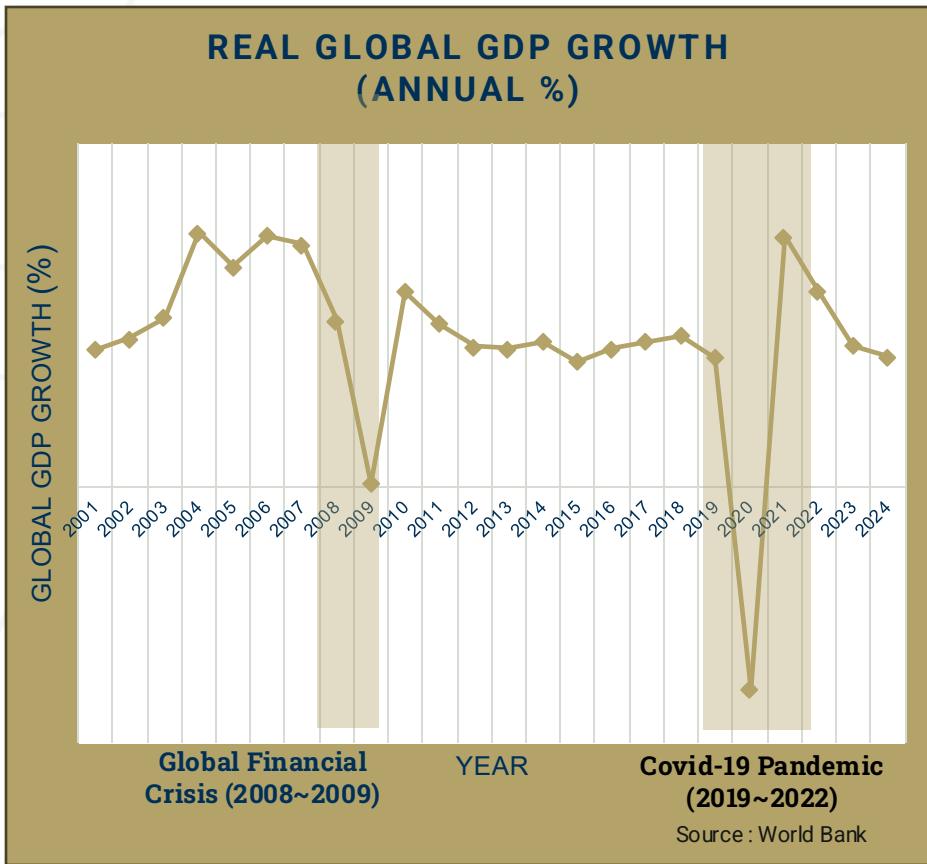


Estimating the Macroeconomic Impact of Industrial Shocks: a Supply Chain Risk Analysis

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Why This Matters - Recent Supply Chain Crises



Annual Global GDP growth percentage

- Global crises (Pandemic, Subprime Crisis) had major impact on supply chains.

Major incidents

- **GM & Chrysler** (2009): Demand collapse + inventory misalignment → Bankrupt
- **Toyota & Ford** (2019~2022): Semiconductor chip shortages → Millions of vehicles not produced
- **Peloton** (2021~2022): Overestimated demand during Covid → Overproduction → inventory surge due to pandemic delivery delay → stock collapse (-90%)
- **Nike** (2022): Freight normalization + demand slowdown → \$9B inventory glut (+44%)

Highlights how difficult it is for firms to anticipate how unexpected global crises propagate through freight, demand, inventory and production.

- *How fast will demand fall? Freight bottleneck ? Inventories spike ? Employment adjust?*

Why This Matters

- We need a **risk analysis tool** that quantifies how shocks propagate through the supply chain and supports planners in decision making.
- Traditional forecasts cannot predict sudden breaks in the economy (pandemic, bubble bursts, global strikes); we need **conditional forecasting**.

Core idea: Time series do not move alone; they are influenced by one another. By **imposing the path** on well-chosen variables, we can get better forecasts on the entire dataset!

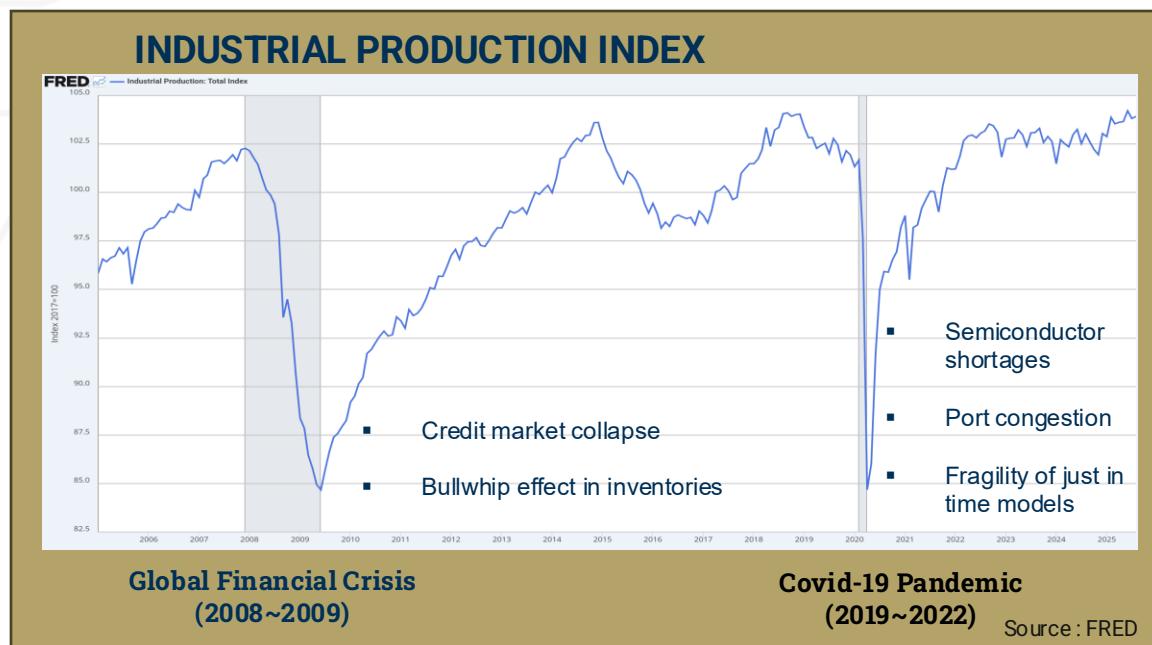
Solution: Vector Auto-Regression (past & present values influence each other)

