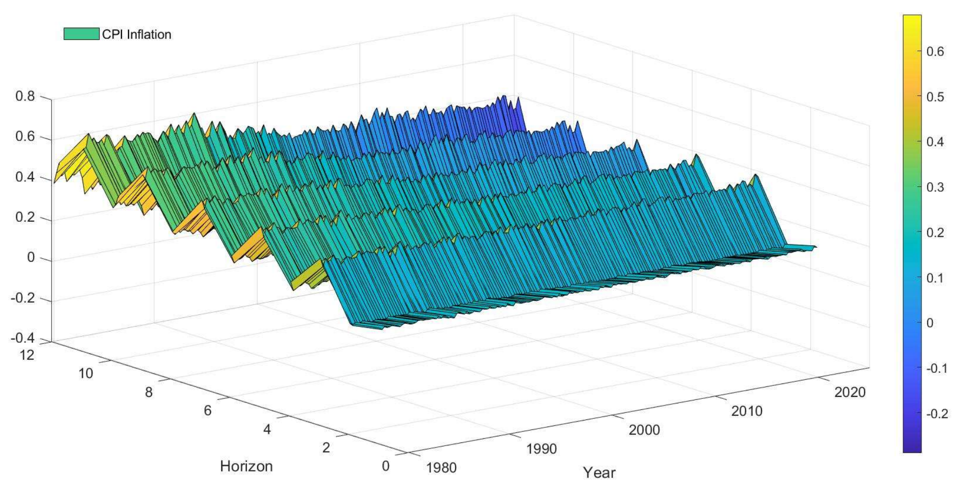
Note: See notes to Figure 1.

Figure A4. The sign-restricted TVP-VAR impulse responses of quarterly GDP growth and CPI inflation to the ACI shock in Canada

(a) Output Growth

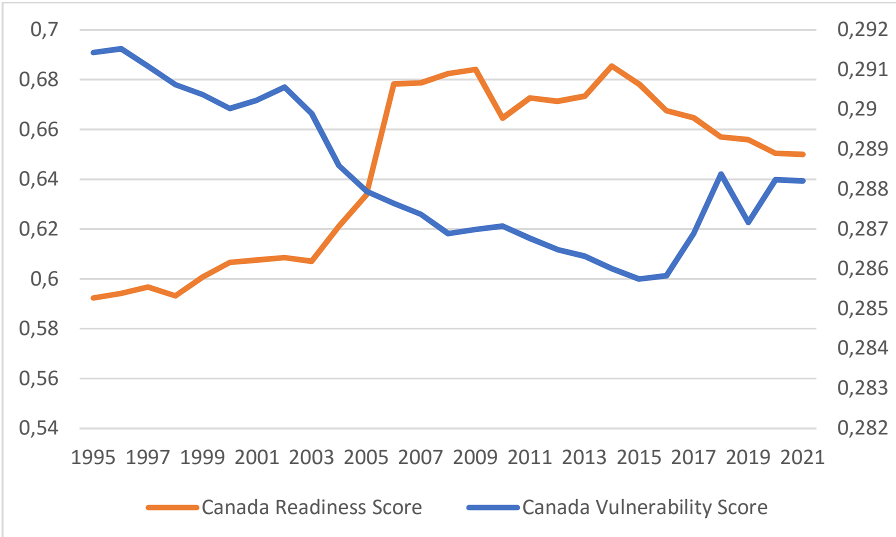


(b) CPI Inflation



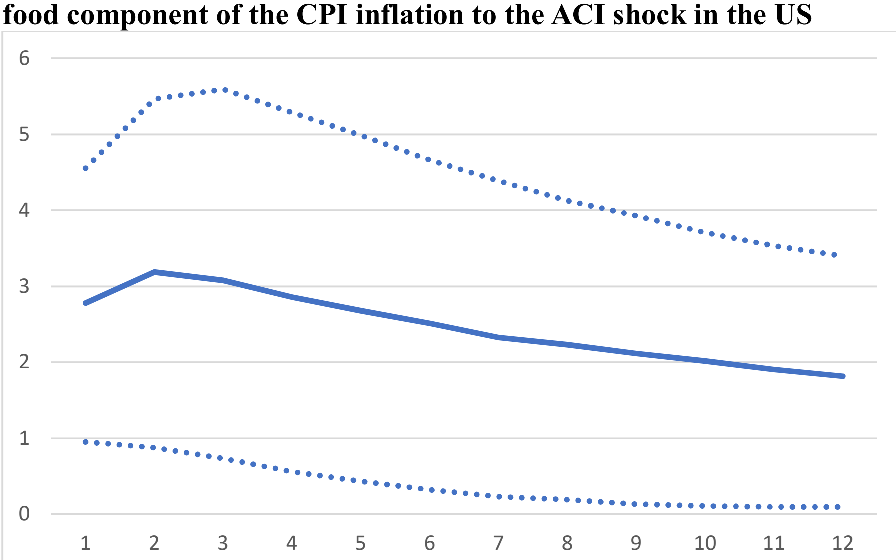
Note: See notes to Figure 2.

Figure A5: Time path of readiness and vulnerability scores for Canada



Note: See notes to Figure 3.

Figure A6. The sign-restricted constant parameter VAR impulse responses of quarterly food component of the CPI inflation to the ACI shock in the US



Note: See notes to Figure 1.