

# ENSO and its Economic Impact in the Peruvian Economy: Economic Activity, Inflation, and Monetary Policy Design

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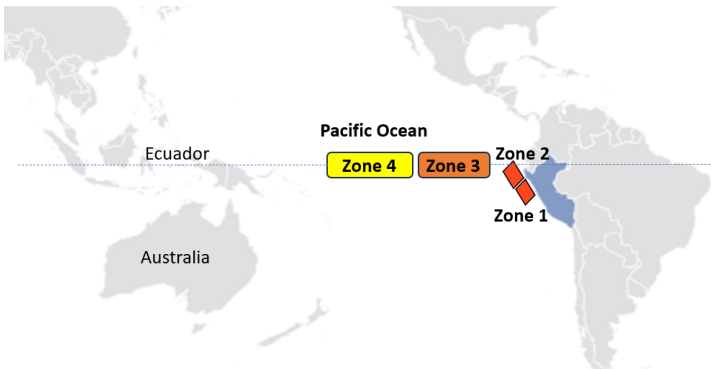
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# Motivation

- Large weather shocks pose significant physical risks, disrupting business cycles and hindering macroeconomic stability.
- Global warming is anticipated to exacerbate these risks
- $\Rightarrow \uparrow$  Uncertainty  $\Rightarrow$  Need to evaluate wide-range impacts of weather events on the economy
- In this paper, we focus on the Peruvian economy to study the physical risks created by a large scale weather shock: El Niño

# El Niño-Southern Oscillation (ENSO)

El Niño-Southern Oscillation (ENSO) is a periodic, large-scale climate disruption in the central and eastern tropical regions of the Pacific Ocean



We focus on El Niño Costero: Warming of sea surface temperatures in the coastal regions of Peru and Ecuador (Zone 1+2)

# Why do we care about El Niño?

- El Niño: recurring climatic event in Peru.
  - Since 1980 until 2024: 11 events categorized as moderate or greater.
  - 4 of them in the last 10 years
- Significant losses from large-size El Niño events:

| Event         | Dur. (months) | Peak severity | GDP losses         |
|---------------|---------------|---------------|--------------------|
| 9/1982-9/1983 | 13            | Very Strong   | 11.6% <sup>b</sup> |
| 3/1992-6/1992 | 4             | Strong        | 2.5% <sup>c</sup>  |
| 4/1997-7/1998 | 16            | Very Strong   | 6.2% <sup>e</sup>  |
| 6/2014-7/2014 | 2             | Moderate      | 2.3% <sup>f</sup>  |
| 2/2017-4/2017 | 3             | Moderate      | 0.8% <sup>g</sup>  |
| 3/2023-1/2024 | 11            | Strong        | 1.1% <sup>h</sup>  |

Sources: <sup>a</sup>Cross 2017, <sup>b</sup>Callahan and Mankin 2023, <sup>c</sup>BCRP 1992, <sup>d</sup>Cross 2017, <sup>e</sup>Callahan and Mankin 2023, <sup>f</sup>BCRP 2014, <sup>g</sup>BCRP 2023, <sup>h</sup>BCRP 2023

# Quick summary of this paper

## Research Questions

- After a large-scale El Niño shock: What is the dynamic response of inflation and economic activity? What are the implications for the design of MP?

## Methodology

- Empirics: Local Projections, a TVP-VAR and a Threshold-BVAR
- Theoretical: IRF matching & simulation using a Large Semi-structural model w/ non-linear transmission channels

## Results

- El Niño shock  $\simeq$  a supply-side shock: inflationary pressures & GDP contraction
  - Heterogeneous persistent across sectors
- MP design: Tighter MP still a key role in stabilizing inflation dynamics
  - But, trade-off between inflation and economic growth requires precision calibration of MP adjustments

