Oil Price Volatility and the Asymmetric Transmission of Energy Shocks

Mock Job Talk

Alireza Azampour Mohammad Naderitabar

IIES

October 28, 2026

Motivation

- Oil shocks seem to play an important role in the business cycle
  - Energy is an important input into production
- Consensus of empirical evidence points towards non-linear effects of prices changes
- Standard modelling assumptions imply linear effects
  - Often oil price is treated a bit like TFP
- Open question: what is the underlying mechanism of non-linear effects?
  - Does this tell us anything about the effect of recent oil price shocks?

Oil prices and the business cycle

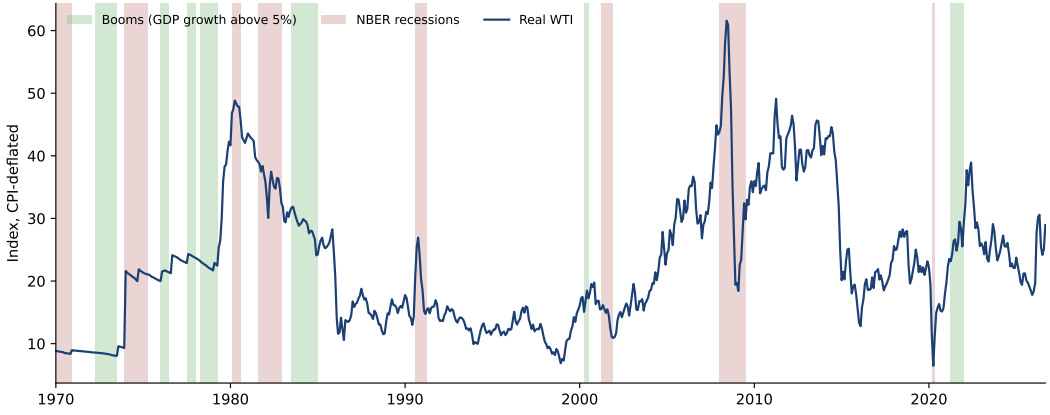


Figure 1: Real WTI, booms, and NBER recessions.

▸ Growth scatter plot

FRED WTISPLC and CPIAUCSL; NBER recessions (USREC) and expansions as the complement.

Research questions

1. Do positive oil price shocks contract activity more than negative shocks expand it?
2. Does the size of the shock matter?
3. What is the mechanism?

What this paper does

1. **Document non-linear empirical facts:**
   - using identified supply shocks → European investment declines more after adverse supply shocks than it expands after favorable ones
   - *later for model validation:* volatility rises with supply shocks and sectoral responses differ
2. **Build a multi-sector heterogeneous agents model:**
   - heterogeneous households with employment-linked investment portfolio exposure
   - two sector production with planned inputs and liquidation risk
   - regional oil prices
3. **Novel mechanism:**
   - oil-price volatility raises idiosyncratic firm-return risk, especially in the oil-intensive sector
   - portfolio weighted to employment sector transmits that risk into capital supply
4. **Method:** nonlinear MIT transitions, compared with an almost-nonlinear level-k algorithm. ▸ Method appendix

Short history of empirical evidence on oil shocks

- **Empirical literature has documented evidence of non-linear responses to oil prices**
- Early literature debated identification
  - Hamilton (2003): nonlinear, reduced-form oil events.
  - Kilian (2009): identified linear VARs; ordinary U.S. shocks look symmetric.
- Recent papers: new identification find evidence of non-linearity
  - Identified shocks: Baumeister–Hamilton & Känzig news shock
  - Sign asymmetry (US): Forni, Franconi, Gambetti, and Sala (2025)
  - Size nonlinearity (US): Caravello and Martínez Bruera (2024)
  - Sign asymmetry on persistence (Europe): Mareels (2026)
- **This paper:** Use Baumeister–Hamilton identified supply shocks to document
  - Asymmetric response of investment in EU to positive and negative shocks
  - Later: evidence of increase in oil price volatility after price shocks

▸ A mapping of the literature

Empirical evidence

Data and Empirical question

Key empirical fact

- Disentangling negative and positive price shocks effects $\{P_t^-, P_t^+\}$

$$i_{t+h} - i_{t-1} = \alpha_h + \theta_h^+ P_t^+ + \theta_h^- P_t^- + \Gamma_h' Z_t + u_{t+h}.$$

- Prices are endogenous so we need identified shocks

Shocks

- Monthly posterior-median oil-supply shocks from Baumeister and Hamilton (2019), original signs.
- **Positive supply shock** means more supply and therefore an **oil-price decline**; a negative supply shock is adverse and raises the oil price.
- Quarterly shocks are the sum of the three months.

Empirical shock: identified oil-supply innovations

Baumeister–Hamilton identification

A Bayesian oil-market SVAR combines sign restrictions with prior information on supply and demand elasticities to separate oil-supply innovations from activity, consumption-demand, and inventory-demand shocks.

- We use the posterior-median monthly **oil-supply shock**, not an unexplained oil-price change.
- The long monthly sample includes major historical disruptions and aggregates naturally to quarterly investment.
- The identification is linear; our empirical and model exercises ask whether propagation depends on sign, size, and subsequent price risk.

▸ How the shock is identified

Baumeister and Hamilton (2019).

EU10 investment response is stronger after adverse shocks

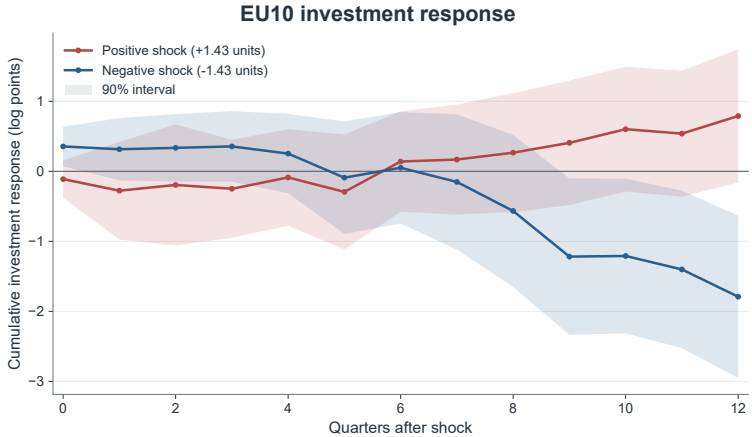
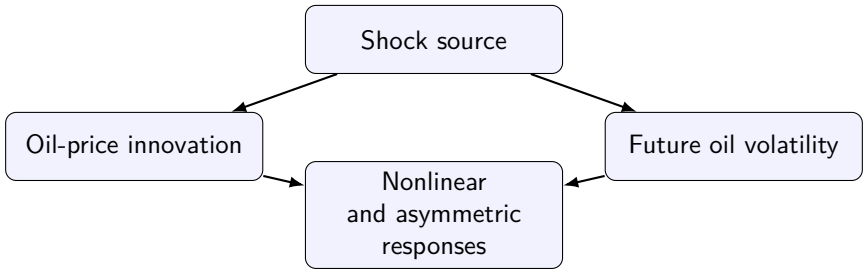


