Severe Weather and the Macroeconomy

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Does severe weather matter for the US Economy?

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  1. developing countries and lower frequencies (Dell, Jones, and Olken 2012; Hsiang and Jina 2014; Bakkensen and Barrage 2018...)
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- **This paper: Direct measures of extreme weather events**
- Have these effects changed over time (evidence of adaptation)?
- **This paper: Use a nonlinear time series model to find that the effects of these shocks, but not their volatility, have become more severe.**

Data

Actuaries Climate Index: Components

A monthly index of climate risks, based on a basket of extreme climate events & sea level rise:

1. T90: Frequency of extreme high temperatures
2. T10: Frequency of extreme low temperatures
3. W: Frequency of high winds
4. P: Maximum amount of heavy precipitation
5. D: Longest period of consecutive dry days last 12 months
6. S: Change in sea level

Actuaries Climate Index: Construction

- Weather data measured on grid with resolution of 2.5 by 2.5 degrees latitude and longitude (except S)
- Standardize each component (using location- and month-specific mean and standard deviation) relative to benchmark period (1961-1990)
- Average across all grid points/locations
- $ACI = \text{mean}(T90_{std} - T10_{std} + P_{std} + D_{std} + W_{std} + S_{std})$

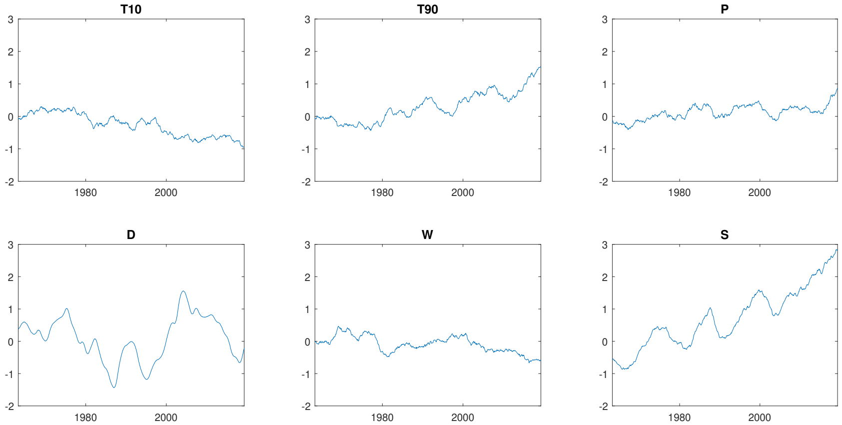
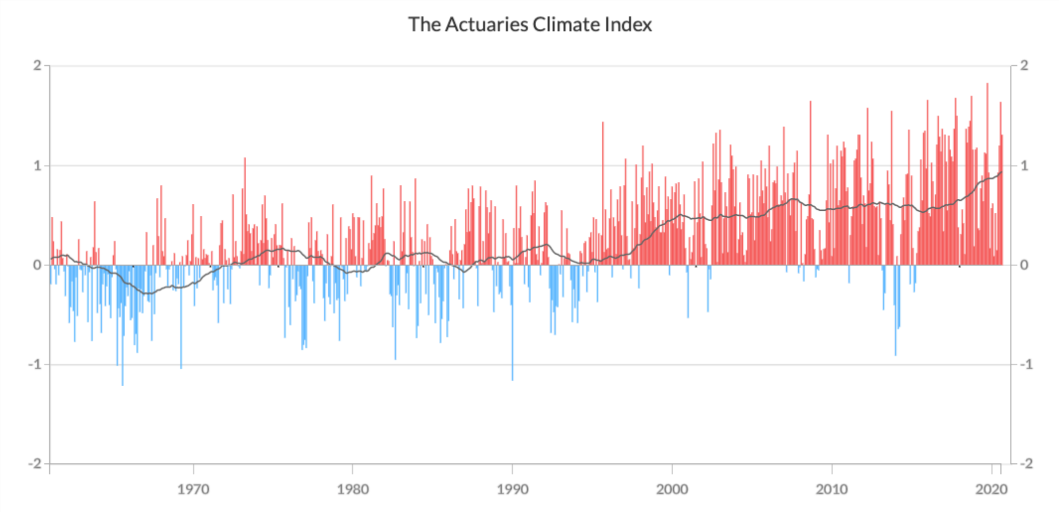


Figure 1: The six components of the ACI (low temperatures, high temperatures, heavy precipitation, drought, high wind and sea level) for the continental US.