# Literature Review

- Anomalous temperatures and GDP
  - USA:  $\uparrow$  temperatures  $\Rightarrow \downarrow$  GDP [Hsiang et al. 2017; Colacito et al. 2019 ]
  - Same effect in other developed countries [Kim et al. 2021 ]
  - Stronger effects in developing countries [Dell et al. 2012; Acevedo et al. 2020; Bandt et al. 2021 ]
- Anomalous temperatures and inflation
  - $\uparrow$  temperatures  $\Rightarrow \uparrow$  inflation via higher food prices [Faccia et al. 2021; Mukherjee and Ouattara 2021 ]
- Physical Risks acts as a ...
  - ... demand shock [Ciccarelli and Marotta 2024 ]
  - ... supply shock [Pozo and Rojas 2024 ]
- El Niño shocks and economics effects in Peru [Chirinos 2021; CEPAL 2014; Vargas 2009 ]

# Empirical Exploration

# Data

Our empirical exploration covers the period January-1994/December-2023 and relies on three databases:

- **BCRPdata:** Sectoral production indices, terms of trade, liquidity of deposit societies, total inflation, food and energy inflation and inflation expectations.
- **FRED:** US industrial production index and Brent oil price index.
- **ENFEN:** Coastal El Niño Index (ICEN).

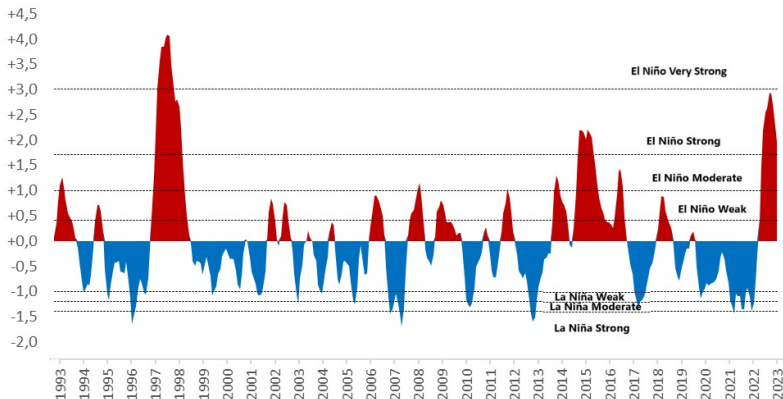


# Measuring El Niño: ICEN

- The Peruvian ENSO center monitors sea surface temperatures to inform the ICEN index (Índice Costero El Niño).
- ICEN: 3-month moving average of sea surface temperature relative to its long-term mean (1981-2010)
- Different categories:

| Category |             | Threshold               |
|----------|-------------|-------------------------|
| El Niño  | Very Strong | $ICEN > 3.0$            |
|          | Strong      | $3.0 \geq ICEN > 1.7$   |
|          | Moderate    | $1.7 \geq ICEN > 1.0$   |
|          | Weak        | $1.0 \geq ICEN > 0.4$   |
| Neutral  |             | $0.4 \geq ICEN > -1.0$  |
| La Niña  | Weak        | $-1.0 \geq ICEN > -1.2$ |
|          | Moderate    | $-1.2 \geq ICEN > -1.4$ |
|          | Strong      | $-1.4 \geq ICEN$        |

# Large-scale El Niño shocks: above Moderate events



# Empirical Strategy

Compute dynamic effects of large-scale El Niño shocks on the economy using Jordà 2005 Local Projections (LP) a la Ramey and Zubairy 2018

$$y_{t+h} = (1 - I_t)[\alpha_{0,h} + \beta_{0,h}x_t + B_{0,h}X_t] + I_t[\alpha_{1,h} + \beta_{1,h}x_t + C_{1,h}X_t] + e_{t+h}$$
$$I_t = \mathcal{I}(x_t > 1)$$

- $y_{t+h}$  is a measure of inflation or economic activity at moment  $t + h$ ,  $h = 1, \dots, 15$ .
- $x_t = ICEN_t \Rightarrow I_t = 1$  if Moderate, Strong or Very Strong El Niño
- Parameter of interest:  $\beta_{1,h}$  for all  $h = 1, \dots, 15$
- $X_t$  control variables (lags of  $y, x$ , oil prices, US GDP growth)