Figure 2: Cumulative EU10 investment responses by shock sign.
Scaled to the median absolute quarterly shock (≈ 1.43). At 12 quarters: $+0.79$ log points after a favorable shock, -1.79 after an adverse shock. Only the contraction's 90% interval excludes zero.

▸ Regression

What causes asymmetry?

- **Our idea:** an increase in uncertainty about future prices lowers investment
- Oil shock is a **combination** of price change and increase in dispersion
  - **Price change:** Changes in production costs makes production more or less expensive
  - **Dispersion innovations:** introduces risk $\rightarrow$ incentive to reduce investment
- **Asymmetry:** volatility reinforces a price increase and offsets part of a price decline.



A simple one firm model

The problem

- The firm sells at a given price $P = 1$.
- $Y = \min(K, O/\theta)^{\nu}$, with $\nu = 0.70$, $\theta = 0.10$, $r = 0.05$.
- Both inputs are chosen before the oil price is drawn a from normal distribution
- Profit risk comes from the oil bill, and the firm has constant absolute risk aversion $\lambda = 0.15$.
- Oil price standard deviation rises from 0.15 to 0.45.

	Output	Capital	Oil
Percent change	-28.2%	-37.7%	-37.7%

Table 1: Capital and oil fall together because the firm remains on the fixed-proportions ray.

▸ details

Main Model

The model in pieces

What is in the economy

- Firms that use capital, land, labor, and oil.
- Two sectors, high-energy H and low-energy L.
- Regions that share an expected oil price but draw a local price shock
- Households that differ in wealth, productivity, and the sector they work in

Who decides what

- **Firms**
  - choose capital, land, oil and labor before the regional price is known
  - can adjust oil and labor subject to adjustment costs
  - face revenue shock and possible liquidation
- **Households**
  - choose consumption, labor, and savings
  - choose diversification within sector of employment and between sectors
- **Oil price:** labor and oil demand is determined after regional price shock

Firm problem: technology

- A firm operates in region j in sector s
- Faces oil price p_j^o and sectoral goods price p_{js}
  - two sectors, H and L, differ in oil intensity $\alpha_{0,H} > \alpha_{0,L}$.
- Gross output is a nested CES:
  - Capital and labor:

$$M_{js} = \left[\alpha_{L,s} L_{js}^{\frac{\epsilon_f - 1}{\epsilon_f}} + \alpha_{K,s} K_s^{\frac{\epsilon_f - 1}{\epsilon_f}} \right]^{\frac{\epsilon_f}{\epsilon_f - 1}}$$

  - Oil, capital–labor composite and land

$$Y_{js}^g = \left[(1 - \phi_s)\alpha_{0,s} O_{js}^{\frac{\rho_f - 1}{\rho_f}} + (1 - \phi_s)\alpha_{LK,s} M_{js}^{\frac{\rho_f - 1}{\rho_f}} + \phi_s T_s^{\frac{\rho_f - 1}{\rho_f}} \right]^{\frac{\rho_f}{\rho_f - 1}}.$$

Firm problem: input timing, adjustment costs and liquidation

Adjustment costs

- At the beginning of the period, firms choose K_s, T_s, $\bar{O}_s$, and $\bar{L}_s$.
- After regional price p_j^o is revealed, oil and labor, O_{js} and L_{js}, can be adjusted at convex costs κ_O and κ_L.

$$\Phi_{js}^I = \kappa_O \frac{(O_{js} - \bar{O}_s)^2}{\bar{O}_s} + \kappa_L \frac{(L_{js} - \bar{L}_s)^2}{\bar{L}_s}.$$

Revenue shock

- To finance production firms use an in-period loan:

$$D_{js} = p_j^o O_{js} + w_j L_{js} + p_{js} \Phi_{js}^I + q_T T_s$$

- At end of period receive an idiosyncratic revenue shock ζ_i.
- If revenue cannot cover loan ($\zeta_i p_{js} Y_{js}^g < D_{js}$) firm liquidates
- fraction C_{liq} of capital is lost

Firm problem: choice problem and returns

Choice problem

Firm FOCs

The firm's problem is to maximize:

$$\max_{K_s, T_s, \bar{O}_s, \bar{L}_s, \{O_{js}, L_{js}\}_j} \mathbb{E}_j\left[p_{js} Y_{js}^g - D_{js} - \mathcal{L}_{js}\right] - (\bar{R}_s + \delta) K_s,$$

$$D_{js} = p_j^o O_{js} + w_j L_{js} + p_{js} \Phi_{js}^I + q_T T_s.$$

Individual-firm net return

The individual return on a firm is given by:

$$R_{js}^i = \frac{\zeta_i p_{js} Y_{js}^g - D_{js}}{K_s} - \delta - \underbrace{C_{\text{liq}}(1-\delta)\mathbf{1}\left\{\zeta_i p_{js} Y_{js}^g < D_{js}\right\}}_{\mathcal{L}_{js}}.$$

- Household working for firm i is potentially exposed to return R_{js}^i
- Can diversify portfolio at cost

Household problem

Bellman equation

$$V_j(a,z,e) = \max_{c,o,n,W,d,\theta} \{u(C,n) + \beta \mathbb{E}[V_{j'}(a',z',e') \mid j,z,e]\}.$$

Budget and wealth

$$x + \underbrace{\left[1 + \kappa_d d^2 + \kappa_s d^2 (\theta - \theta_e^0)^2\right]}_{\text{diversification cost } C_{div}} W = \underbrace{a + w_j z n + \tau_T}_{\text{wealth + current income}}, \quad x = c + p_j^o o, \quad C = CES(o, c, \chi_o, \epsilon_o)$$

Portfolio choice

$$R_p' = (1-d)R_{i,e}' + d\left[(1-\theta)R_H' + \theta R_L'\right], \qquad a' = R_p' W.$$

- Default household portfolio ($d = 0$) is own firm
  - Can diversify away from own firm d.
  - And between sectors θ
- Saving W chosen at t supplies sectoral capital at $t+1$.