The Actuaries Climate Index
2
1
0
-1
-2
1970
1980
1990
2000
2010
2020

Figure 2

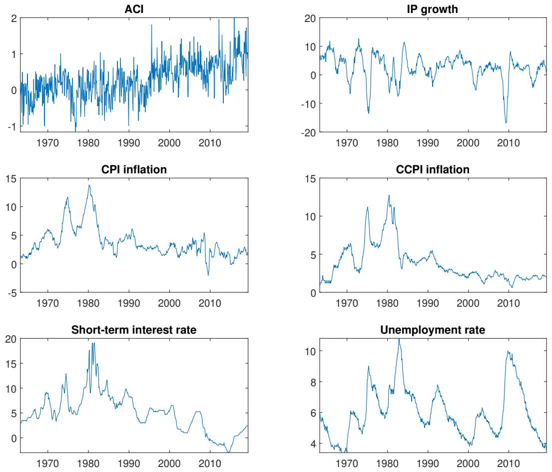


Figure 3: US data (after seasonal adjustment)

Identification and Econometric Model

Identification: Some preliminaries

- I'll talk about identification in a linear model first to economize on notation
- **Definition of forecast error:** $\mathbf{u}_t = \mathbf{y}_t - E_{t-1}\mathbf{y}_t$
- **Going from forecast error to structural shocks:** $\mathbf{u}_t = \Sigma \mathbf{e}_t$, $\mathbf{e}_t \sim N(0, I)$
- For what follows next, assume that *ACI* is ordered first in $\mathbf{y}_t$

Identification (in a linear model for simplicity)

Assumption (Identification)

We assume that all variation in the ACI coming from unexpected changes from one month to the next (i.e. coming from $\mathbf{u}_t$) is due to the ACI shock we want to identify.

$$\mathbf{u}_t^1 = \Sigma_{11}\mathbf{e}_t^1$$

This assumption implies that all elements in the first row of Σ except for the very first element Σ_{11} are equal to zero.

- Smooth Transition VAR with $\mathcal{L} = 12$ lags:

$$\mathbf{y}_t = \tilde{z}_{t-1}(\mathbf{m}_1 + \sum_{\ell=1}^{\mathcal{L}} \mathrm{A}_{\ell,1}\mathbf{y}_{t-\ell} + \Sigma_1\mathbf{e}_t) + (1 - \tilde{z}_{t-1})(\mathbf{m}_2 + \sum_{\ell=1}^{\mathcal{L}} \mathrm{A}_{\ell,2}\mathbf{y}_{t-\ell} + \Sigma_2\mathbf{e}_t) \qquad (1)$$

- $0 \leq \tilde{z}_{t-1} \leq 1$

Econometric model: How we allow for time variation

- Expectations and Forecast Error:

$$E_{t-1}\mathbf{y}_t = \tilde{z}_{t-1}(\mathbf{m}_1 + \sum_{\ell=1}^{\mathcal{L}} \mathrm{A}_{\ell,1}\mathbf{y}_{t-\ell}) + (1-\tilde{z}_{t-1})(\mathbf{m}_2 + \sum_{\ell=1}^{\mathcal{L}} \mathrm{A}_{\ell,2}\mathbf{y}_{t-\ell}) \tag{2}$$

$$\mathbf{u}_t = (\tilde{z}_{t-1}\Sigma_1 + (1-\tilde{z}_{t-1})\Sigma_2)\mathbf{e}_t \tag{3}$$

- Benchmark: time-transition

$$\tilde{z}_t := \frac{t+1}{T}, \quad \forall 0 \leq t \leq T-1$$

Why is time variation important?