**Problem:** ICEN exogenous but **correlated**  $\Rightarrow \beta_{1,h}$  biased!

# Empirical Strategy: Solving the estimation bias

- ICEN index is a persistent time series  $\Rightarrow \beta_{1,h}$  biased, due to
  - Current  $x_t$  being correlated with  $y_{t+h}$ ,  $h = 1, \dots, 15$  Bias
    - Control for lagged values of  $x_t$  is not sufficient
    - Solution: Use shocks to  $x_t$ . Compute residuals from an ARMA(2,3) model adjusted to ICEN data (1950m2-2024m4) Estimated ARMA model

$$x_t = \rho_0 + \sum_{j=1}^2 \rho_j x_{t-j} + \varepsilon_t + \sum_{j=1}^3 \phi_j \varepsilon_{t-j} \text{ with } \varepsilon_t \sim \mathcal{N}(0, \sigma_\varepsilon^2),$$

- Non linear effects,  $I_t$ , also depends on  $x_t$ .
  - Solution: Lag structure of the dummy variable  $I$ :  $I_{t-1}$
- Then, our final empirical specification is :

# Empirical Strategy: Empirical Specification

$$y_{t+h} = (1 - I_{t-1})[\alpha_{0,h} + \beta_{0,h}\hat{\varepsilon}_t + B_{0,h}X_t] + I_{t-1}[\alpha_{1,h} + \beta_{1,h}\hat{\varepsilon}_t + C_{1,h}X_t] + e_{t+h}$$

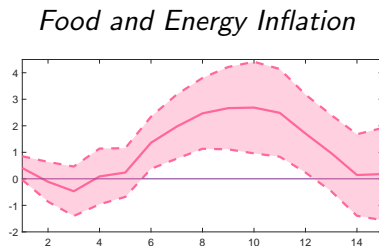
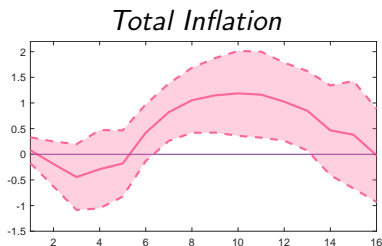
$$I_{t-1} = \mathcal{I}(x_{t-1} > 1)$$

Then,  $\{\beta_{1,h}\}_{h \leq H}$ , can be estimated consistently only one month after the event materializes.

$$\frac{\partial y_{t+h}}{\partial \varepsilon_t} = \beta_{2,h} + (\beta_{1,h} - \beta_{2,h})\mathcal{I}(x_{t-1} > 1) = \begin{cases} \beta_{2,h}, & \text{if } x_{t-1} < 1 \\ \beta_{1,h}, & \text{if } x_{t-1} > 1 \end{cases}$$

# LP IRF Results: Inflation

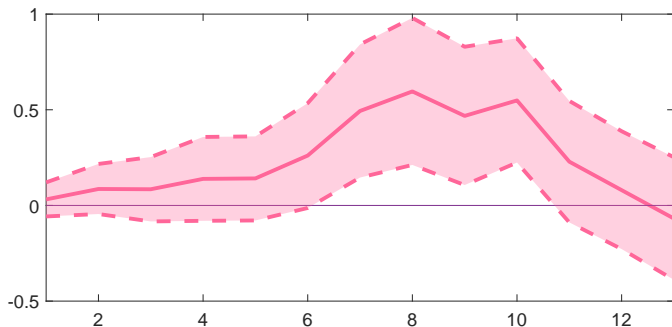
- El ICEN shock, consistent with an El Niño event that has a duration of 9 months and a mean magnitude of 1.7, ...
- ... has inflationary effects that takes 7 months to manifest, with a peak effect of 136pbs, and are persistent ...



- ... that is mainly attributable to foods and energy inflation, which rises up to 269pbs ...

