# Supply Chain Uncertainty, Energy Prices, and Inflation

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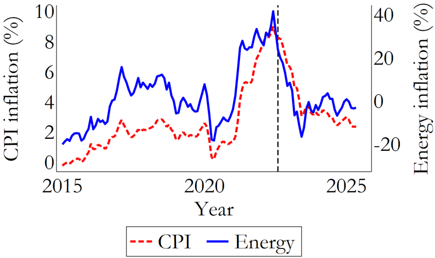
Federal Reserve Bank of Boston

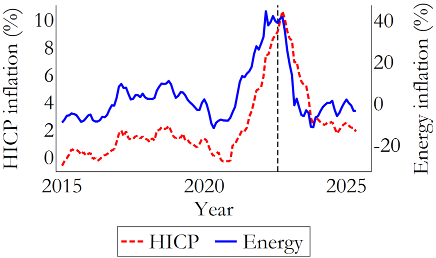
*The U.S. Economy in a Changing Global Landscape*

November 2025

# Energy and CPI Inflation in the US and the Euro area



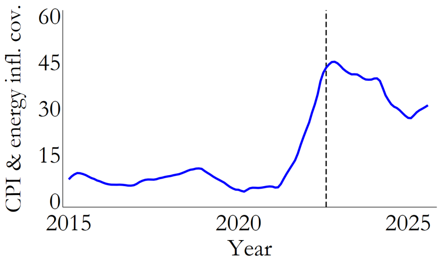

U.S.




Euro area

**In 2021 energy and CPI inflation accelerate in tandem**

# Rising Covariance btw. Energy and CPI Inflation

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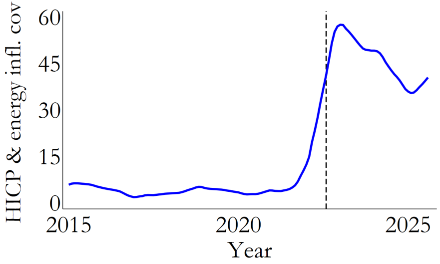
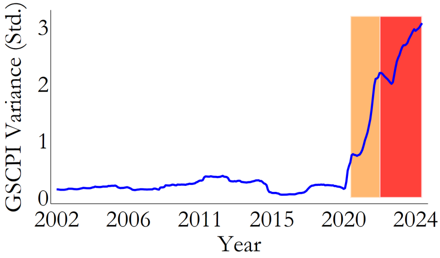


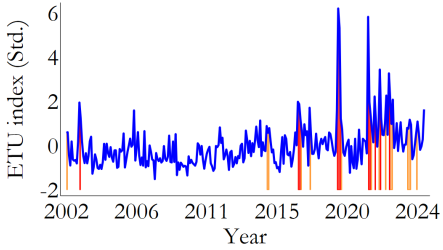

Euro area

**After 2021 energy and CPI inflation co-move much more strongly**

# Heightened Uncertainty in Global Supply Chains




(a) Rolling variance of GSCPI




(b) ETU index

Top 10% Top 20%

**Heightened uncertainty in global supply chains after 2020**

Earnings calls

# Pass-through of energy price shocks to inflation

# Local Projections: Oil News Shocks

- Low and high **supply chain uncertainty** regimes.

$$D_t = \mathbf{1}\{\mathrm{Var}(GSCPI)_t > p_{80}\}\,.$$

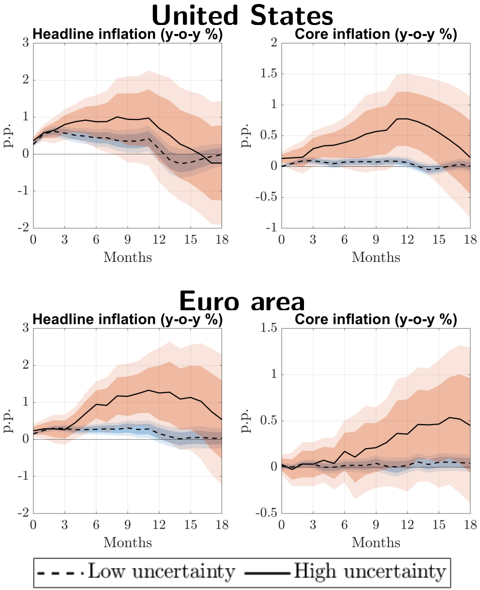
where $D_t = 1$ when supply chain uncertainty is in the top 20% of its distribution (**Jan. 2002–Dec. 2024**).

- Estimate **state-dependent local projections**:

$$\pi_{t+h} = \alpha_h + \beta_h \varepsilon_t^{\text{oil}} + \beta_h^H \underbrace{\left(D_t \cdot \varepsilon_t^{\text{oil}}\right)}_{\text{interaction}} + \sum_{j=1}^{J} \gamma_{j,h} \pi_{t-j} + \nu_{t+h}$$

- Dummy $D_t$ interacted with high-frequency **oil supply news** surprises $\varepsilon_t^{\text{oil}}$ (Känzig, 2021).

# Local Projections: Oil News Shocks and Inflation




**Pass-through** on inflation of oil news shocks significantly **larger** conditional on high **supply-chain uncertainty**

Robustness

**Main idea:**

**supply-chain uncertainty amplifies pass-through of energy price shocks to inflation**

# Core Mechanism

- Background: purely **i.i.d. energy** price shocks + **transportation** shocks.
- Firms use **two inputs** shipped on **same** routes:
  1. **energy** (E)
  2. **specialized input** (M) (e.g., microchips).