▸ Household details ▸ Why sectoral exposure?

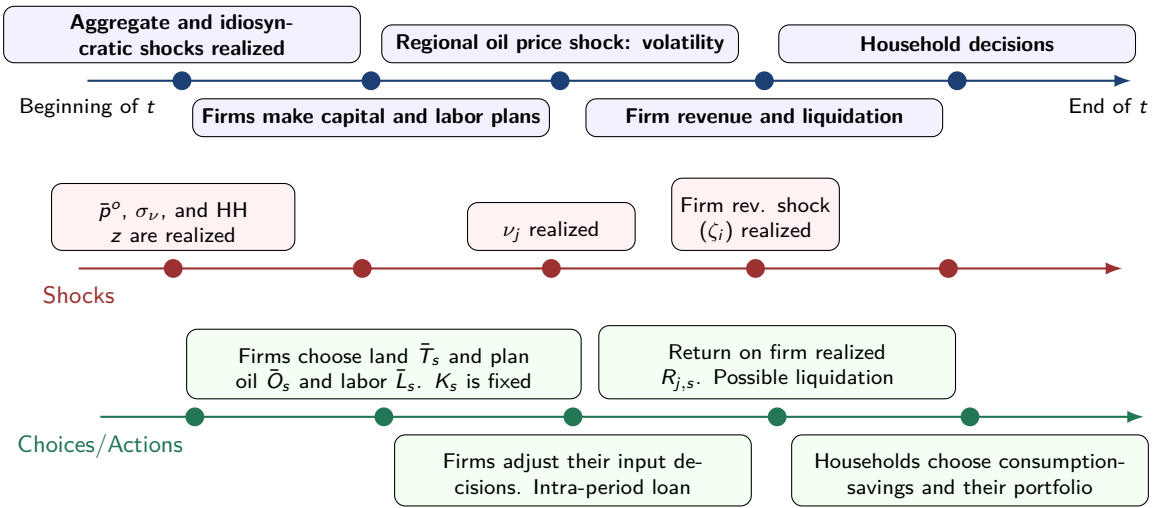
Oil prices, volatility, and regions

The oil price in a region is composed of an aggregate and regional component

$$p_j^o = \bar{p}^o(1+\nu_j), \qquad \mathbb{E}[\nu_j] = 0, \qquad \text{Var}(\nu_j) = \sigma_\nu^2.$$

- From the perspective of the firm the regional price captures uncertainty or volatility
  - $\bar{p}^o$ is the expected oil-price level
  - ν_j is an iid regional price shock. σ_ν is cross-region oil-price dispersion ▸ Oil-price dispersion
- Interpretation: aggregate is the EU; a **region** is an EU country
  - Evidence that there is significant price dispersion across EU countries in response to shocks ▸ EU10 price residuals
- **Oil shock:** can move $\bar{p}_t^o$, $\sigma_{\nu,t}$, or both.
- After shock firms anticipate a path of $\bar{p}^o$ and σ_ν back to steady state.
  - ν_j drawn every period

Timing inside a period



Equilibrium and market clearing

- A stationary equilibrium is a set of Prices, policies, and household distribution in which
  - capital, labor, land, and good markets clear
  - the distribution maps into itself
- Capital markets cleared by $\bar{R}_H, \bar{R}_L$
  - Sectoral capital demanded equals capital supplied from households' decision in last period
- Labor, cleared by regional wages w_j

$$\sum_{s \in \{H,L\}} L_{js} = N_j \qquad \text{for each oil state } j.$$

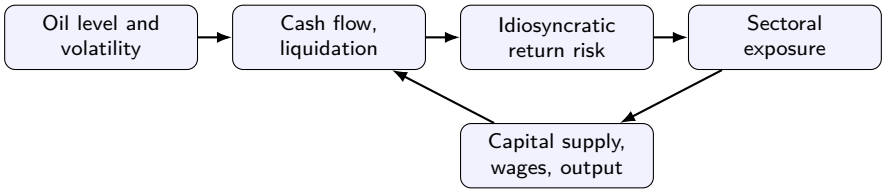
- Goods, cleared by p_H/p_L

$$Y_j = \mathrm{CES}(Y_{jH}, Y_{jL}, \omega, \eta), \qquad \mathbb{E}[Y_j] = c + \delta K + \mathbb{E}\left[p_j^o o_j + \sum_{H,L} (p_j^o O_j s + \mathcal{L}_{js} + \Phi_{js}^I) + C_{div} \right].$$

- Land, cleared by the rent q_T

$$T_H + T_L = \bar{T}.$$

Key portfolio risk mechanism



- Volatility (σ_ν) increases costs variance ($Var(D_{js})$) and raises downside risk ($Var(R^i_{js})$)
- Households cannot costlessly diversify that risk.
- Required returns rise and investment falls in both sectors
- Effect of increase in risk stronger in high energy sector
- After a price increase, costs and volatility reinforce each other

Result: Small increase in price risk has a substantial effect on investment and reallocation

Calibration

External parameterization

- Oil share in production $\alpha_{o,H}, \alpha_{o,L}$ is set to categorize L and H sectors
- ω and η set sectoral responses' importance
- ϵ_f **is consequential** on translation of investment drop to GDP changes

Parameter	Value	Role/source
β	0.99	Kydland–Prescott (1982)
σ	3	Aiyagari (1994)
γ	2	Chetty (2012)
ρ_z	0.95	Cooley–Prescott (1995)
σ_z	0.08	Iacoviello–Pavan (2013)
δ	0.015	Cooley–Prescott (1995)
χ_o	0.90	Audzei–Sutoris (2024)
ϵ_o	0.30	Natal (2012)
ρ_f	0.30	Natal (2012)

Parameter	Value	Role/source
ϵ_f	0.50	Chirinko (2008)
η	0.75	Atalay (2017)
ω	0.20	Own EU classification
$\alpha_{o,H}, \alpha_{o,L}$	.175, .025	High/low oil-intensity
κ_O, κ_L	1, 2	$\kappa_L = 2\kappa_O$
ρ_e	0.90	Employment persistence
κ_d	.001	Calvet et al. (2007); Betermier et al. (2017)
κ_s	.005	Sectoral return premium

Table 2: External benchmark parameters.