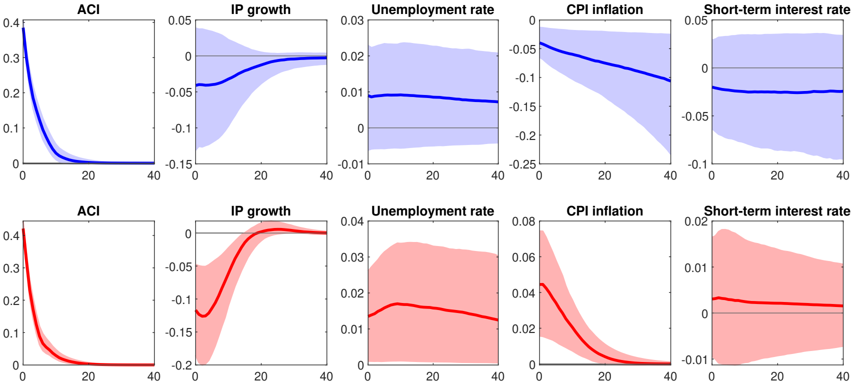
- Microeconometric studies have tried to tackle time variation by splitting their sample (Barreca, Clay, Deschene, Greenstone, and Shapiro 2016) $\longrightarrow$ nested in our approach
- Allowing for time variation is key to studying **adaptation**

Estimation

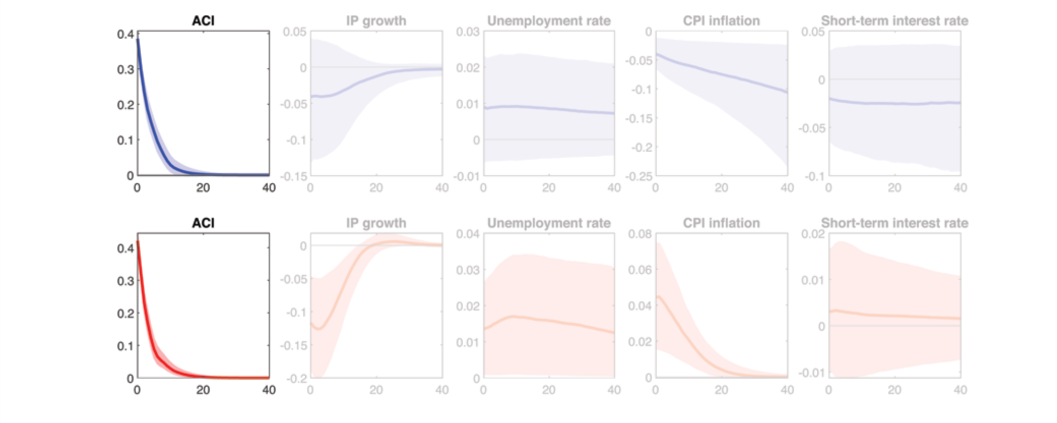
- Bayesian approach
- Approximate posterior via sequential Monte Carlo (SMC) - Herbst & Schorfheide, Bognanni & Herbst
- Standard Minnesota type-priors for $\mathbf{A}$.
- **Priors are the same for both sets of parameters (beginning and end of sample) $\rightarrow$ differences over time driven by likelihood**