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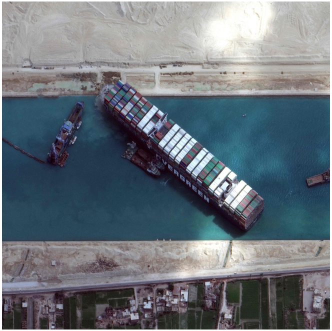

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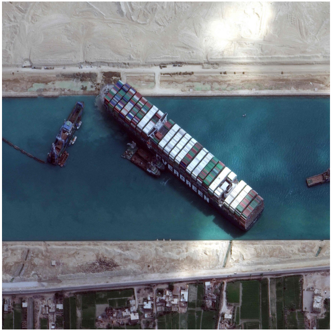


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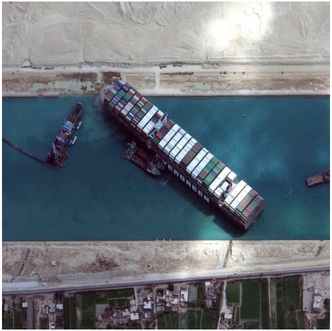

- **"Choke point"** → Transportation **capacity constraint** becomes **binding**.

→ Asymmetry: **energy** remains available via **liquid** local markets at **premium** price $p_E$; **microchips** face stochastic delivery **delay**.

# Core Mechanism (con't)

- $p_E$ **information sensitive** $\rightarrow$ Reacts quickly to congestion $\Rightarrow$ Noisy **signal** of **true** transportation shock

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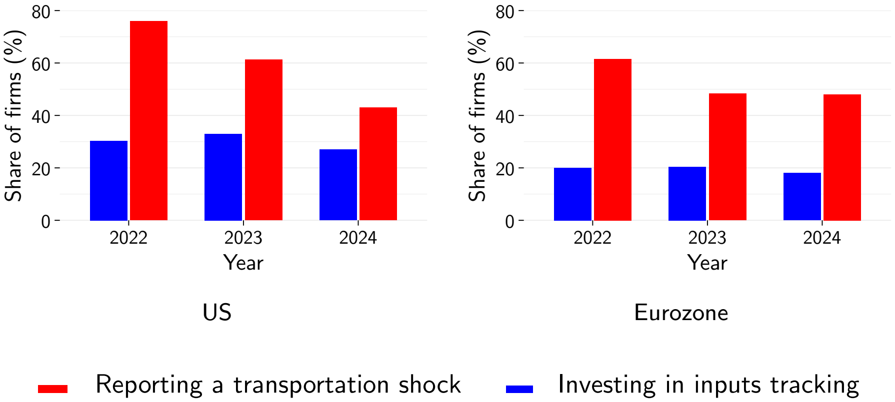
- Bayesian signal extraction problem: when agents observe a **higher energy** price they partially **misinterpret** it as signal of persistent **transportation delay**
- This raises **perceived** marginal cost **beyond** direct **pass-through** from $p_E$.

  1. $\Rightarrow$ **Static** price pass-through **amplified** by supply-chain **uncertainty** (*precautionary* pricing)
  2. $\Rightarrow$ **Dynamic** price pass-through **non-linearly** related to supply-chain uncertainty

# Supply chain disruption shocks are persistent

- EIB (2024) **survey**: share of firms investing in digital inventories and inputs tracking and reporting **obstacles to logistics** and **transport**.



# Information value of energy prices: Kalman filter estimation

# Information role of energy prices: Kalman filter estimation

**State (latent transportation delay):**

$$\psi_t = \rho_\psi \psi_{t-1} + \varepsilon_{\psi,t}, \qquad \varepsilon_{\psi,t} \sim \mathcal{N}(0, \sigma_\psi^2)$$

**Signals (observation equation):**

$$\underbrace{\begin{bmatrix} \pi_t^E \\ \text{BDI}_t \end{bmatrix}}_{\text{noisy signals}} = \underbrace{\begin{bmatrix} \alpha_E \\ \alpha_{\text{BDI}} \end{bmatrix}}_{\text{loadings}} \psi_t + \varepsilon_t, \qquad \varepsilon_t \sim \mathcal{N}\left(0, \begin{bmatrix} \sigma_E^2 & 0 \\ 0 & \sigma_{\text{BDI}}^2 \end{bmatrix}\right)$$

- $BDI_t \equiv$ *Baltic Dry Index* (direct).
- $\alpha_{BDI} \equiv$ loading on **BDI**.
- $\alpha_E \equiv$ loading on **energy inflation** $\Rightarrow$ How much **energy** is estimated to signal the transportation shock ("delay") $\psi_t$ on top of **freight BDI index**.

# Baltic Dry Index and Energy price

- **BDI (Baltic Dry Index)**: global benchmark for cost to ship **raw materials** by sea.

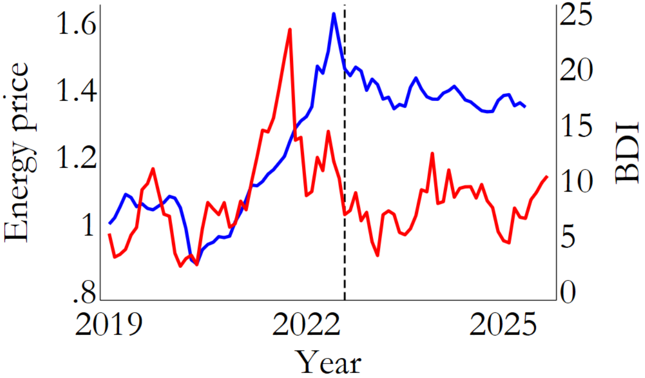



Figure: Measures standardized to be 1 in January 2019

BDI    US energy price

# State dependency: high vs low supply chain uncertainty

- Divide the sample in **two regimes**: **high** vs **low** supply chain uncertainty based on $D_t$

$$D_t = \mathbf{1}\{\mathrm{Var}(GSCPI)_t > p_{80}\},$$

  where $D_t = 1$ when supply chain uncertainty is in the top 20% of its distribution (Jan. 2002–Dec. 2024).