▸ EU employment and output shares

Internally calibrated objects

- C_{liq} and $\text{Var}(\zeta)$ set the importance of σ_ν for $\text{Var}(R^i_{js})$
- $\alpha_{L,s}$ also tunes the effect of capital changes on GDP
- A higher $\bar{p}^o$ makes σ_ν more important

Moment	Target	Model	Object	Value
Land rent / GDP	0.045	0.044	ϕ_s	0.03
Oil expenditure / GDP	0.08	0.076	$\bar{p}^o$	0.175
Labor compensation / GDP	0.65	0.70	$\alpha_{L,s}$	0.60, 0.70
Sector-H employment share	0.175	0.19	$\alpha_{K,s} = 1 - \alpha_{L,s}$	0.40, 0.30
Quarterly liquidation rate	0.015	0.014	$\text{Var}(\zeta)$	0.0208
Idiosyncratic return variance	0.0025	0.0025	C_{liq}	0.30

Table 3: Internally calibrated objects and steady-state targets.

Oil Shock Experiments

Oil price experiments

MIT shocks to oil price and dispersion

Use MIT shocks to investigate non-linear responses and valuate the mechanism

- An oil price shock is a combination of a **price change** and an increase in **price dispersion**.
  - Calibrated to match empirical magnitudes.
- **Model asymmetry:** compare **price increase** with a **price decline**.
- Understand mechanism by shutting down **price dispersion** or **price change**.
- Each path is unexpected at $t = 1$. After aggregate paths have perfect foresight.
- But firms *don't know* their ex-post volatility realization.
  - Interpretation: aggregate uncertainty/regional variation.

New solution method: an almost-nonlinear level-k transition **preserves nonlinear policies** while reducing the cost of repeated full-horizon solves. ▸ Method appendix

Joint price–dispersion shock paths

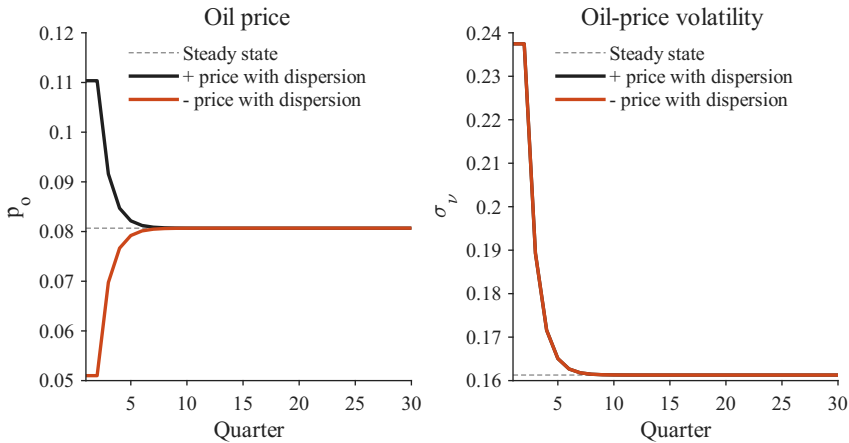


Figure 3: Price and dispersion paths for the joint positive–negative comparison.

Price volatility and dispersion in response to a supply shock

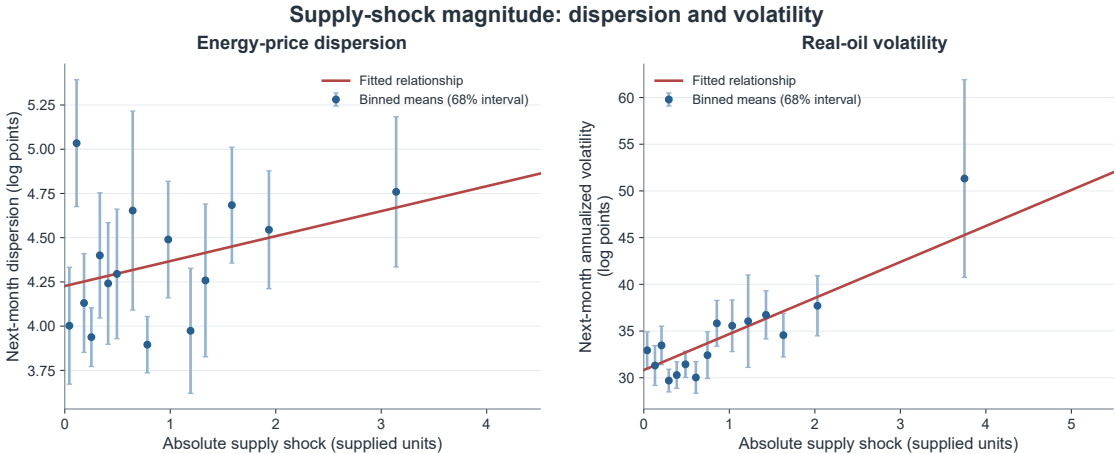
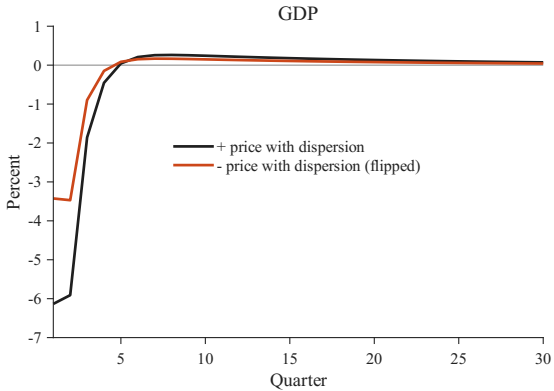


Figure 4: A supply shock raises both volatility (right) and dispersion (left) of energy prices in EU

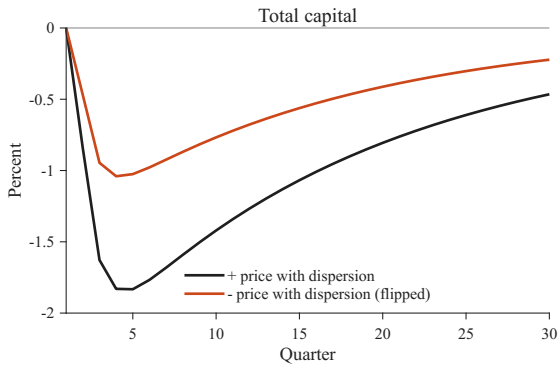
▸ Different horizons dispersion ▸ Both signs ▸ Regression

The adverse joint shock has the larger absolute effect

Both experiments include a **dispersion increase**.