Results

Impulse responses to ACI shock at beginning & end of sample



Impulse responses to ACI shock at beginning & end of sample



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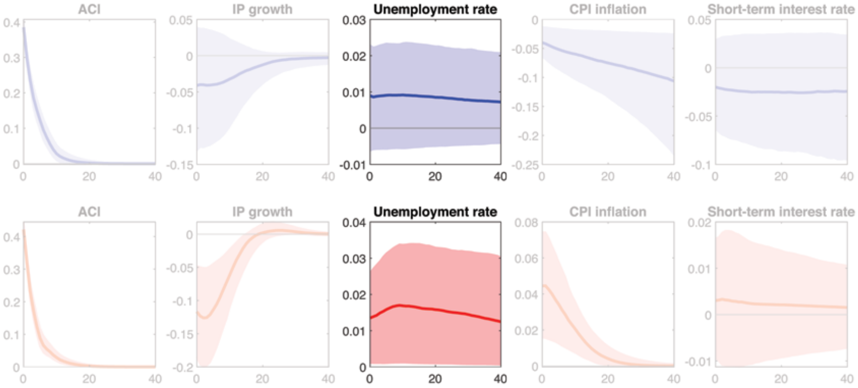
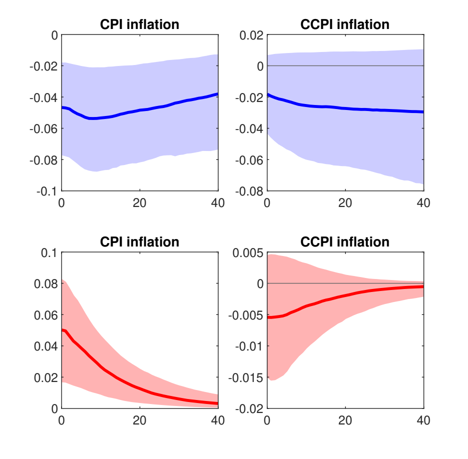


Impulse responses to ACI shock at beginning & end of sample

IMPULSE RESPONSES TO ACI SHOCK AT BEGINNING & END OF SAMPLE

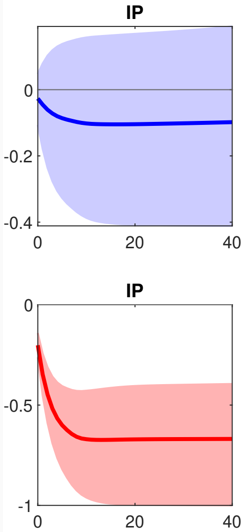
Digging deeper: Inflation

- Run same specification as before, but add core CPI inflation (y/y) as an additional variable
- Responses of other variables very similar to benchmark



Digging deeper: Level effect on log IP

- Run same specification as before, but replace y/y IP growth with m/m annualized IP growth - then cumulate those responses.
- Responses of other variables very similar to benchmark
- Reminiscent of Hsiang and Jina's finding of trend of effects of cyclones
- Substantial discussion of trend vs growth rate effects (Dell, Jones, and Olken)
- Useful for calibration of damage function in equilibrium / IA models



How important are weather shocks?

Beginning of Sample					
	ACI	IP growth	Unemployment rate	CPI inflation	interest rate
	h=12	h=12	h=12	h=12	h=12
16th	99.97%	0.03%	0.03%	0.21%	0.01%
50th	99.99%	0.30%	0.39%	1.52%	0.15%
84th	99.99%	1.16%	1.66%	3.96%	0.66%
End of sample					
	ACI	IP growth	Unemployment rate	CPI inflation	interest rate
	h=12	h=12	h=12	h=12	h=12
16th	100.00%	0.37%	0.10%	0.16%	0.11%
50th	100.00%	1.79%	0.97%	1.12%	1.15%
84th	100.00%	4.76%	3.31%	3.23%	4.92%

Table 1: Variance decomposition

How important are weather shocks?