$$\begin{pmatrix} x_t \\ y_t \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} \begin{pmatrix} x_{t-1} \\ y_{t-1} \end{pmatrix} + error_t \quad \text{VAR(1) with two variables}$$
$$\mathbf{z}_t = A_1 \mathbf{z}_{t-1} + \dots + A_p \mathbf{z}_{t-p} + error_t \quad \text{Generalized VAR(p)}$$

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Case Study – Modelling a Pandemic

- COVID-19: largest & fastest macro disruption in modern times.
- Lockdown: Created a dip in U.S. Industrial Production. This shock propagated through all the economy; influencing employment, inventories, sales, prices...



Industrial Production Index (IP)

- Output of the U.S. manufacturing, mining and utilities (electric and gas) sectors.
- Measures how much physical output the U.S. goods producing sector is generating.

→ Widely used as a proxy for supply side activity in the industrial economy.

IP is a great indicator to model the dip in Supply Production shocks caused by a lockdown

By conditioning on this variable, we should be able to model the effects of a global pandemic.

The Solution : Factor Augmented Vector Auto Regression

Core Idea:

- Compress hundreds of correlated macro variables into a few **latent factors** (F_t).
- These factors capture the common movements in the economy.
- Greatly reduces the dimensionality while retaining essential dynamics.

Mathematical Formulation:

- FAVAR(1) – 1 lag:

$$\mathbf{z}_t = \begin{pmatrix} F_{1,t} \\ F_{2,t} \\ F_{3,t} \\ IP_t \end{pmatrix} = A_1 \begin{pmatrix} F_{1,t-1} \\ F_{2,t-1} \\ F_{3,t-1} \\ IP_{t-1} \end{pmatrix} + error_t$$

- F_t : latent factors extracted through **Principal Component Analysis**.
- IP_t : Industrial Production at t (the variable we set the conditional path on)

100+ macroeconomic variables \Rightarrow 3 latent factors + Industrial Production Index

Stable estimation, interpretable structure, efficient forecasting !

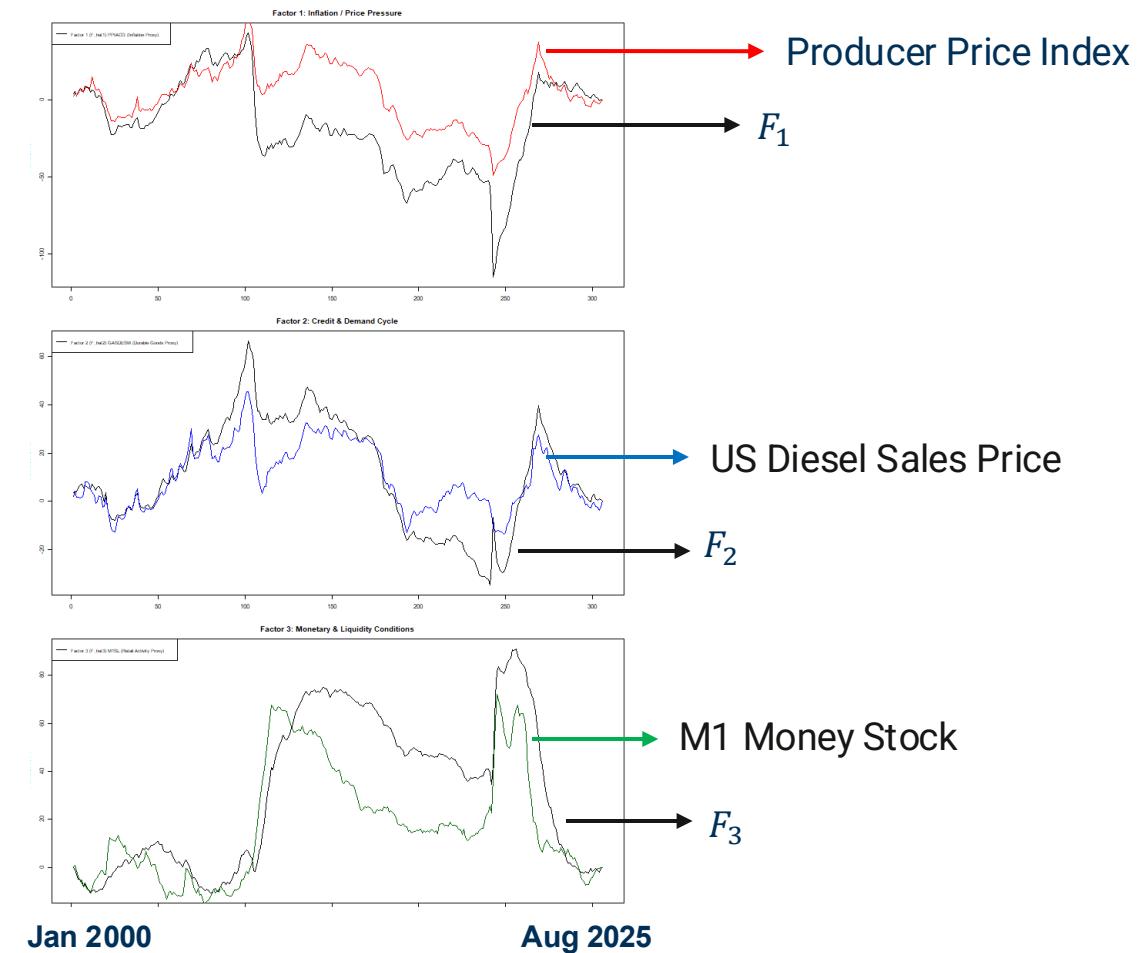
Follow up question: what do these factors mean?