GDP responses



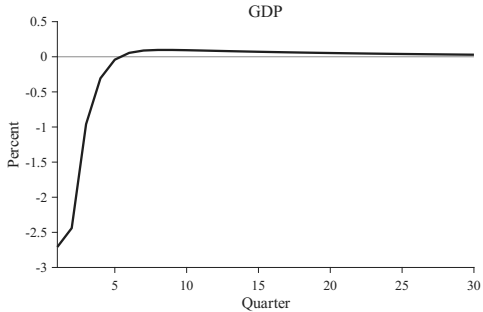
Total-capital responses

The asymmetry between two responses

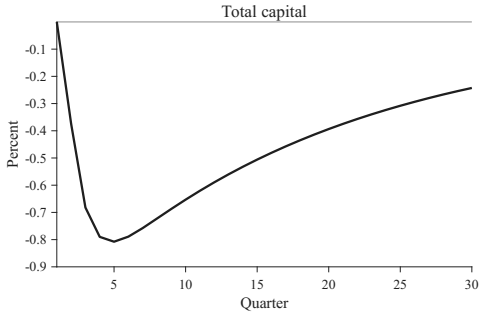
The plotted asymmetry is

$$\mathcal{A}_t = r_t(p^o \uparrow, \sigma_\nu \uparrow) + r_t(p^o \downarrow, \sigma_\nu \uparrow).$$

A negative value means that the contraction after the adverse shock exceeds the expansion after the favorable shock in absolute value.



GDP asymmetry



Total-capital asymmetry

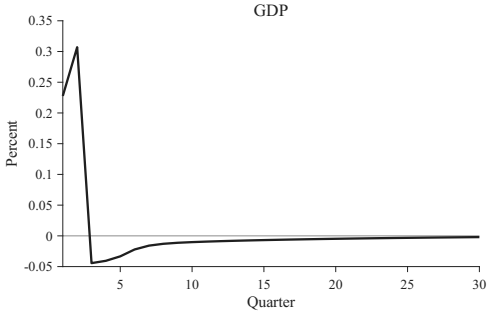
▸ Direct GDP responses ▸ Direct capital responses

Price shocks alone generate the opposite asymmetry

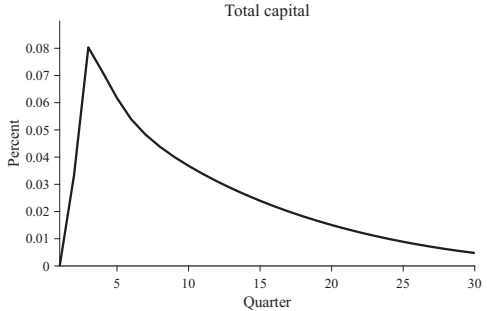
Holding dispersion at steady state, the plotted asymmetry is

$$\mathcal{A}_t = r_t(p^o \uparrow) + r_t(p^o \downarrow).$$

A positive value means that the expansion after the favorable price decline exceeds the contraction after the adverse price increase in absolute value.



GDP asymmetry

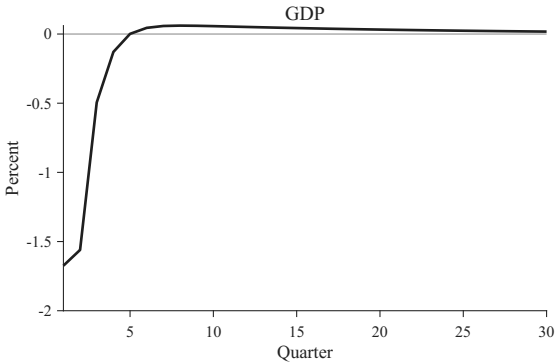


Total-capital asymmetry

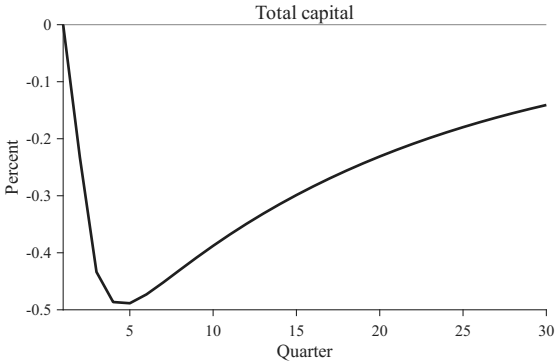
▸ Direct GDP responses ▸ Direct capital responses ▸ Shock paths

A pure dispersion shock lowers GDP and capital

The mean oil price remains at steady state while **cross-regional dispersion rises**.



GDP response

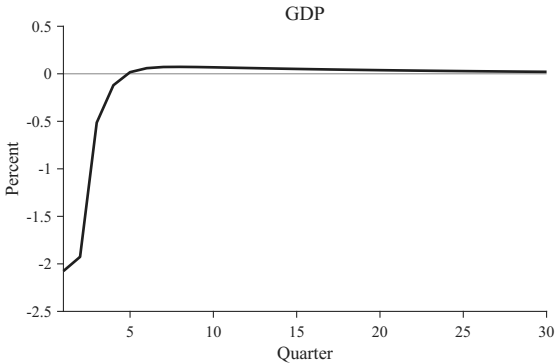


Total-capital response

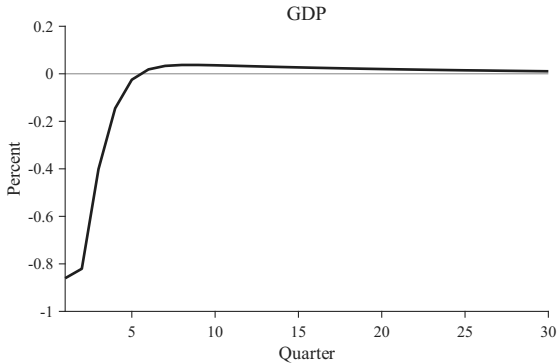
▸ Shock path

Dispersion is more contractionary after a price increase

Each panel isolates the incremental effect of adding the same **dispersion shock** to a price movement.