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	h=12	h=12	h=12	h=12	h=12
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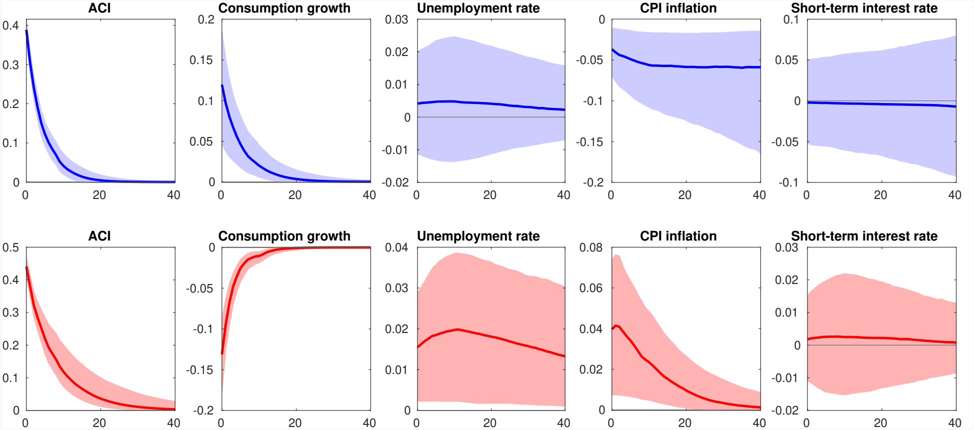
84th	100.00%	4.76%	3.31%	3.23%	4.92%

- Compare to Smets-Wouters: Monetary policy shock at posterior mode explains 10 percent or less of GDP growth and inflation at similar horizons.

Further Results

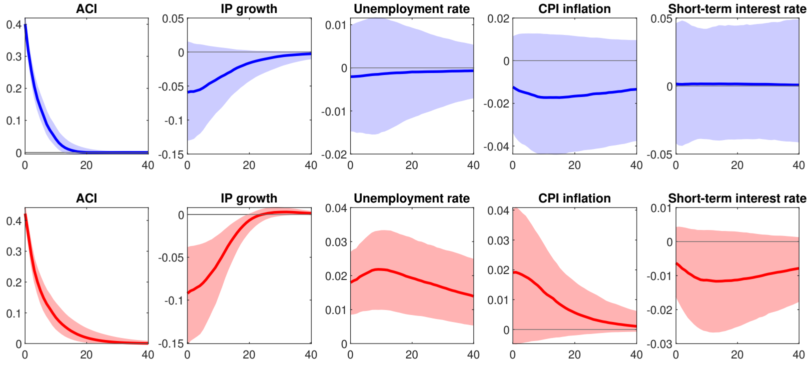
Consumption Growth



Further Results

- Robustness checks
  - Splitting the sample: $\tilde{z}_{t-1} = 0$ until 1990, $\tilde{z}_{t-1} = 1$ after Result
  - With non-seasonally adjusted data Result
  - t-distributed errors Result
  - Detrended ACI Result
  - Principal Component Analysis Result
  - Alternative transition variables: lagged MA of ACI & lagged MA of CO2 concentration Results

Splitting the sample: $\tilde{z}_{t-1} = 0$ until 1990, $\tilde{z}_{t-1} = 1$ after



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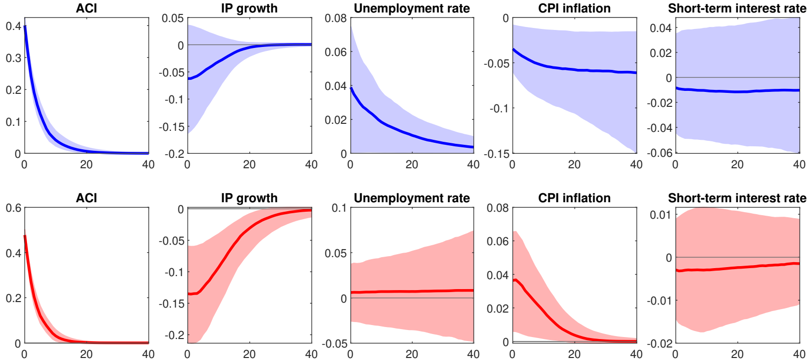
Non Seasonally Adjusted