- **Estimate model parameters via MLE**.

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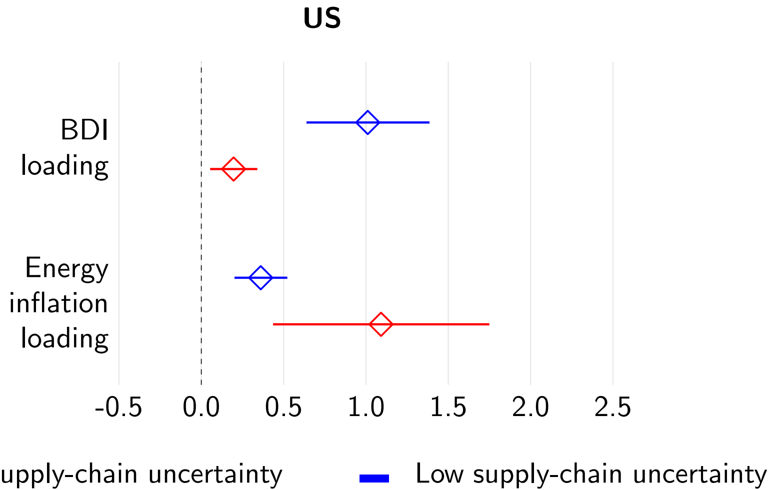
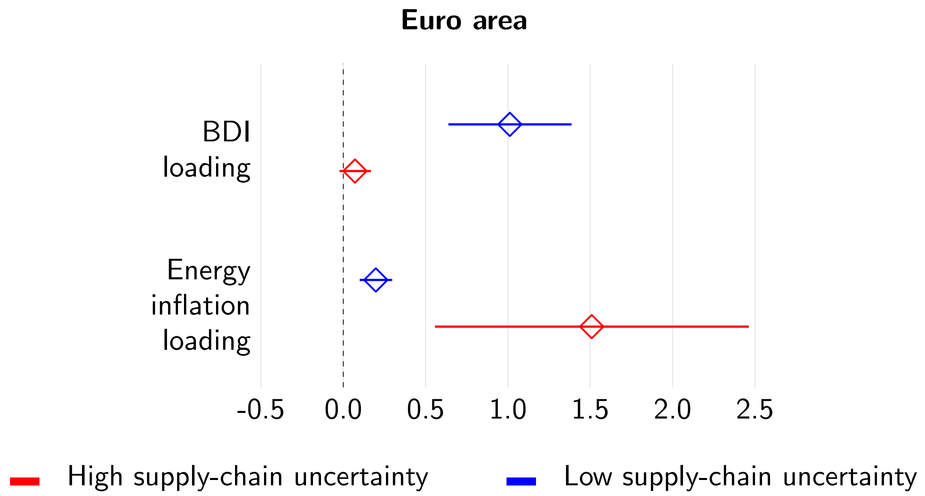
- **Estimate model parameters via MLE**.
- **Intuition**: measure whether **energy** prices have a particularly high information content during **high supply uncertainty** states.

# Kalman filter: signal loadings and uncertainty




**Result**: loading $\alpha_E \geq \alpha_{BDI}$ conditional on **high** supply chain uncertainty

# Kalman filter: signal loadings and uncertainty




Parameter estimates

# Summary of empirical evidence for US and EZ

- In high **supply-chain uncertainty** states:

1. **Pass-through** of energy price shocks on inflation is **higher**
2. **Information** value of **energy prices** as **signals increases**

# A Stylized Model of the Supply Chain

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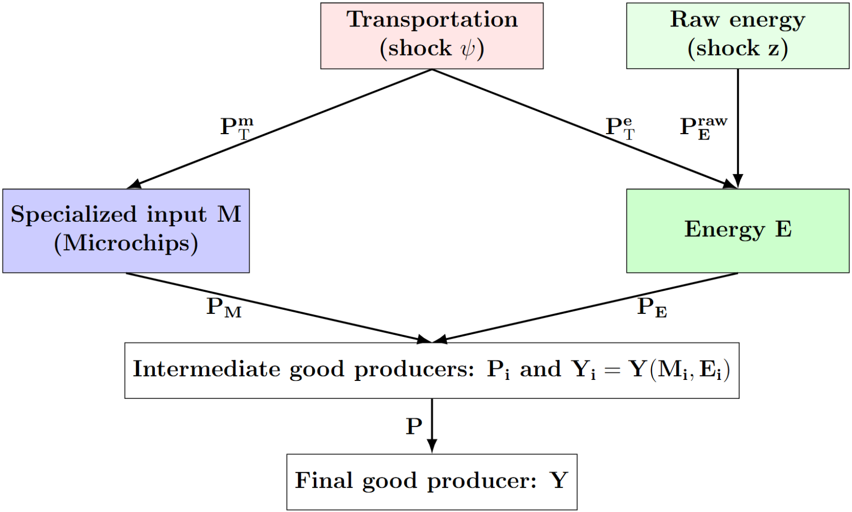
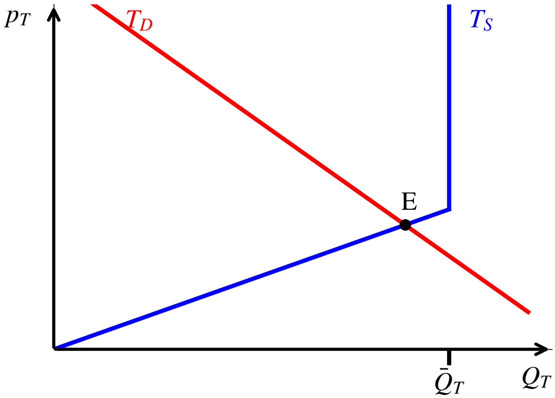