Economic Interpretation of the Three Latent Factors (F_t)

How does these factors compare to a few variables over time ?

Factors over time along close correlated time series

Factor	
F_1	<i>Inflation & Cost Pressure</i> ✓ Tracks prices, energy costs, and production margins.
F_2	<i>Credit & Demand Cycle</i> ✓ Captures lending activity and cyclical demand.
F_3	<i>Monetary Policy & Liquidity</i> ✓ Reflects Fed policy stance and interest rates.



These three factors explain + 65% of the variance of the entire dataset !

Conditional FAVAR Framework

FAVAR is a great candidate to extend on with a conditional forecast model !

- ✓ Variable of interest = IP_t
- ✓ VAR framework = high interpretability
- ✓ Factor Analysis = covers a large panel of info.

Model:

- We will be using a state/space formulation + Kalman filtering to impose a conditional path on IP_t .
- Assuming FAVAR(2): $z_t = A_1 z_{t-1} + A_2 z_{t-2} + \text{error}_t$
- State/Space reformulation:

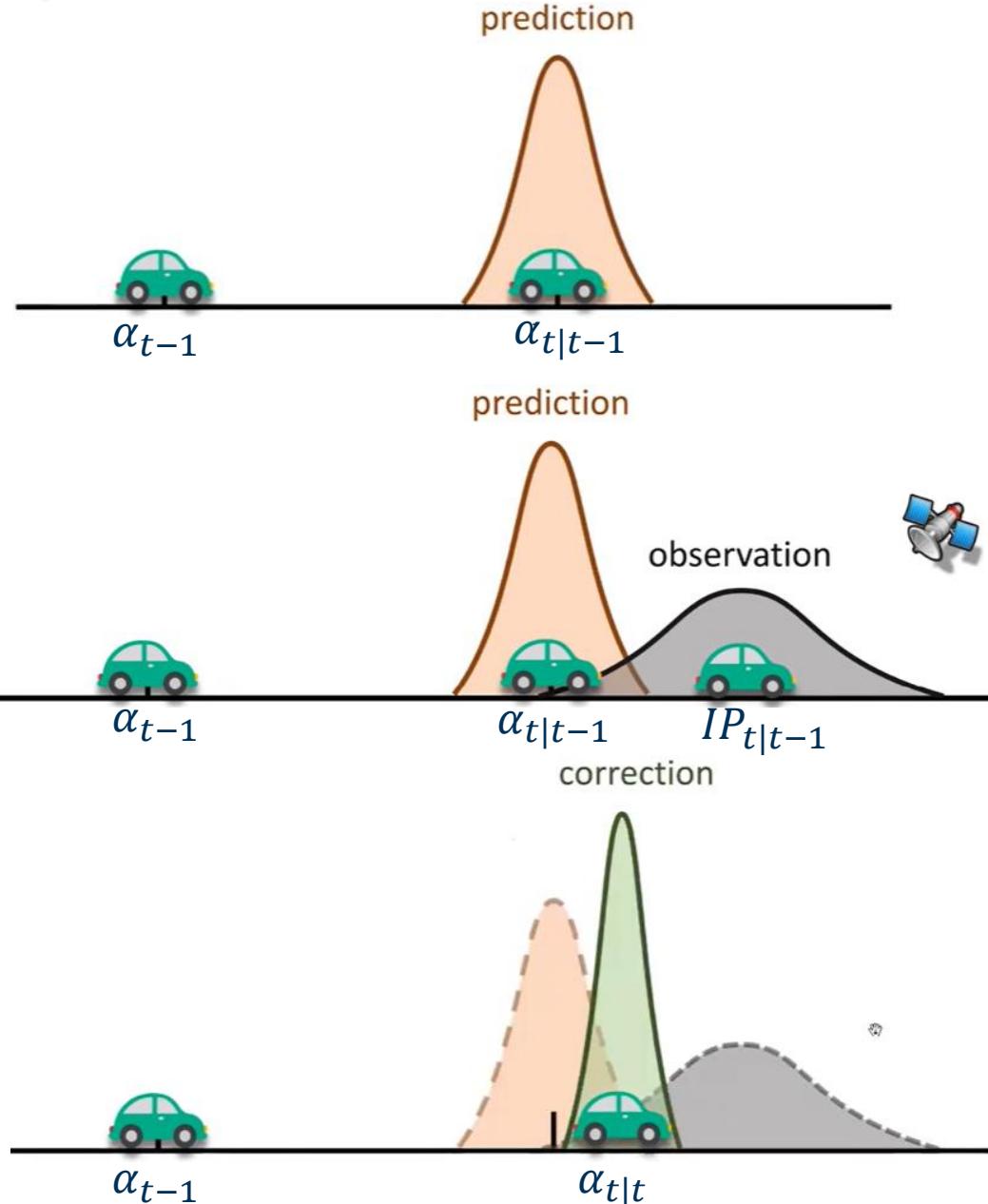
$$\begin{pmatrix} z_t \\ z_{t-1} \end{pmatrix} = \begin{pmatrix} A_1 & A_2 \\ I & O \end{pmatrix} \begin{pmatrix} z_{t-1} \\ z_{t-2} \end{pmatrix} + \begin{pmatrix} \text{error}_t \\ 0 \end{pmatrix}$$