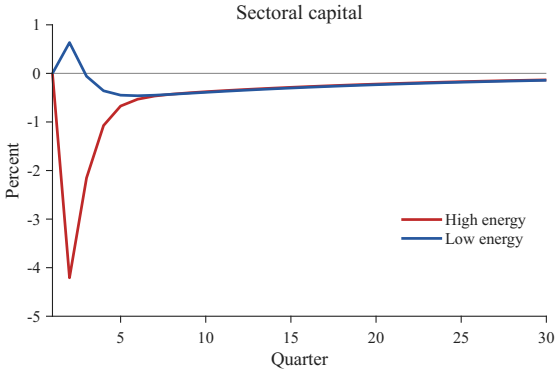
Dispersion effect with an **oil-price increase**



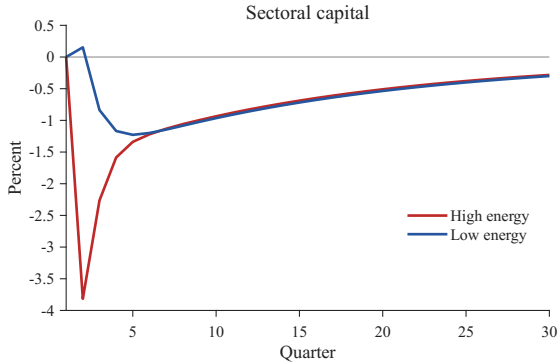
Dispersion effect with an **oil-price decline**

Dispersion reallocates capital strongly across sectors

- A **dispersion increase** has different sectoral implications than an **oil-price increase**.
  - Using the simple model structure with two sectors, reallocation is weak ▸ Simple model

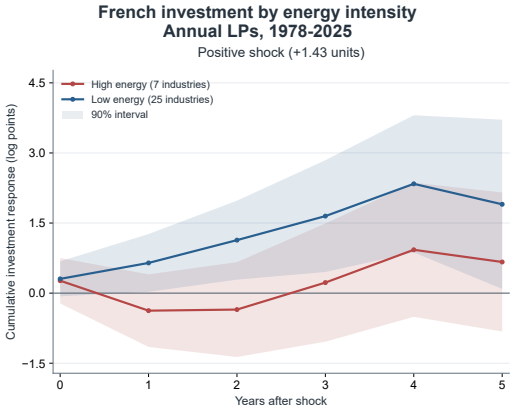


Response to a **dispersion increase**

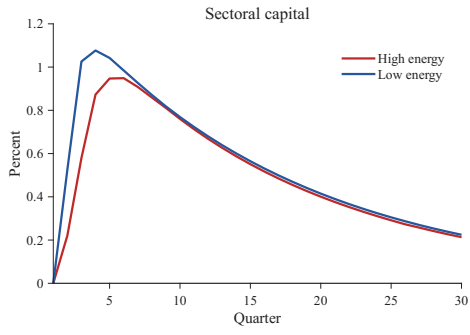


Response to an **oil-price increase**

A negative price joint with dispersion shock change sectoral response



Cumulative French investment responses by energy intensity.



Sectoral capital response

the positive shock on the French data is the a positive supply shock

▸ Regression ▸ Sectoral Response without dispersion shock

Responses summary

Main take aways

- The joint shocks cause asymmetric response while pure price shock show little asymmetry
- The effect of variance increase in **adverse shocks** is more important
- There is significant reallocation between sectors

	Single shock			Amplification with σ_ν	
Outcome	$p^o \downarrow$	$p^o \uparrow$	$\sigma_\nu \uparrow$	$\sigma_\nu \uparrow p^o \downarrow$	$\sigma_\nu \uparrow p^o \uparrow$
Peak output (%)	4.29	−4.06	−1.67	3.46	−6.13
Peak total investment (%)	39.4	−37.2	−15.5	32.1	−56.3
Sectoral capital corr.	−0.27	−0.31	−0.84	0.88	−0.54

Table 4: Peak aggregate responses across the five experiments.

$p^o \downarrow$ **is favorable**; $p^o \uparrow$ **is adverse**. The correlation is calculated through the last nonzero shock period.

Cross-sectional facts

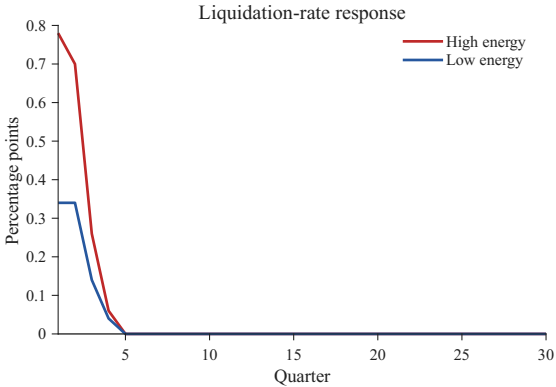
Return Dispersion and premia

- Forni, Franconi, Gambetti, and Sala (2025): U.S. uncertainty (VXO) and the excess bond premium rise after oil-supply news of *either* sign (their Figure 11).
- On our definition, the energy-intensive sector earns a **positive dividend premium**: $+0.095$ percent per month ($+1.14$ percent annualized, 1960–present, value-weighted).

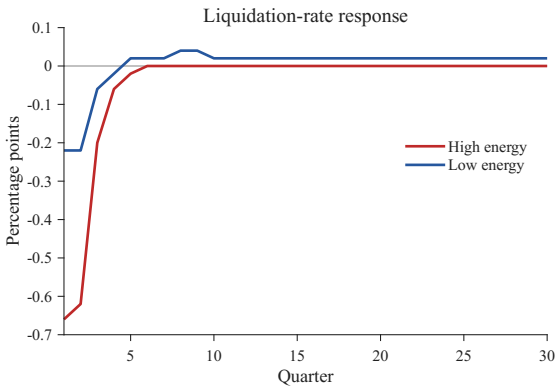
Forni, Franconi, Gambetti, and Sala (QE 2025); energy_intensity_premiums.xlsx; dividend_yield_dispersion.xlsx.

Price increases raise liquidation; price declines reduce it

The **oil-price increase** raises liquidation in both sectors; the **price decline** lowers it. Sectoral differences contribute to the return premium.