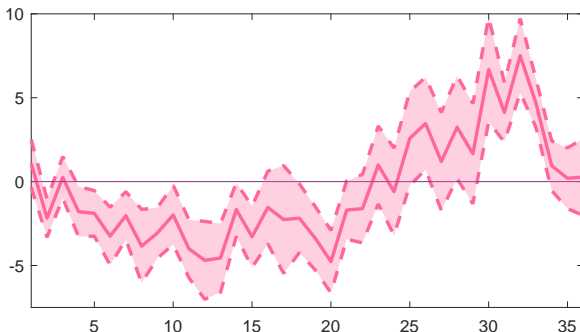
# LP IRF Results: Inflation expectations

... it also increases inflation expectations, although the impact is modest and less persistent ...



# GDP growth

.. on the other side, a significant decline in GDP growth, reaching a trough of about -4.8 percent 11 months later, before a gradual recovery....



- ... permanent effects:  $|\sum IRF_{t+h} \mathcal{I}_{\Delta\%y < 0}| > |\sum IRF_{t+h} \mathcal{I}_{\Delta\%y > 0}|$
- ... and heterogeneous across sectors: strong effects on primary sectors and smaller on non-primary sectors Sectoral



# Robustness

- LP impulse responses captures the average impacts by aggregating all El Niño events:
  - Time-Varying Parameters Vector Autoregression with Stochastic Volatility (TVP-VAR-SV) to check the different intensities of El Niño across time.
  - Results: Pronounced responses correlate with most severe El Niño episodes, specifically those in 1998, 2017, and most recently, 2022-2023
- Robustness to non linear LP methodology:
  - Threshold BVAR approach with an ICEN of 1 that could trigger a regime switch.
  - Results: Confirm potential differences in the responses to shocks in the ICEN variable, depending on whether the initial conditions are below or above the threshold.

# Discussion

- The empirical results provide evidence that large-scale El Niño shocks have similar effects on the economy as supply-side persistent shocks:
  - Inflationary pressures lasting more than a year that also spillovers on higher inflation expectation
  - Persistent contractions of GDP that also trigger permanent effects
- MP implications:
  - The central bank's response to these shocks are limited
  - Inflation expectations responses create a risk scenario for central banks
  - We use a semi-structural model to understand the complex implications of large-scale El Niño shocks for MP

# Semi-Structural Model

# Semi-Structural Model

- Baseline model: Semi-structural model fitted for the Peruvian Economy (Aguirre et al. 2022)
- We add four non-linear transmission channels through which large-scale El Niño shock affects the economy.

|              | Effect on ...                |               |
|--------------|------------------------------|---------------|
| $ICEN > 1$   | Inflation of food and energy | Output gap    |
| $ICEN > 1.7$ | Inflation expectations       | Potential GDP |

# Semi-Structural Model (II)

- GDP definition

$$\Delta Y_t = y_t - y_{t-4} + \Delta Y_t^p$$

- i) Aggregate demand channel

$$y_t = a_y y_{t-1} + a_y^e (y_{t-1} + \Delta y_{t+1}^e) + a_\phi \phi_{t-1} + a_q q_t + a_g g_t + a_\tau \tau_t \\ + a_{y^*} y_t^* + \Omega^{f/y} I_{(ICEN_{t-1} > 1)} ICEN_t + \epsilon_t^y$$

- ii) Potential GDP channel

$$\Delta Y_t^p = (1 - \lambda^p) \Delta Y + \lambda^p \Delta Y_{t-1}^p + \Omega^{f/p} I_{(ICEN_{t-1} > 1.7)} ICEN_t + \epsilon_t^p$$

# Semi-Structural Model (III)

- Inflation Definition

$$\pi_t = c_{sae} \pi_t^{sae} + (1 - c_{sae}) \pi_t^{ae}$$

- iii) Inflationary channel via food & energy inflation

$$\begin{aligned} \pi_t^{ae} = & (1 - \lambda_{ae}) [b_s \pi_t^{sae} + (1 - b_s) \pi_t^m] \\ & + \lambda^{f/ae} I_{(ICEN_{t-1} > 1)} \pi_{t-1}^{ae} + \Omega^{f/ae} I_{(ICEN_{t-1} > 1)} ICEN_t + \epsilon_t^{ae} \end{aligned}$$