$\alpha_t = T \quad \alpha_{t-1} + \eta_t$

It is a Markov Process !
⇒ we can apply a Kalman Filter

α_t : state vector

Kalman Filter – Analogy



Kalman Filtering for Conditional Forecasting
is a 4-step iterative process.

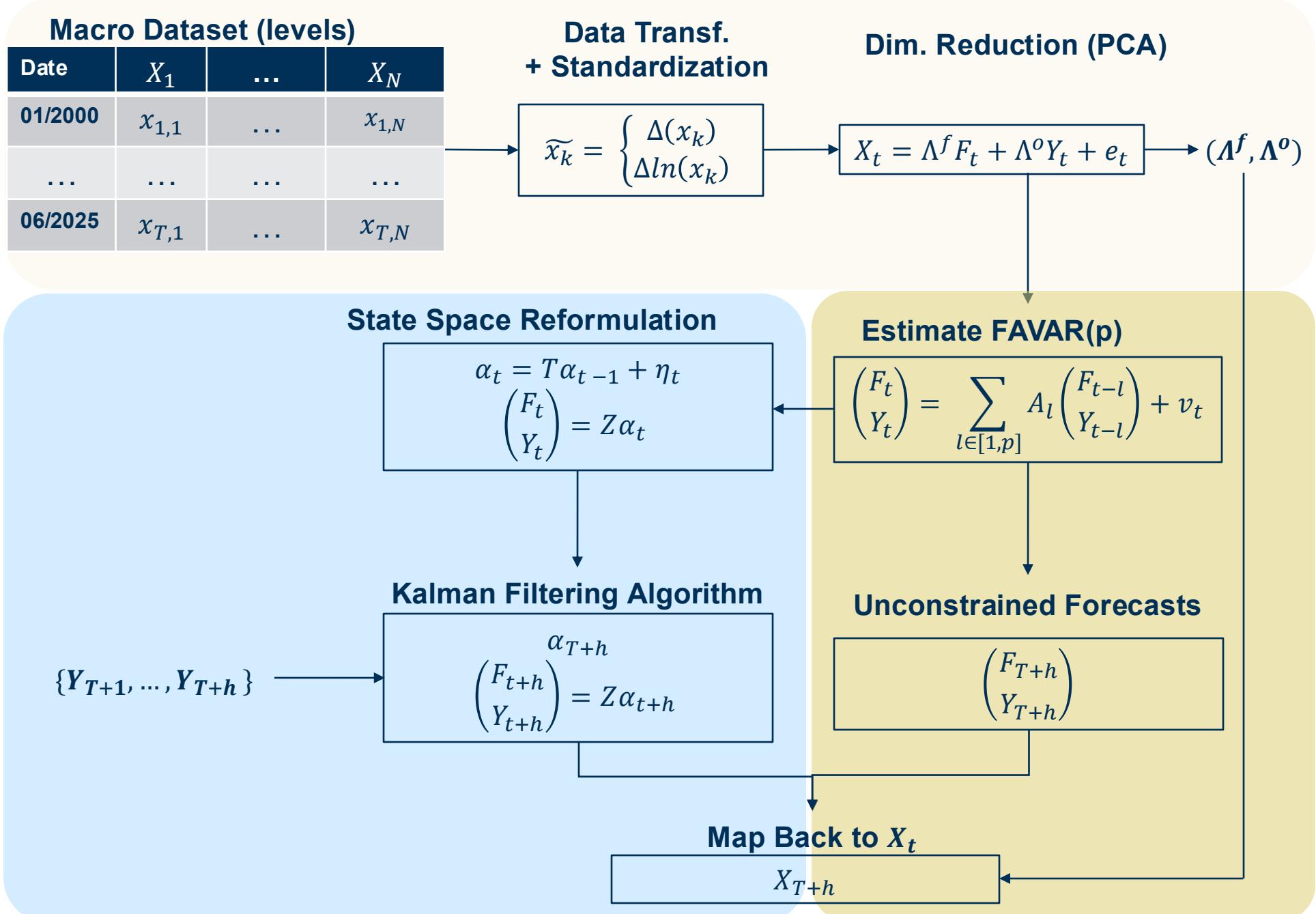
Step 1: Unconstrained pred. using Markov Eq.

Step 2: Consider the future value ("observable").