**Transportation shock** $\psi_t$ hits both inputs: Microchips and Energy

# Transportation Market

Three facts

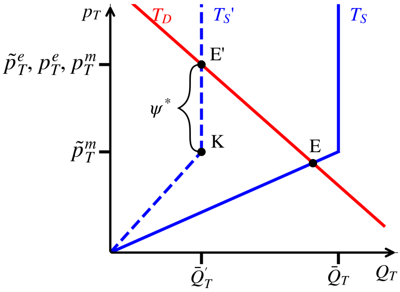
# Transportation Market



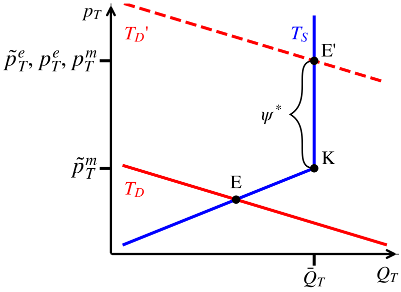

← *capacity constraint*

**Unconstrained** equilibrium in the transportation market

# Shocks in Transportation Market




*"Strait of Hormuz" congestion supply shock*

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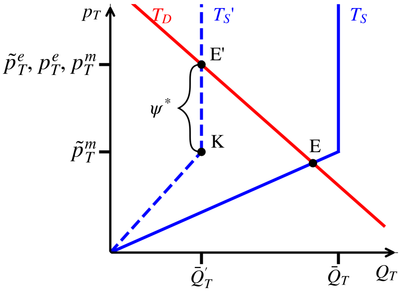


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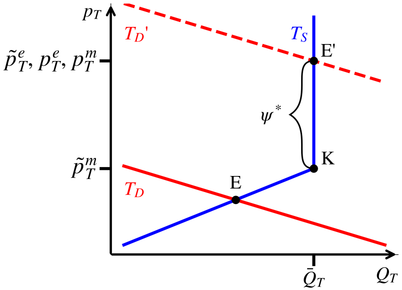


*"Covid" demand shock*

$$\underbrace{p^m_{T,t}}_{\text{effective price}} = \underbrace{\tilde{p}^m_{T,t}}_{\text{market price}} + \underbrace{\psi^*_t}_{\text{unobserved delay}}$$

**Wedge $\psi^*_t$ between effective and market transportation price of microchips**

# Transportation Prices

- Microchips : unobserved delay $\psi_t^*$ creates **wedge** btw. *effective* and *market* price of transportation

$$\underbrace{p^m_{T,t}}_{\text{effective price}} = \underbrace{\tilde{p}^m_{T,t}}_{\text{market price}} + \underbrace{\psi_t^*}_{\text{unobserved delay}}$$

- Energy

$$\underbrace{p^e_{T,t}}_{\text{effective price}} = \underbrace{\tilde{p}^e_{T,t}}_{\text{market price}} = \underbrace{\psi_t}_{\text{true transportation shock}}$$

# Kalman Filter: Recursive Learning

- Firms form a **Bayesian estimate** of the transportation delay $\psi_t^*$ from **observed** energy prices.
- Price of energy $p_E$ noisy **signal** of **true** transportation shock
- Updating is **recursive**

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## Update (in logs)

$$\underbrace{\psi_t^*}_{\text{posterior}} = \underbrace{\mathbb{E}_{\mathcal{P}_{\psi,(t-1)}}\{\psi_t\}}_{\text{prior}} + \underbrace{\mathbb{K}(\mathcal{S})}_{\text{Kalman gain}} \cdot \underbrace{\left(p_{E,t} - \mathbb{E}_{\mathcal{P}_{\psi,(t-1)}}\{p_{E,t}\}\right)}_{\text{error correction with new signal}}$$

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$$\mathcal{S} \equiv \frac{\sigma_\psi^2}{\sigma_v^2} \quad \text{(signal-to-noise ratio)}$$

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$\mathcal{S}$ increasing in the variance of the transportation shock ($\sigma_\psi^2$).

# Real Marginal Cost Under Uncertainty

- Price of **specialized input** M

$$
\begin{aligned}
p_M(\psi_t^*) = {} & (1-\nu)\, y_t \\
& + \nu(1-\delta) \cdot \underbrace{\left[\mathbb{E}_{\mathcal{P}_{\psi,(t-1)}}\{\psi_t\} + \mathbb{K}(\mathcal{S})\big(p_{E,t} - \mathbb{E}_{\mathcal{P}_{\psi,(t-1)}}\{p_{E,t}\}\big)\right]}_{\substack{\psi_t^* \\ \equiv \text{ estimated delay}}}
\end{aligned}
$$

# Real Marginal Cost Under Uncertainty

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- Real **marginal cost**

$$mc_t = \alpha_E \cdot \underbrace{p_{E,t}}_{\text{energy price}} + \alpha_M \underbrace{\left[(1-\nu)\, y_t + \nu(1-\delta)\, \psi_t^*\right]}_{\text{specialized input price: } p_M(\psi_t^*)}$$

# Pass-through Decomposition

## Pass-through of energy prices on final prices

$$\frac{dp_t}{dp_{E,t}} = \underbrace{\alpha_E}_{\text{direct}} + \underbrace{\alpha_M \, \nu \, (1-\delta) \, \mathbb{K}(\mathcal{S})}_{\text{uncertainty effect}}$$

Direct effect $=$ energy cost share $\alpha_E$

Uncertainty effect $\propto \mathbb{K}(\mathcal{S})$

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Direct effect $=$ energy cost share $\alpha_E$ Uncertainty effect $\propto \mathbb{K}(\mathcal{S})$

## Intuition

Firms use observed **energy price** as a *noisy signal* of delivery delays for specialized inputs. Under **incomplete information** ($\mathbb{K}(\mathcal{S}) \neq 0$), marginal costs rise **beyond** the direct energy-cost share $\alpha_E$.