- Core inflation

$$\begin{aligned} \pi_t^{sae} = & b_m \Pi_t^m + (1 - b_m) [b_{sae} \pi_{t-1}^{sae} + (1 - b_{sae}) \Pi_t^e] \\ & + b_y y_{t-1} + \varepsilon_t \end{aligned}$$

# Semi-Structural Model (IV)

- v) Inflation expectations channel

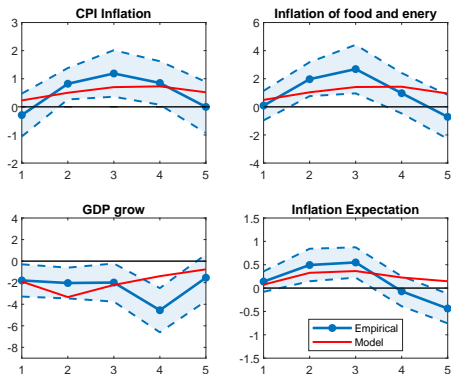
$$\begin{aligned}\Pi_t^e &= \lambda_{\Pi^e} \Pi_{t-1}^e + (1 - \lambda_{\Pi^e}) \left[ (1 - c_p) E_t \Pi_{t+4}^{sae} + c_p \Pi_{t-1} \right] \\ &\quad + \Omega^{f/exp} I_{(ICEN_{t-1} > 1.7)} ICEN_t + \epsilon_t^{\Pi^e}\end{aligned}$$

# Calibration and Estimation

- The model was calibrated to replicate some conditional and unconditional moments for the Peruvian economy.
  - Baseline model parameters are calibrated on estimated values from [Aguirre et al. \(2022\)](#)
  - Parameters that govern the transmission of El Niño shocks to the economy calibrated via Impulse Response Matching (Model implied IRFs vs empirical LP IRFs).

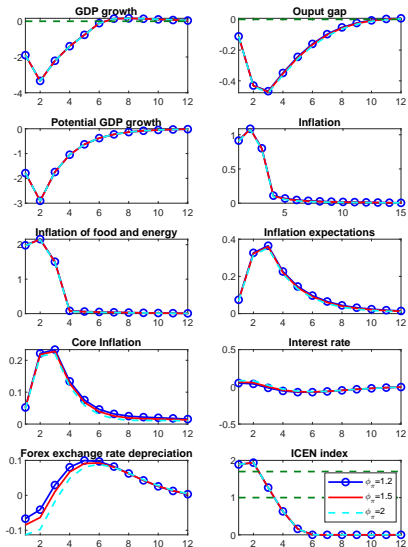


# IRF matching: Large-scale El Niño Shock



|                                     | Parameters       | Value  |
|-------------------------------------|------------------|--------|
| Potential GDP                       | $\Omega^f/p$     | -0.945 |
| Output Gap                          | $\Omega^f/y$     | -0.047 |
| Inflation Expectations              | $\Omega^f/exp$   | 0.219  |
| $\pi$ Food and Energy - Persistence | $\lambda^{f/ae}$ | 0.029  |
| $\pi$ Food and Energy - Sensitivity | $\Omega^f/ae$    | 0.999  |

# Large-size El Niño Shock: Macro effects



# El Niño Shocks & Macro responses

- The impulse responses produced by a large-size El Niño shock are similar to a "cost-push shock" as described by [Woodford \(2003\)](#) or a relative price shock discussed in [Aoki \(2001\)](#).
- However, here the shock has non-linear effects.
- Different shock sizes  $\neq$  MP stabilization costs
- We explore this via simulations

# MP responses for different intensities of El Niño shock

- We simulate different intensities of El Niño shock using as a proxy the shock volatility.

| $\sigma_{ENSO}^2$                        | 0.50  | 1.00  | 2.00   |
|--|-------|-------|--------|
| % El Niño occurrences out of 80 quarters |       |       |        |
| ENSO > 1                                 | 1.23% | 8.05% | 15.61% |
| ENSO > 1.7                               | 0.02% | 2.30% | 10.05% |

- Evaluate MP loss function

$$\mathcal{L} = \alpha \text{var}(y) + \text{var}(\pi)$$

for different preferences of inflation stabilization (Taylor rule coefficient for inflation).