Step 3: Estimate the corrected state (cond. Forecast)

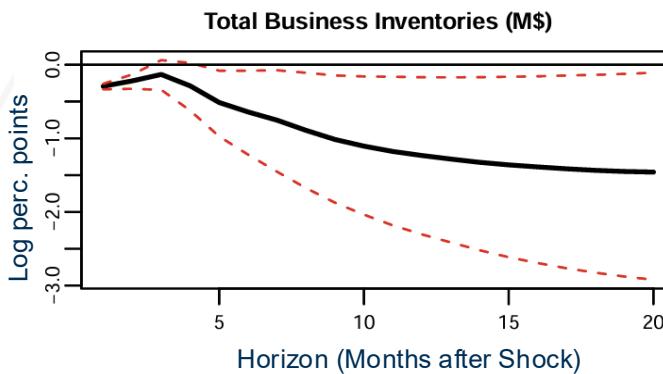
Roadmap

1. DATA PREPROCESSING
2. FAVAR
3. CFAVAR

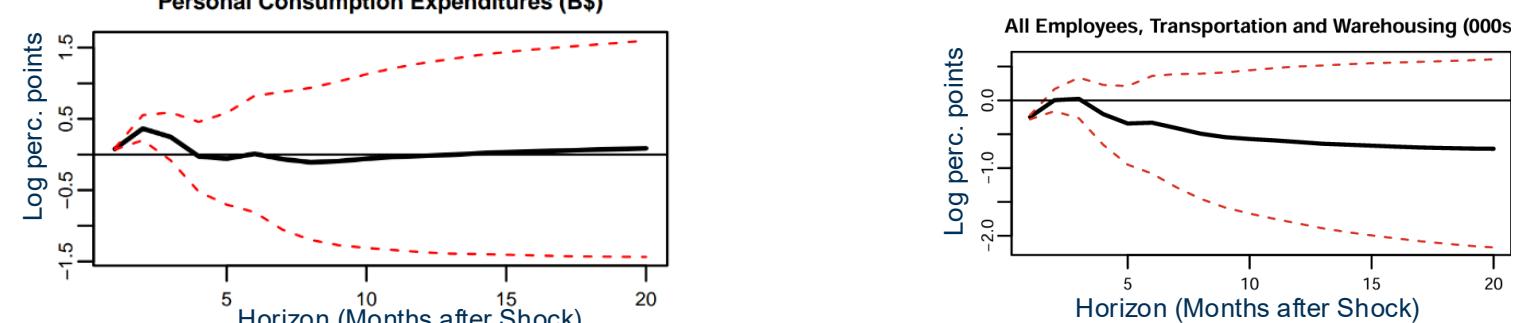
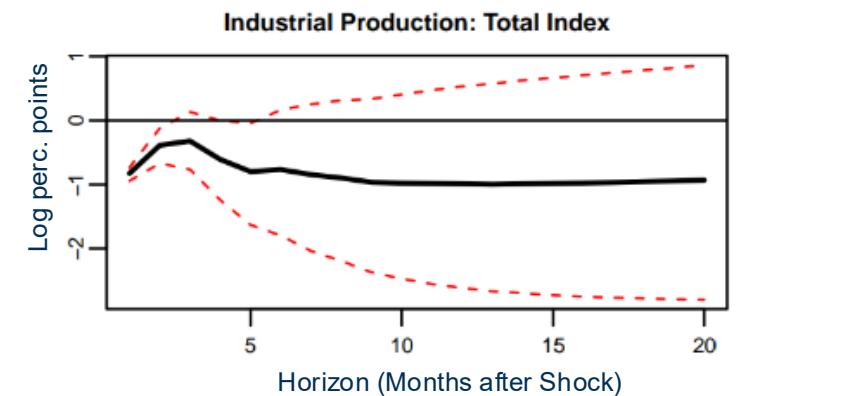
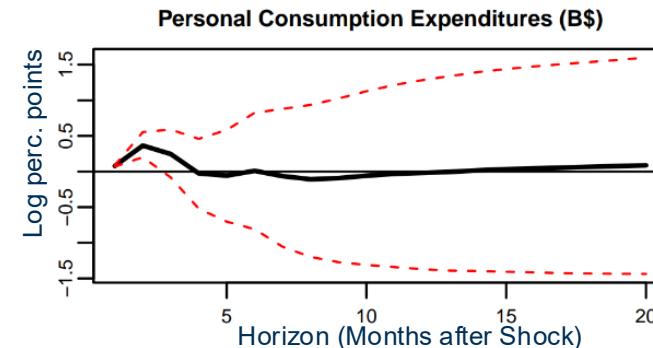


Sensitivity Analysis of the Model – Impulse Response (IRF)

- Sensitivity testing based on fluctuations of Industrial Production.
- Using the inverse PCA transformation \Rightarrow map back the effect to all the variables.
- IRFs are not forecasts \Rightarrow indicate how variables react on one another over time.
- Verifies the consistency of the FAVAR model.



— Median response
- - - 95% CI



- Decrease in production ($t = 0$) impacts inventories negatively over time.
- Happens when production does not follow demand.

- Constant median PCE.
- Industrial Production alone does not impact individual spending.
- Retail demand stays the same.

- Decrease of employees in Supply Chain sectors.
- Slow Supply Chain activity \Rightarrow less need for workforce.