Oil-price increase

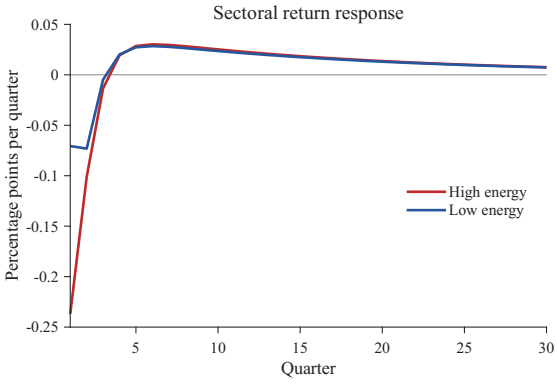


Oil-price decline

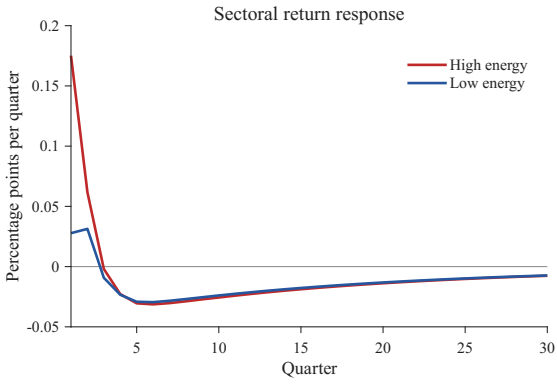
▸ Sectoral variance responses

Price shocks move sectoral returns in opposite directions

Returns are percentage-point deviations from their sector-specific steady states.



Oil-price increase

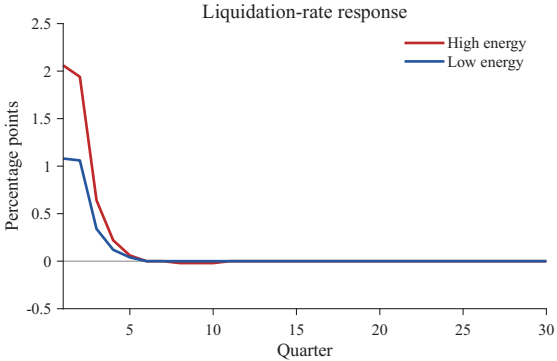


Oil-price decline

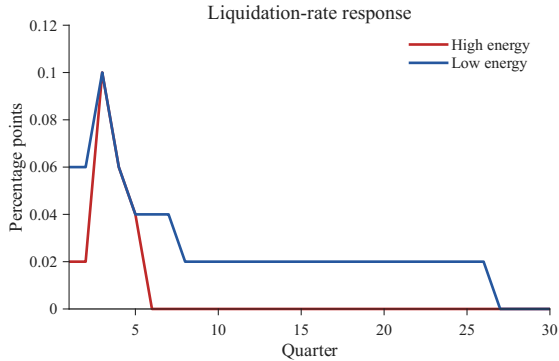
▸ Sectoral variance responses

Dispersion raises liquidation after either price movement

Adding the same **dispersion increase** raises liquidation after both price movements, with the larger response following the **oil-price increase**.



Price increase + dispersion

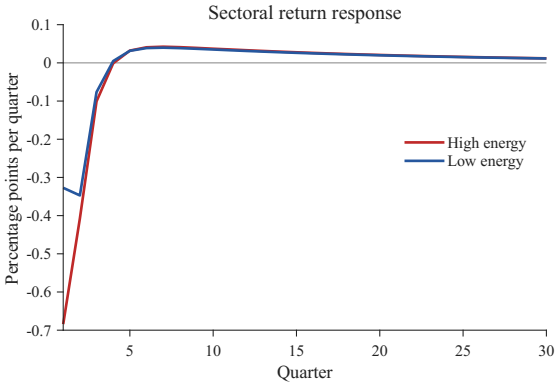


Price decline + dispersion

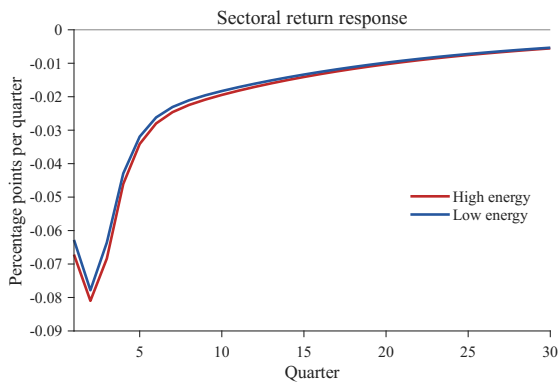
▸ Sectoral variance responses

Joint shocks widen the sectoral return response

Returns are percentage-point deviations from their sector-specific steady states.



Price increase + **dispersion**



Price decline + **dispersion**

▸ Sectoral variance responses

Responses summary

Main take aways

- Price decrease alone boosts the relative return of H sector, and price increase reduces it
- Inclusion of the the volatility shock reduces cancels out that effect in a decrease and strengthen it in an increase
- The main channel is through the effects on liquidation
- This means the return variance also increases

	Single shock			Amplification with σ_ν	
Outcome	$p^o \downarrow$	$p^o \uparrow$	$\sigma_\nu \uparrow$	$\sigma_\nu \uparrow p^o \downarrow$	$\sigma_\nu \uparrow p^o \uparrow$
Peak relative return (p.p.)	0.14	-0.16	-0.19	-0.00	-0.34
Peak liquidation (p.p.)	-0.29	0.41	0.71	0.09	1.25
Peak variance ($\times 10^4$)	-4.8	6.6	10.1	1.4	19.2

Table 5: Peak liquidation and idiosyncratic-variance responses.

Conclusion

Conclusion

- Positive oil price shocks contract investment more than negative shocks expand it.
- Larger shocks also predict greater price risk.
- In the model, oil-price dispersion raises firm-level downside risk, especially in the oil-intensive sector.
- Sectoral exposure transmits that risk into lower capital supply.
- Price dispersion reinforces a price increase and offsets part of the expansion from a price decline.

Next step

- Investigate **portfolio diversification** vs *change in energy share* as a cause of smaller pass-through of recent shocks.
- Add New-Keynesian block to study impact on inflation.