# Uncertainty Effect: Dynamic Pass-Through

## Dynamic Pass-through

$$\underbrace{\frac{d\,\mathbb{E}_t\{p_{t+k}\}}{dp_{E,t}}}_{\text{dynamic pass-through}} = \underbrace{\alpha_M\,\nu\,(1-\delta)\,\mathbb{K}}_{\text{impact under uncertainty}} \cdot \underbrace{\left[\rho_\psi\left(1-\mathbb{K}\,\nu\,(1-\delta)\right)\right]^k}_{\text{learning-driven persistence}}$$

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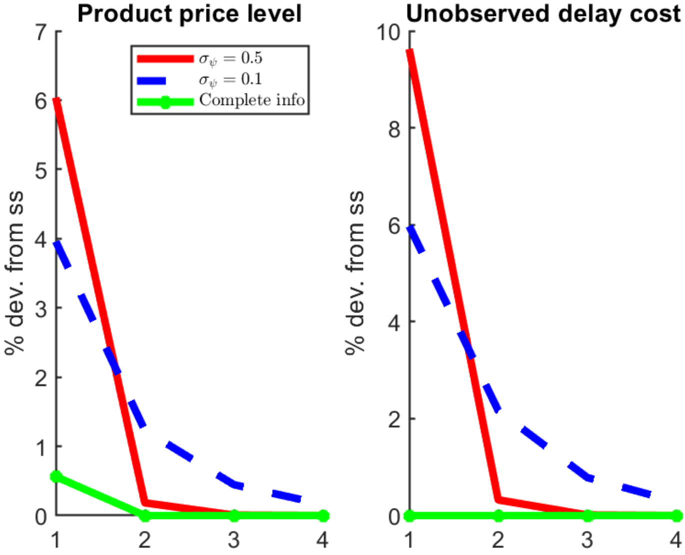
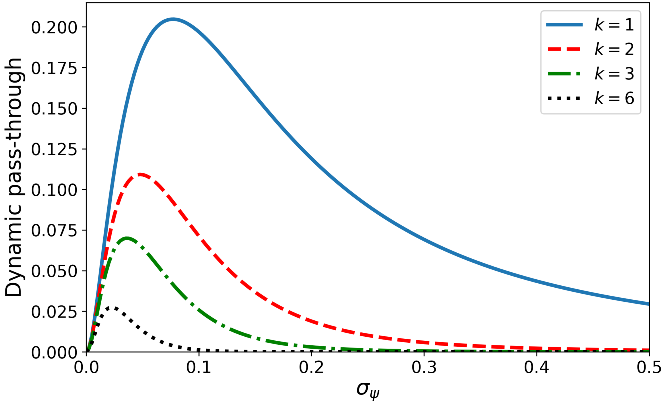
## Intuition

Under uncertainty, some of the **persistence** in the transportation shock "contaminates" (*i.i.d.*) energy price shock.

# Uncertainty Effect: Impact Pass-Through of Energy on Prices



# Effect of Uncertainty on Dynamic Pass-Through




**U-shaped** effect of transportation uncertainty $\sigma_\psi$ on dynamic pass-through at horizon $k$

# Nominal Rigidities and NKPC

# General Equilibrium NK Model with Supply Chain Uncertainty

- Extend to **general equilibrium**: households + firms + supply chain
- **Labor** in production function + labor supply
- **Calvo pricing** for intermediate goods firms → Derive **NKPC under supply chain uncertainty**
- Key result: uncertainty generates **endogenous cost-push** component in NKPC

# Endogenous cost-push effect in the Phillips curve

## NK Phillips curve with uncertainty

$$\pi_t = \beta\,\mathbb{E}_t\{\pi_{t+1}\} + \frac{(1-\theta)(1-\theta\beta)}{\theta}\,mc_t + \underbrace{G\,u_t}_{\text{uncertainty cost-push}}$$

$$u_t = L\,u_{t-1} + \mathbb{K}(\mathcal{S})\,\nu\,\underbrace{FE(p_{E,t})}_{\text{forecast error}}, \qquad L \equiv \left[1-\mathbb{K}(\mathcal{S})\,\nu\,(1-\delta)\right]\rho_\psi$$

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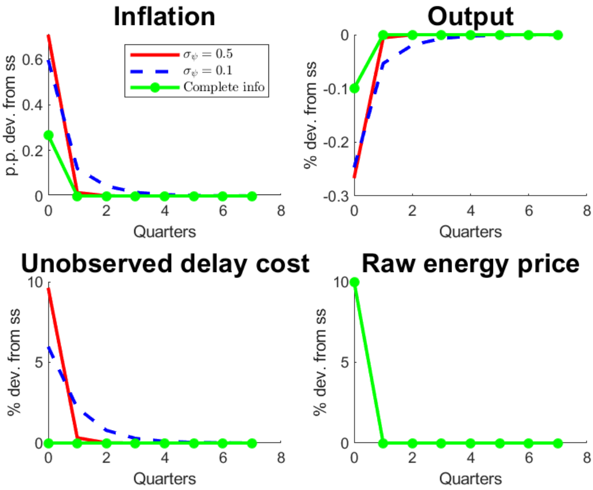
- **Comparative statics:** larger $\mathbb{K} \Rightarrow$ stronger amplification; higher $\mathbb{K} \Rightarrow$ lower $L$ (faster learning, less persistence).
- **Benchmark (complete information)** if $\mathbb{K}=0$ then $u_t=0 \rightarrow$ NKPC reverts to **standard** form.