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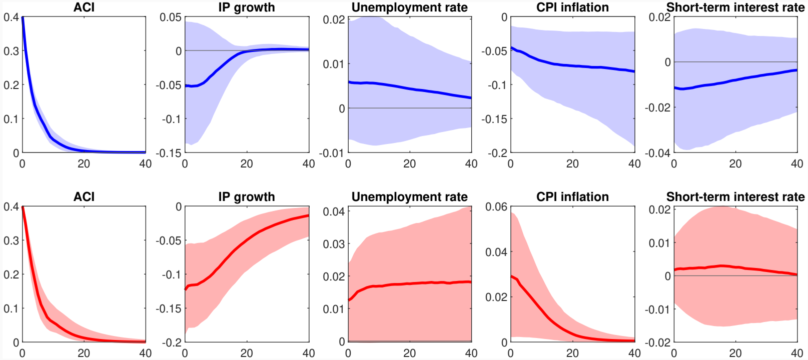
T-DISTRIBUTED ERRORS



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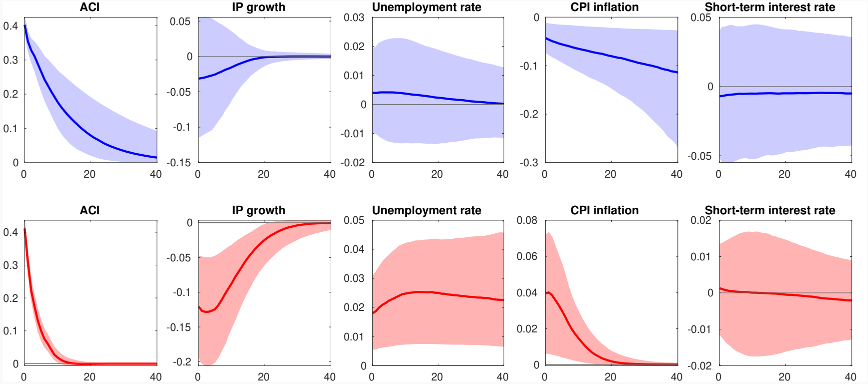
Detrended ACI



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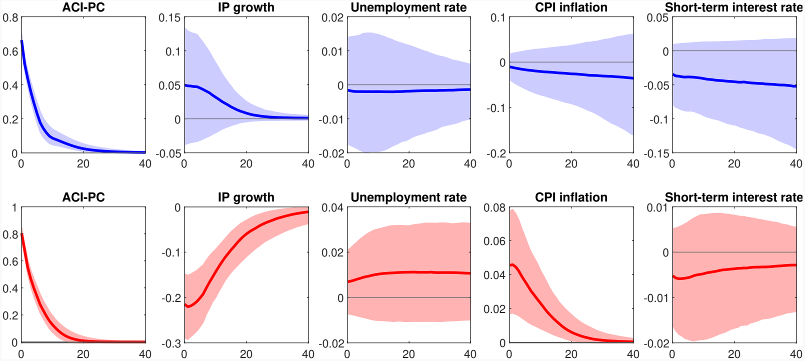
Principal Component Analysis w/ disaggregate components



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Individual ACI components

- **What drives our results?**
  - Adding one ACI component at a time to our STVAR
  - Precipitation has no effect on IP growth either at beginning or end of the sample, but does increase unemployment at end of the sample Result
  - The decrease in IP growth at end of the sample is driven by changes in both high and low temperatures Result
  - Sea level changes lead to changes in inflation consistent with those we see in our benchmark results Result