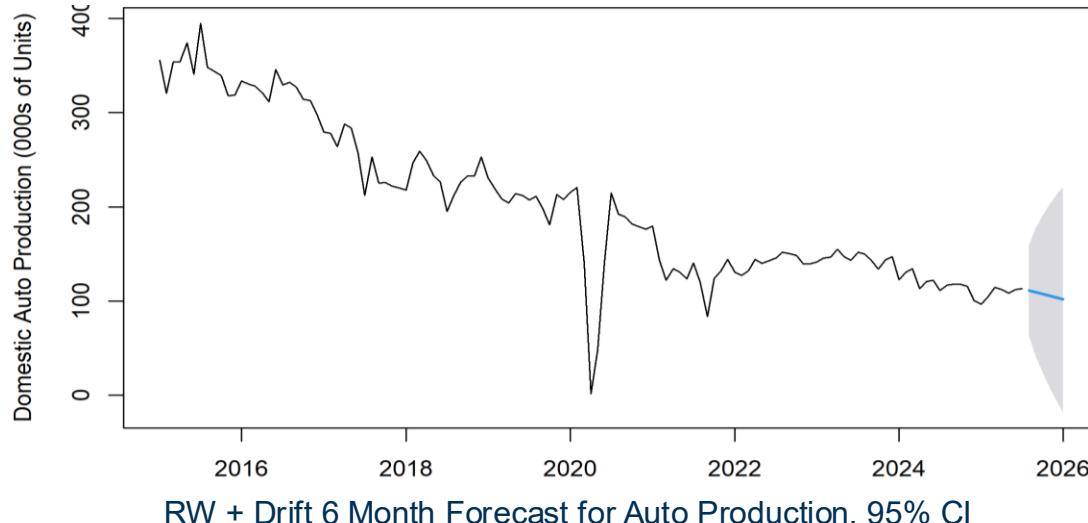
Validation and Performance

Motivation :

- Is the model **efficient** in a real-world scenario?
Is it a **reliable** risk analytic tool?
- We will compare it to a **baseline** model: **Random Walk + Drift**.

$$\hat{X}_{(t+h|t)}^{RW} = X_t + h * \bar{\Delta}X$$

- In Macroeconomics, this model is **difficult to beat** on the long run !



Validation :

- Computing the **Mean Square Errors** (MSE) of both models (FAVAR and CFAVAR) to the RW.
- Evaluating MSE Ratios FAVAR/RW & CFAVAR/RW at different horizons.

Setup :

- 100 **rolling windows** from 2000~2025 (train = 200 obs, test = 100).

$$MSE_{j,h}^{(m)} = \frac{1}{100} \sum_{w=1}^{100} (X_{t_w+h} - \hat{X}_{t_w+h|t_w,j})^2$$

Model m
Variable j
Horizon h

True value

Predicted value

Backtesting Results

- Run FAVAR and CFAVAR and RW models \Rightarrow compute MSE at different horizons \Rightarrow Estimate the Ratios
- Set the conditional path to be the Industrial Production Index

MSE Ratios for some selected variables

Model	FAVAR			CFAVAR		
	$\frac{MSE^{FAVAR}}{MSE^{RW}}$			$\frac{MSE^{CFAVAR}}{MSE^{RW}}$		
Ratio	1 month	2 months	4 months	1 month	2 months	4 months
Horizon						
M2 Money Stock	0.85	1.42	3.43	0.81	0.94	0.92
Federal Funds Rates	1.29	1.59	2.16	0.78	0.80	0.79
CPI for All Urban Consumers	0.68	0.88	1.03	0.72	0.76	0.54
Industrial Production: Total Index	1.63	2.87	5.62	0.00	0.00	0.00
Total Vehicle Sales	1.56	1.49	1.50	0.88	0.74	0.58
...
Employees Truck Transportation	2.32	4.38	9.22	0.91	0.81	0.53
Business Inventories	0.63	0.87	1.59	0.54	0.54	0.61
Employees Trans.& Warehousing	1.88	3.47	6.30	0.91	0.83	0.55
Population	1.19	1.23	1.27	1.24	1.29	1.35

Unrestricted forecasting
Conditional forecasting

- If Ratio < 1 : (Cond.)FAVAR better than RW
- Expected, we constrained this value
- Sometimes, even CFAVAR performance is worse than RW+ drift

Validation Results

- Efficiency ratio ER : Proportion of variables for which the Model **outperforms** a Random Walk benchmark
(MSE Ratio < 1)

$$ER \frac{FAVAR}{RW}$$

Forecast Horizon	Efficiency
1 month	39%
2 months	29%
4 months	14%

$$ER \frac{CFAVAR}{RW}$$

Forecast Horizon	Efficiency
1 month	56%
2 months	57%
4 months	63%

Key Takeaways:

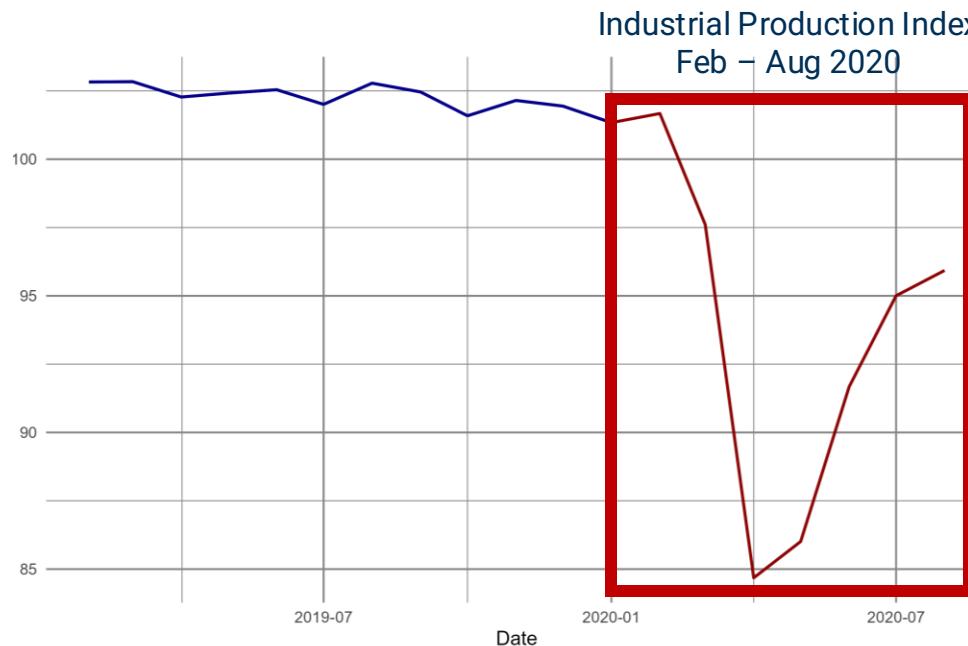
- Forecasting without conditionality is not performing well against benchmark.
 - VAR relies on **recent dynamics**, RW uses the entire **historical average change**.
 - Forecasting performance **improves drastically vs. RW** when imposing
- ⇒ Cond. forecasts : **reduce uncertainty** at the cost of **relying on assumptions**.

FAVAR's forecasting adv. deteriorates as horizon increases; it is the opposite for CFAVAR !

Case Study – Validating CFAVAR through Historical Crisis

Methodology:

- Impose the actual COVID-19 drop in Industrial Production in Feb-Aug 2020 (-10% drop in Feb 2020)
- Forecast horizon : 6 months
- Forecasted variables : Truck Traffic volume, Inventories, Employees for Transportation & Warehousing...



(1) CFAVAR (Conditional)

- Conditions on the imposed Industrial Production shock

$$\begin{pmatrix} F_t \\ IP_t \end{pmatrix} = A_1 \begin{pmatrix} F_{t-1} \\ IP_{t-1} \end{pmatrix} + \nu_t + \text{Kalman Filtering}$$

(2) Random Walk

- Baseline, unconditioned historical drift model

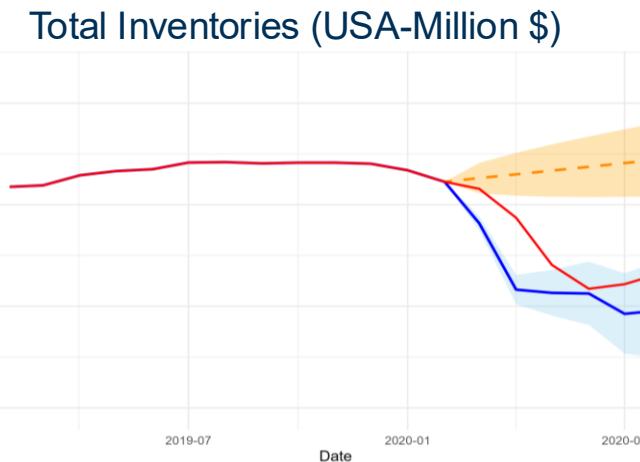
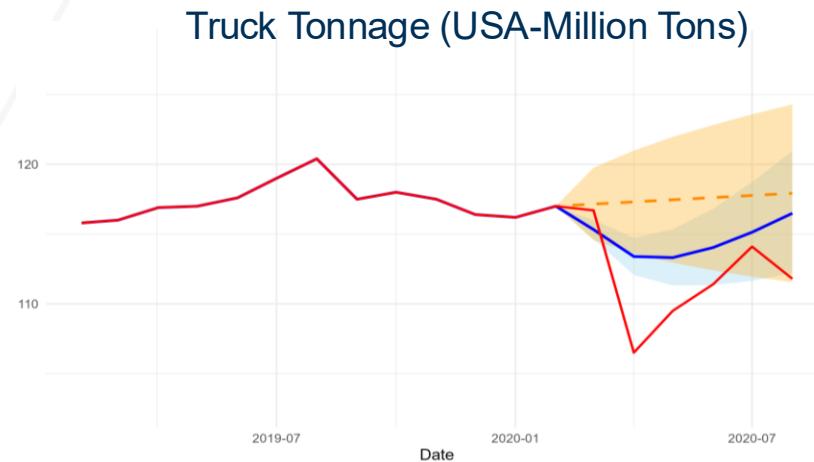
(3) Realized Path

- Actual observed values during the crisis

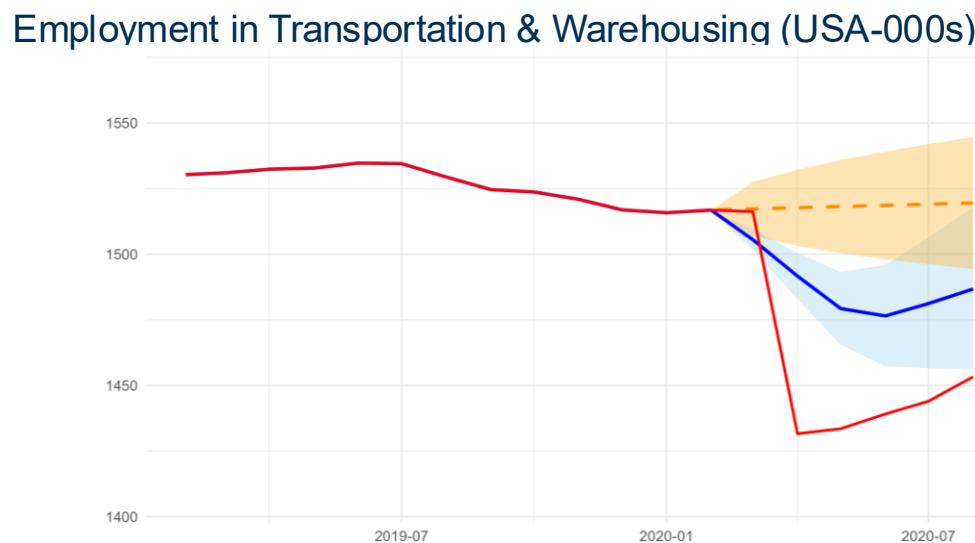
What if Industrial Production shocks, How do other macroeconomic variables respond?