# IRFs to a raw energy price shock




- **Incomplete information**
  1. **Amplifies** the effect of energy price shock on inflation
  2. Morph energy price shock into **cost-push**

# Takeaways

- **Key insight:** volatility of supply chain shocks **amplifier** of energy price shocks.
- Explains why 2021–23 inflation so sensitive to energy price spike.
- Policy implication: Central banks must condition responses on **supply-chain uncertainty**, not just shock size.

# Background slides on earnings calls

# Earnings calls: data and approach

**Data:** Firm-level **earnings calls transcripts** from NL Analytics. Differentiate the headquarters in the US and the Euro area.

**Earnings calls:**

- The management of publicly listed firms comments on past performance and future challenges.
- No cheap talk: communications during earnings calls carry real consequences.
- Limited time available creates a natural prioritization of topics. The more a topic is discussed, the more it is important.

**Approach:** Compute the share of sentences in each earnings call that contain at least a keyword. Take the monthly average.
**Keywords:** "Supply chain" , "Supply chain risk" , "Energy"

Keywords | Back

# Examples of sentences that mention both "Supply chain" and "Energy"

| From the earnings call | Firm | Sector | Date |
|---|---|---|---|
| Energy cost is the biggest driver and trigger of our inflation cost because after a few spikes, all these increasing costs translate into the entire supply chain within a range of 1 to 3 months. | Amrest Holdings SE | Cyclical Consumer Services | 2023-03-01 |
| ... it's not only the inflation, but it's a double effect from supply chain distortions and raw material energy inflation. | Hannover Rueck SE | Insurance | 2022-03-10 |
| We're seeing pressures across the supply chain, given the hike in oil price. | Newpark Resources Inc | Energy (Fossil Fuels) | 2021-08-04 |
| This has impacted the global economies profoundly, evident from the surge in crude oil and commodity prices and further global supply chain disruptions. | HDFC Bank Ltd | Banking & Investment Services | 2022-04-16 |
| The supply chain impact is much more difficult and demanding to rest than the energy price impact. | Raiffeisen Bank International AG | Banking & Investment Services | 2021-11-03 |

Back

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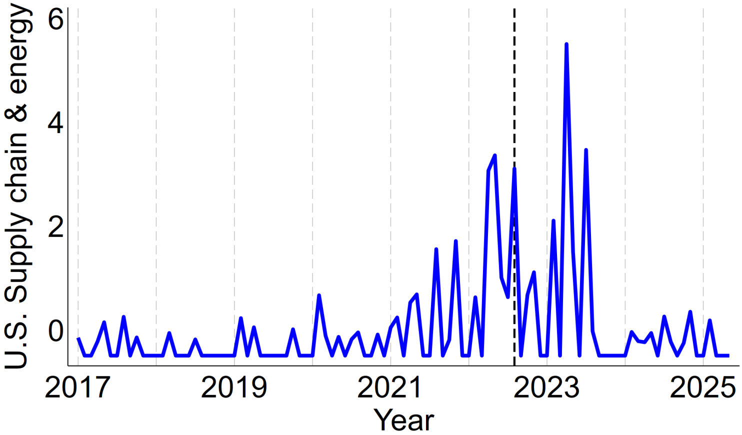
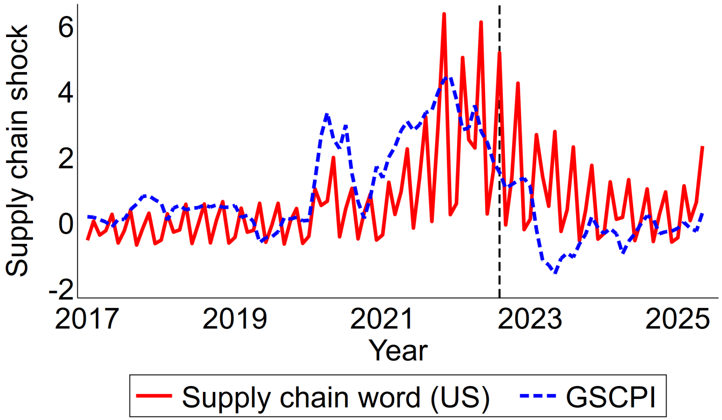



Back

# Share of sentences that mention "Supply chain"

**New firm-level measure of perceived supply chain shocks** $(\psi^*)$




Back

# Correlates of CPI inflation (United States)

| | U.S. CPI inflation | | |
|---|---|---|---|
| | (1) | (2) | (3) |
| U.S. energy inflation | 0.094*** | 0.088*** | 0.091*** |
| | (0.005) | (0.005) | (0.005) |
| GSCPI | | 0.341*** | 0.224*** |
| | | (0.049) | (0.053) |
| U.S. supply chain words | | | 0.240*** |
| | | | (0.050) |
| Adj. $R^2$ | 0.867 | 0.889 | 0.898 |
| N | 240 | 240 | 240 |

*Notes*: Standard errors in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Monthly data.

Earnings calls variables are standardized.

*Perceived supply chain shocks* (U.S. supply chain words) have an effect on the U.S. CPI inflation **over and above** the effect of *energy inflation* and of *actual* supply chain shocks (GSCPI).

Back

# Correlates of CPI inflation (Euro area)

| | EA HICP inflation | | |
|---|---|---|---|
| | (1) | (2) | (3) |
| EA energy inflation | 0.086*** | 0.080*** | 0.080*** |
| | (0.004) | (0.004) | (0.004) |
| GSCPI | | 0.112*** | 0.071*** |
| | | (0.024) | (0.027) |
| EA supply chain words | | | 0.083*** |
| | | | (0.027) |
| Adj. $R^2$ | 0.970 | 0.972 | 0.973 |
| N | 240 | 240 | 240 |

*Notes*: Standard errors in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Monthly data. Earnings calls variables are standardized.