Precipitation Shock

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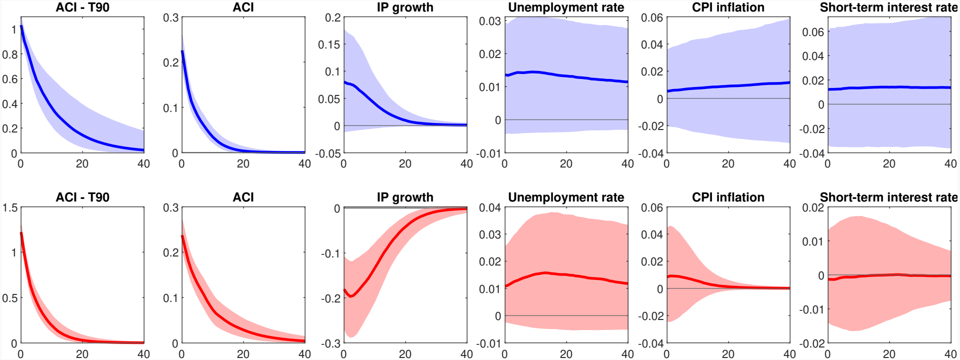
High Temperature Shock



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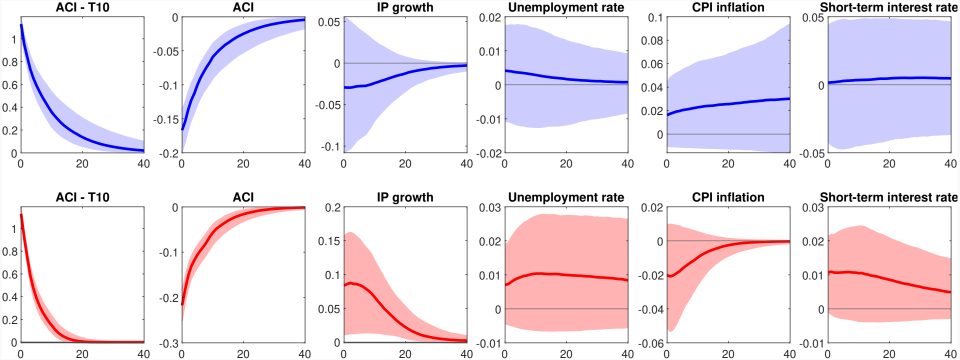
ACI - T10
ACI
IP growth
Unemployment rate
CPI inflation
Short-term interest rate
ACI - T10
ACI
IP growth
Unemployment rate
CPI inflation
Short-term interest rate

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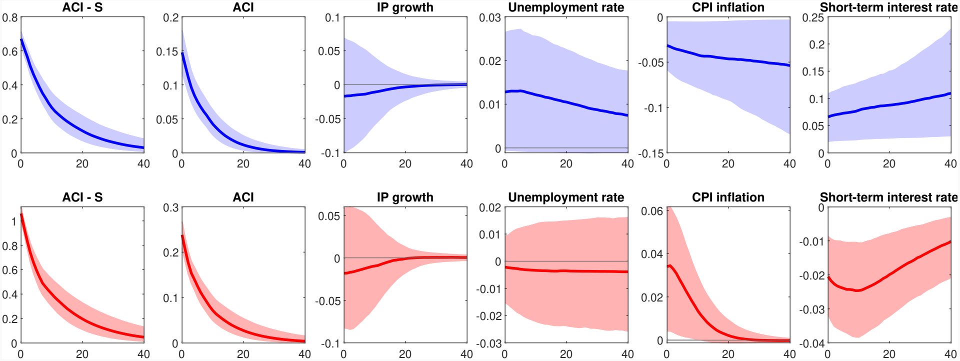
Sea Level Shock



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Conclusions

- Substantial changes in the effects of extreme weather events over the last decades
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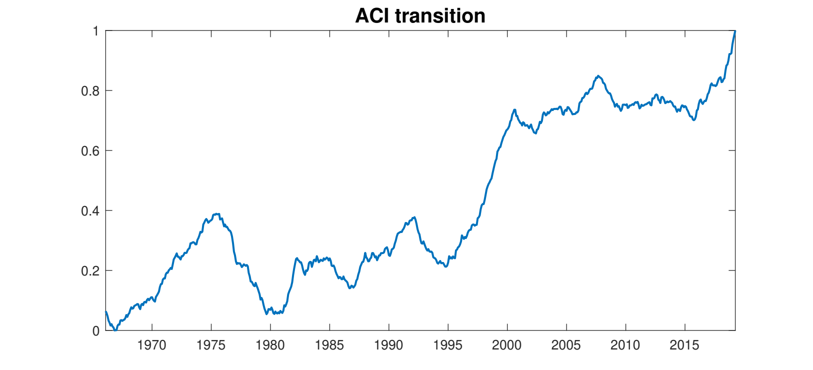
- Working hypothesis: lack of adaptation
- The road ahead: effects on different sectors, different regions