Case Study – Supply Chain Activity After COVID-19

Compared across how Freight, Inventories, and Employment metrics responded after COVID-19 crisis



- Realized path
- Median Conditional Forecast
- - - Median RW unconstrained forecast
- 95% CI Cond. Forecast
- 95% CI RW



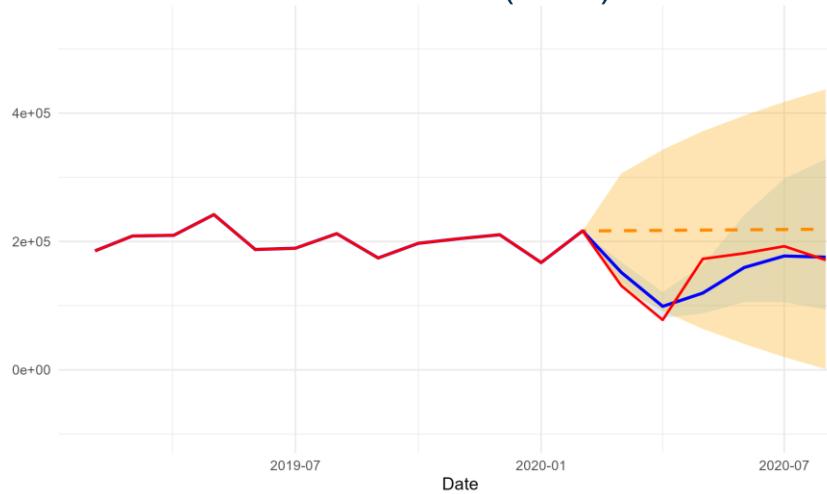
Result: CFAVAR provides **tighter** and **more realistic** forecast ranges
➤ Great baseline, helping planners to production scheduling, labor & inventory planning

Case Study – Industrial Application (Ford)

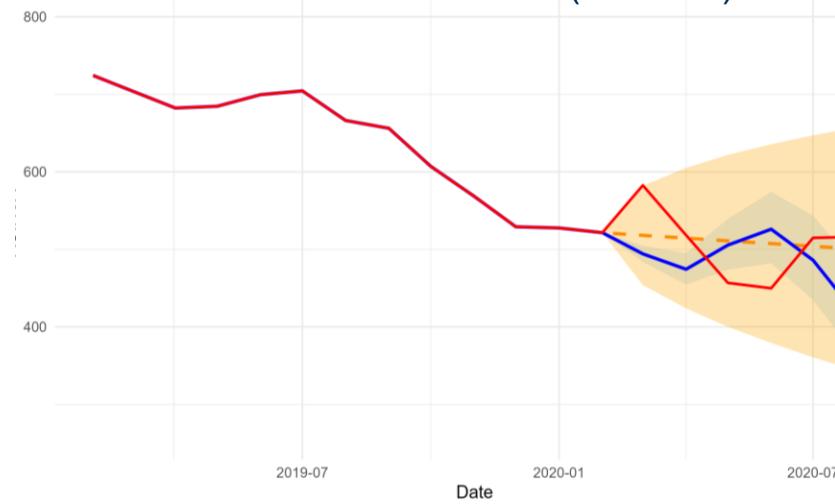
How firms can use CFAVAR to anticipate market responses after severe supply chain shocks

- How would Ford's Vehicle Sales & Inventories have responded to COVID-19?

Ford's vehicle sales (Units)



Domestic Auto Inventories (1K Units)



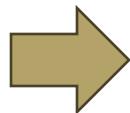
- Realized path
- Median Conditional Forecast
- Median RW unconstrained forecast
- 95% CI Cond. Forecast
- 95% CI RW

- ✓ CFAVAR allows us to impose a macro shock (e.g., Industrial Production drop) and trace how it propagates into Ford's internal situation (sales, shipments, orders, inventory..etc)

Conclusion

Why CFAVAR Is a Better Tool for Supply Chain Risk Analysis

- Traditional forecasting assumes the future will behave like the past → fails when structural breaks occur (pandemics, tariffs, financial crises, labor strikes).
- Conditional forecasting lets us impose a scenario or shock path and observe how the rest of the system responds in a coherent way



CFAVAR is a better **risk-management tool**, it does not predict unexpected events but helps quantify “if this happens, then what?”

Conclusion

Flexibility and Limitations of CFAVAR

- Flexible and Not limited to Industrial Production
 - Industrial Production was one example shock, but CFAVAR can work with any macro driver (tariff , federal funds rate, oil shock..)
- Limitations
 - The results are **conditional** on the scenario you impose
 - If the imposed path is unrealistic or incorrect, the resulting forecast will also diverge
 - CFAVAR does not tell when unexpected shock will occur, only happens after you impose

Thank you