Back

# Earnings calls correlates: claims

- **Key correlation:** "Supply chain words" ($w_{SC,t}$) and "Energy words" ($w_{E,t}$)
- **Unconditional** correlation is positive and significant

# Earnings calls correlates: claims

- **Key correlation:** "Supply chain words" ($w_{SC,t}$) and "Energy words" ($w_{E,t}$)
- **Unconditional** correlation is positive and significant
- Test **conditional** correlation:

$$w_{SC,t} = \alpha + \beta_1 \pi_{E,t} + \beta_2 w_{E,t} + \beta_3 \left[ \mathrm{Var}(\mathrm{GSCPI})_t \times w_{E,t} \right] + \varepsilon_t$$

**Results:**

- $\beta_2 > 0 \Rightarrow$ "Energy words" co-moves with "Supply chain words" **independently of energy inflation** (= firms treat energy prices as signals for supply chain shocks)
- $\beta_3 > 0 \Rightarrow$ the *energy signal* is more cited **when supply chain uncertainty is high**

Back

# Earnings calls correlates: results (United States)

| | U.S. supply chain word | | |
|---|---|---|---|
| | (1) | (2) | (3) |
| U.S. energy word | 0.403*** | 0.400*** | 0.145** |
| | (0.055) | (0.053) | (0.059) |
| U.S. energy inflation | | 0.019*** | 0.016*** |
| | | (0.004) | (0.004) |
| Var(GSCPI) $\times$ U.S. energy word | | | 0.497*** |
| | | | (0.067) |
| Adj. $R^2$ | 0.160 | 0.220 | 0.350 |
| N | 275 | 275 | 275 |

*Notes*: Standard errors in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Monthly data. Earnings calls variables are standardized. *Var(GSCPI)* is the 48-month rolling variance of the GSCPI.

*Supply chain word* and *energy word* especially **correlated** during **high** supply chain uncertainty

Back

# Earnings calls correlates: results (Euro area)

| | EA supply chain word | | |
|---|---|---|---|
| | (1) | (2) | (3) |
| EA energy word | 0.748*** | 0.700*** | 0.377*** |
| | (0.039) | (0.038) | (0.049) |
| EA energy inflation | | 0.021*** | 0.012*** |
| | | (0.004) | (0.003) |
| Var(GSCPI) $\times$ EA energy word | | | 0.320*** |
| | | | (0.035) |
| Adj. $R^2$ | 0.574 | 0.618 | 0.706 |
| N | 273 | 273 | 273 |

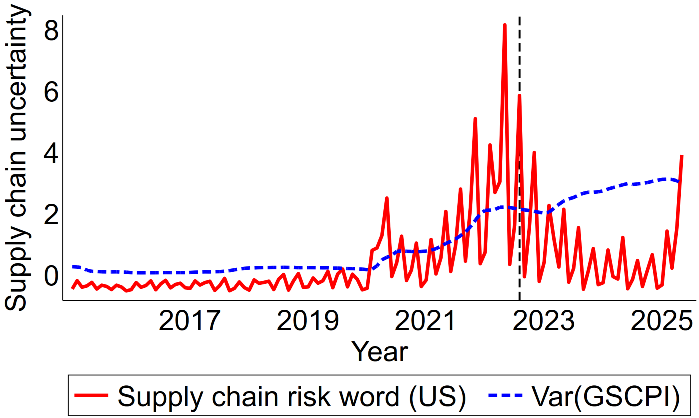
*Notes*: Standard errors in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Monthly data. Earnings calls variables are standardized. *Var(GSCPI)* is the 48-month rolling variance of the GSCPI.

*Supply chain word* and *energy word* especially **correlated** during **high** supply chain uncertainty

Back

# Share of sentences that mention: "Supply chain risk"

**New firm-level measure of supply chain uncertainty** $(\sigma_\psi^2)$




Back

# Earnings calls: Keywords

## Supply chain keywords

supplier, supplier network, supply assurance, supply base, supply bottleneck, supply chain, supply challenge, supply constraint, supply crunch, supply disruptions, supply front, supply impact, supply issue, supply logistic, supply network, supply partner, supply pressure, supply problem, supply shock, supply shortage, supply side, supply squeeze, supply tightness

## Supply chain risk keywords

At least one **supply chain keyword** and one synonym for **risk**

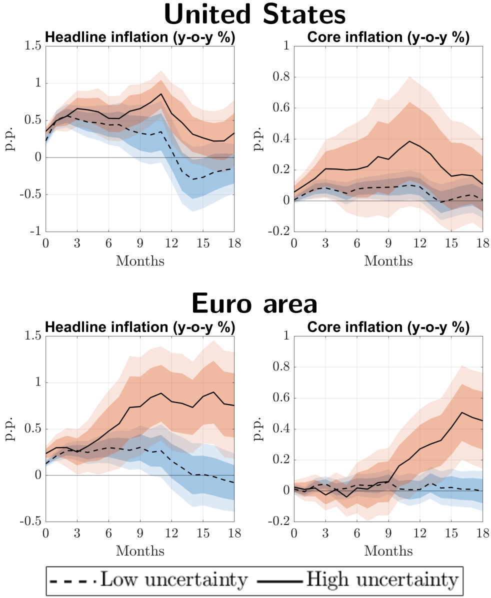
## Energy price keywords

energy price, energy cost, energy shock, fuel price, electricity price, gas price, LNG/LPG price, propane, kerosene, oil price, crude price, diesel price, gasoline price, coal price