- Key assumption for MP: No loss of CB credibility across scenarios.

# El Niño shocks & MP responses

- $\uparrow \sigma_{ENSO}^2$  (El Niño Intensity)  $\Rightarrow \uparrow \mathcal{L}$  (MP losses)
- Low  $\sigma_{ENSO}^2$  &  $\uparrow \phi_\pi \Rightarrow \overline{\mathcal{L}}$  (MP losses): No gains for MP from stricter inflation stabilization preferences.
- High  $\sigma_{ENSO}^2$  &  $\uparrow \phi_\pi \Rightarrow \downarrow \mathcal{L}$  (MP losses): Higher gains from stricter inflation stabilization preferences.
- But,  $\uparrow \phi_\pi \Rightarrow$  higher interest rates volatility

| $\phi_\pi$        | 1.20  |       |        | 1.50  |       |        | 2.00  |       |        |
|-------------------|-------|-------|--------|-------|-------|--------|-------|-------|--------|
| $\sigma_{ENSO}^2$ | 0.50  | 1.00  | 2.00   | 0.50  | 1.00  | 2.00   | 0.50  | 1.00  | 2.00   |
| $ENSO > 1$        | 1.23% | 8.05% | 15.61% | 1.23% | 8.05% | 15.61% | 1.23% | 8.05% | 15.61% |
| $ENSO > 1.7$      | 0.02% | 2.30% | 10.05% | 0.02% | 2.30% | 10.05% | 0.02% | 2.30% | 10.05% |
| $\pi^{sae}$       | 0.016 | 0.111 | 0.375  | 0.016 | 0.106 | 0.347  | 0.016 | 0.100 | 0.315  |
| $\Pi^e$           | 0.004 | 0.095 | 0.405  | 0.003 | 0.090 | 0.377  | 0.003 | 0.083 | 0.344  |
| $i$               | 0.007 | 0.073 | 0.292  | 0.007 | 0.076 | 0.312  | 0.008 | 0.082 | 0.339  |
| $\pi$             | 0.065 | 0.290 | 0.687  | 0.066 | 0.286 | 0.668  | 0.066 | 0.282 | 0.644  |
| $y$               | 0.014 | 0.146 | 0.439  | 0.013 | 0.149 | 0.454  | 0.013 | 0.152 | 0.474  |
| $\mathcal{L}$     | 0.004 | 0.085 | 0.481  | 0.004 | 0.083 | 0.456  | 0.004 | 0.081 | 0.426  |

# Conclusions

- El Niño shock tends to be similar a cost or supply shock,
- However, a large-scale shock is more complex: multiple transmission channels and it includes permanent effects on GDP and persistent inflationary pressures.
- MP design is size-shock dependent
- Strict monetary policy continues to influence stabilization inflation dynamics
- But large scale shocks also requires a careful calibration of MP to minimize the negative effects on inflation and economic activity.

# Appendix

# Bias in LP

- Assume a LP with non-linearity,

$$y_{t+h} = a_h + \gamma_h x_t + B_h X_t + e_{t+h} \quad (1)$$

Let  $x$  be persistent (as the ICEN). Assume  $x \sim AR(p)$ .

$$x_t = \rho_0 + \sum_{i=1}^p \rho_i x_{t-i} + \varepsilon_t \Rightarrow \frac{\partial E_t x_{t+j}}{\partial x_t} = \varrho_j \quad (2)$$

- Together, the population equation for  $y_{t+h}$  should look something like

$$y_{t+h} = a_h + \left( \gamma_h + \underbrace{\sum_{i=1}^h c_i \varrho_i}_{\text{Bias}} \right) x_t + B_h X_t + e_{t+h}. \quad (3)$$