Alternative transition: Lagged MA of ACI



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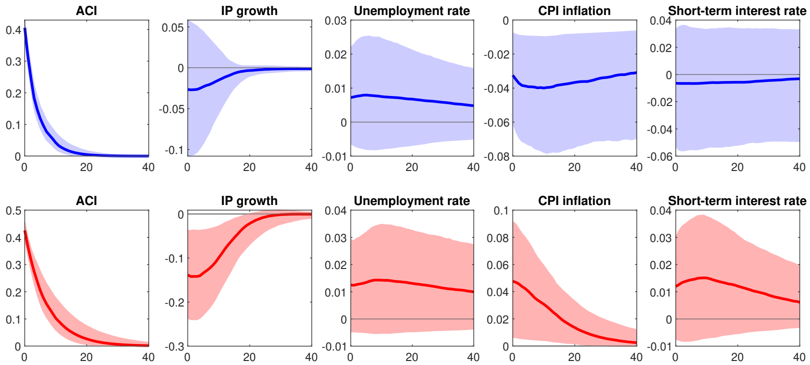
Responses to ACI shock: Lagged MA of ACI as transition variable



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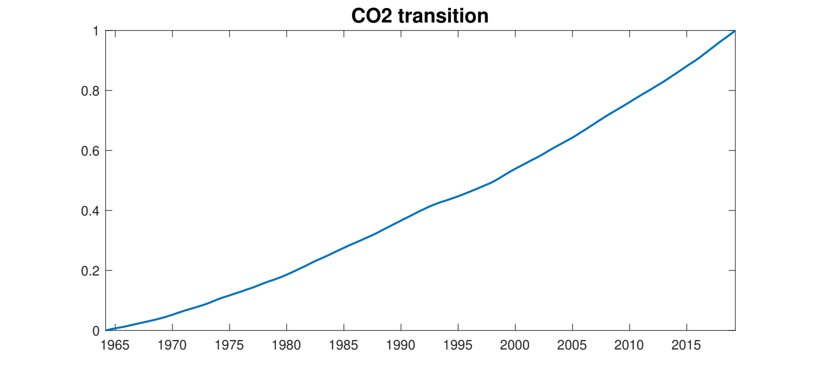
Alternative transition: Lagged MA of CO2 Concentration



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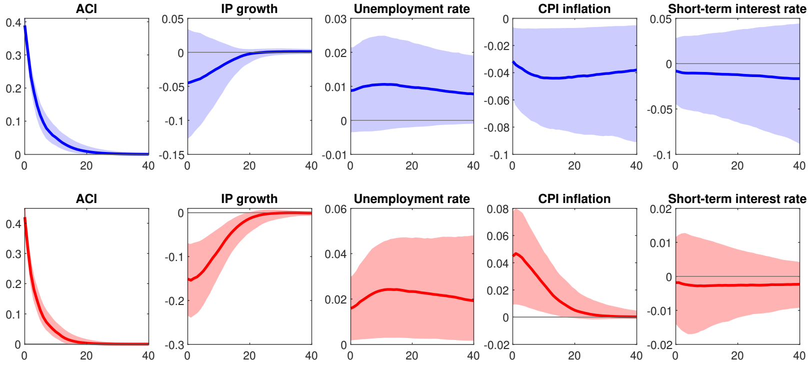

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