Back

# Robustness

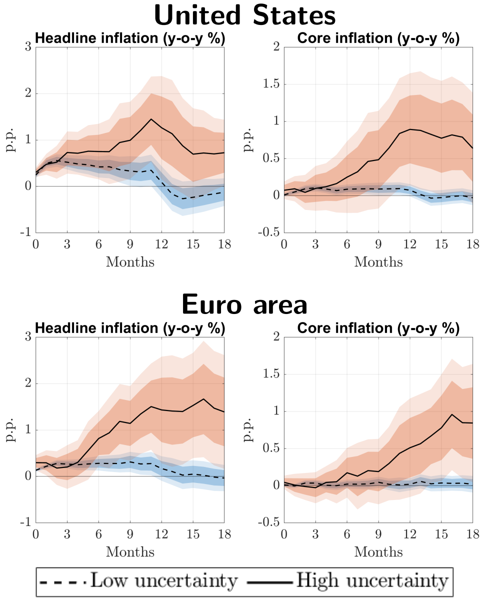
# Local projection: ETU index (top vs bottom 20%)




**ETU index measures perceived supply chain uncertainty.**

Back

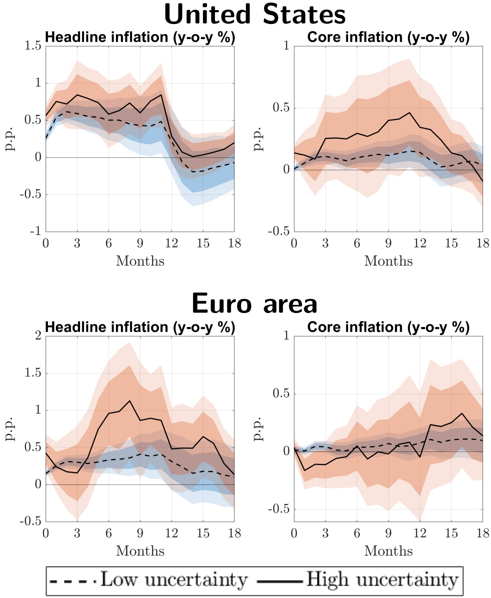
# Local projection: ETU index (top vs bottom 10%)




**Larger pass-through on inflation when the ETU index is in the top 10%. Larger confidence bands due to lower sample variation in $D_t = 0$ vs. $D_t = 1$.**

Back

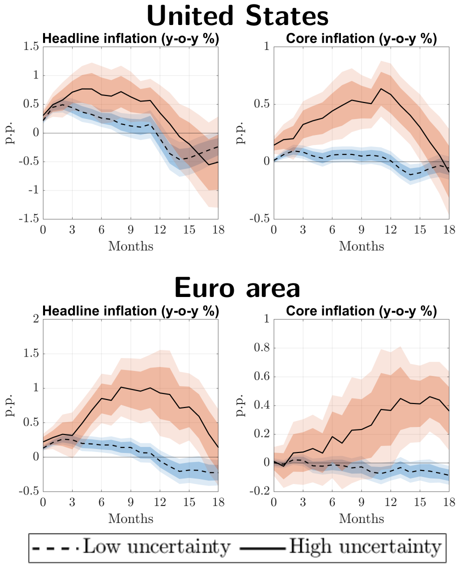
# Local projection: Var GSCPI (top vs bottom 10%)




**Larger pass-through on inflation when the Var GSCPI is in the top 10%.**

Back

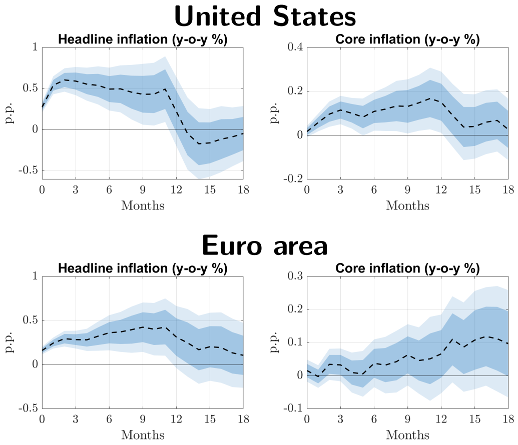
# Local projection: Var GSCPI (top vs bottom 20%), with a control for the level of the GSCPI supply chain shock




**The result is robust to the addition of levels and lags of the GSCPI to the regression equation. Adding controls sharpens identification and shrinks the confidence bands**

Back

# Local projection: unconditional IRFs




**Standard effect of an unconditional oil news shock on headline and core inflation**

Back

# Appendix

# Kalman filter procedure estimates

| Parameter | Low uncertainty | High uncertainty |
|---|---|---|
| Energy loading $\alpha_1$ | 0.36 | 1.09 |
| | (0.10) | (0.40) |
| BDI loading $\alpha_2$ | 1.01 | 0.20 |
| | (0.23) | (0.09) |
| Persistence $\rho_\psi$ | 0.96 | 0.95 |
| | (0.02) | (0.03) |
| Obs. var. (energy) $v_1$ | 0.72 | 0.00 |
| | (0.07) | (0.00) |
| Obs. var. (BDI) $v_2$ | 0.00 | 0.16 |
| | (0.00) | (0.03) |
| State var. $\sigma_\psi^2$ | 0.08 | 0.10 |
| | (0.04) | (0.07) |

Table: Kalman gain across uncertainty regimes in the U.S.

Back

# Three Facts about Maritime Transportation

1. **Maritime dominance.** Over 80% of global merchandise trade **moves by sea**
2. **Finite capacity.** Supply is a fixed fleet ($\sim$5,589 container ships) $\Rightarrow$ *vertical kink*: once fully deployed, quantity cannot rise even if demand increases.
3. **Choke points.** Shipments concentrate on a few hub ports and fixed routes (network concentration Gini $> 0.85$) $\Rightarrow$ disruptions at hubs propagate widely.

Back