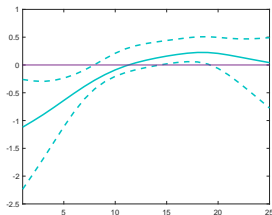
# ARMA(2,3) model for ICEN

Table: ICEN as an ARMA(2,3) process

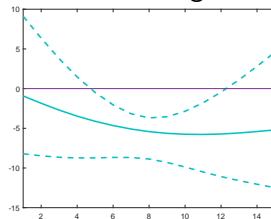
|                        | Coef.  | Std. Err. | $z$                                     | $P >  z $ | [95% Conf. interval ] |        |
|------------------------|--------|-----------|---|-----------|-----------------------|--------|
| $\rho_0$               | -0.233 | 0.109     | -2.130                                  | 0.033     | -0.446                | -0.019 |
| $\rho_1$               | 1.712  | 0.077     | 22.37                                   | 0.000     | 1.562                 | 1.862  |
| $\rho_2$               | -0.755 | 0.068     | -11.100                                 | 0.000     | -0.888                | -0.621 |
| $\phi_1$               | 0.301  | 0.091     | 3.310                                   | 0.001     | 0.123                 | 0.479  |
| $\phi_2$               | 0.270  | 0.090     | 2.990                                   | 0.003     | 0.093                 | 0.447  |
| $\phi_3$               | -0.659 | 0.089     | -7.380                                  | 0.000     | -0.833                | -0.484 |
| $\sigma_\varepsilon^2$ | 0.151  | 0.003     | 49.430                                  | 0.000     | 0.145                 | 0.157  |
| Sample:                |        |           | Feb-1950 to Apr-2024 (891 observations) |           |                       |        |

# SLP IRF: Primary GDP sector

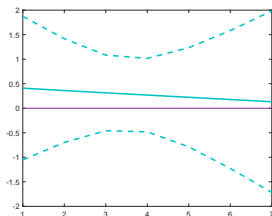
## A. Agriculture



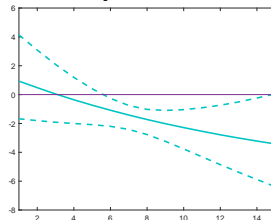
## B. Fishing



## C. Mining



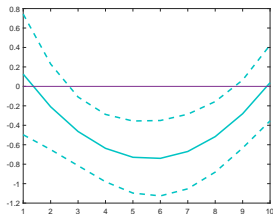
## D. Primary Manufacturing



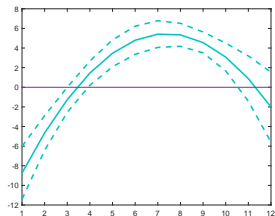
Note: SLP (Barnichon and Brownlees 2019 LP) impulses responses. 68% confidence intervals.

# SLP IRF: Non-Primary GDP sector (I)

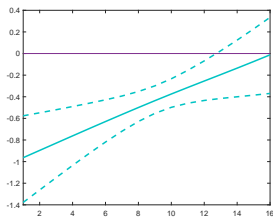
## A. Electricity



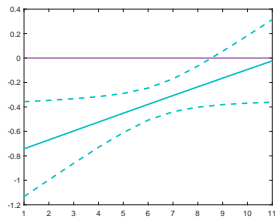
## B. Construction Sector



## C. Commerce Sector

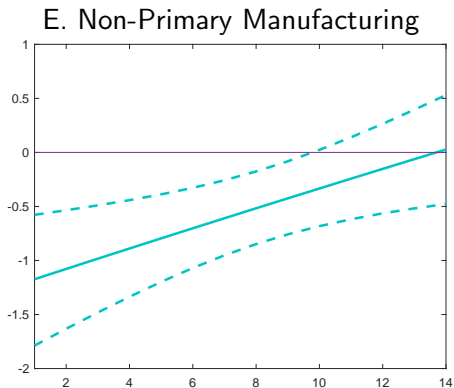


## D. Service Sector



Note: SLP (Barnichon and Brownlees 2019 LP) impulses responses. 68% confidence intervals.

# SLP IRF: Non-Primary GDP sector (II)



Note: SLP (Barnichon and Brownlees 2019 LP) impulses responses. 68% confidence intervals.

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