Appendix

Appendix:Correlation of growth and oil price changes

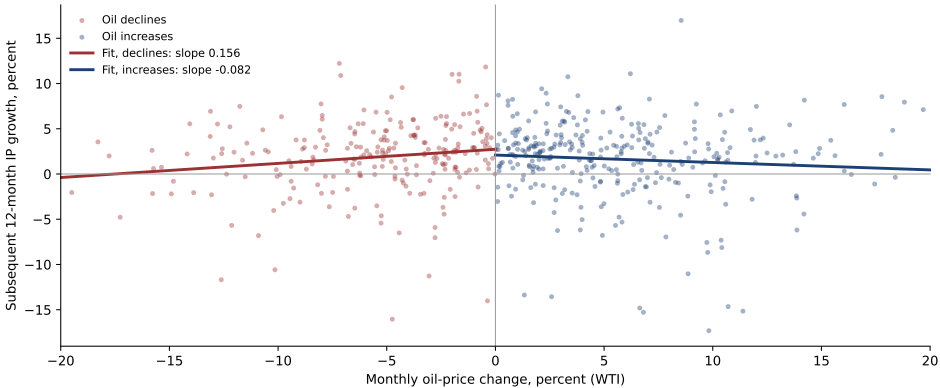


Figure 5: Monthly oil-price changes and subsequent 12-month industrial-production growth.

▸ Back to Oil & Business cycle

FRED WTISPLC and INDPRO. Oil changes displayed in $[-20, 20]$ percent.

Appendix: Oil and the macroeconomy; a map of the literature

Empirical: identification

- Hamilton (1983, 1996, 2003, 2009): large oil events and net price increases; the 2007–08 shock.
- Kilian (2009): the same price move is not one shock—supply, activity, and precautionary demand differ.
- Baumeister–Hamilton (2019): Bayesian SVAR; supply still accounts for a large share of price variation.
- Känzig (2021): OPEC-announcement news. Follow-ons: Känzig–Stock–Zanotti (2026) on the shale exporter shift; Mori–Peersman (2026) on financial predictability of the news.

Empirical: sign, size, volatility

- Kilian–Vigfusson (2011); Herrera, Lagalo, and Wada: ordinary U.S. innovations look close to linear.
- Hamilton (2011); Lee, Ni, and Ratti (1995): nonlinearity and oil-price variability.
- Forni, Franconi, Gambetti, and Sala (2025): sign asymmetry; uncertainty rises after either sign.
- Caravello–Martínez Bruera (2024): size nonlinearity.
- Mareels (2026): European hysteresis after temporary increases.
- Ramey–Vine: sectoral automobile channel.

Theoretical and quantitative modeling

- Complementarities and energy in production: Basu (1995); Kim–Loungani; Rotemberg–Woodford; Finn; Atkeson–Kehoe.
- Monetary and open-economy DSGE: Leduc–Sill; Blanchard–Galí; Bodenstein–Erceg–Guerrieri; Balke–Brown; Gagliardone–Gertler (2026).
- Oil-price *volatility*: Plante–Traum (2012)—precautionary saving can raise investment.
- Heterogeneous-agent energy: Auclert–Monnery–Rognlie–Straub (2023); Pieroni (2023); Guerrieri–Lorenzoni–Werning (2025).

▸ Back to paper contribution to literature

Appendix: Simple model, objective and first-order condition

- Idle capital has a rental cost and does not cut risk.
- Oil beyond the required proportion only raises the mean and the variance of the oil bill.
- The firm therefore sets $K = X$ and $O = \theta X$, which gives $Y = AX^{\nu}$.

Profit is normal. With mean oil price $\bar{p}$ and standard deviation σ_p, its certainty equivalent is:

$$PAY - \big(r + \bar{p}\,\theta\big)X - \frac{\lambda}{2}(\theta\sigma_p X)^2.$$

In first-order condition we have marginal revenue = expected marginal cost + a risk premium:

$$\nu PAX^{\nu-1} = r + \bar{p}\,\theta + \lambda\theta^2\sigma_p^2 X.$$

- The premium rises with scale, with θ^2, and with the oil-price variance.
- The objective is strictly concave, so this root is the unique optimum.
- With $\sigma_p = 0$ it is explicit: $X = \big(\nu PA/(r + \bar{p}\,\theta)\big)^{1/(1-\nu)}$.
- With $\sigma_p > 0$ the same equation is solved for X. Its derivative is negative:

$$\frac{dX}{d\sigma_p^2} = -\frac{\lambda\theta^2 X}{(1-\nu)(r + \bar{p}\,\theta)X^{-1} + (2-\nu)\lambda\theta^2\sigma_p^2}.$$

Back to Simple model

Appendix: Baumeister–Hamilton identification

The monthly system contains world oil-production growth q, OECD+6 industrial production y, real oil-price growth p, and 24 lags. Oil produced but not consumed is the true inventory change $\Delta i^\star$.

$$
\begin{aligned}
q_t &= \alpha_{qp} p_t + \text{lags} + u_t^s, \\
y_t &= \alpha_{yp} p_t + \text{lags} + u_t^y, \\
q_t &= \beta_{qy} y_t + \beta_{qp} p_t + \Delta i_t^\star + \text{lags} + u_t^d, \\
\Delta i_t^\star &= \psi_1 q_t + \psi_3 p_t + \text{lags} + u_t^i.
\end{aligned}
$$

- These are shocks to **supply**, **activity**, **consumption demand**, and **inventory demand**. A positive u^s raises current production. We use the posterior median of u^s.
- Observed OECD inventories are a noisy fraction of world stocks, $\Delta i_t = \chi \Delta i_t^\star + e_t$. Income affects inventories only through q and p.
- Priors are Student-t and truncated by sign, not a Cholesky zero. Modes: supply elasticity $\alpha_{qp} = 0.1 > 0$, demand elasticity $\beta_{qp} = -0.1 < 0$, income elasticity $\beta_{qy} = 0.7 > 0$.
- The posterior medians are a supply elasticity of 0.15 and a demand elasticity of -0.35.

▸ Back to oil-supply shock

Appendix: Regression behind Fact 1

Let S_t be the quarterly sum of monthly supply shocks, $S_t^+ = \max\{S_t, 0\}$, $S_t^- = \max\{-S_t, 0\}$, and $i_t = 100 \log I_t$. For each horizon h:

$$i_{t+h} - i_{t-1} = \alpha_h + \theta_h^+ S_t^+ + \theta_h^- S_t^- + \Gamma_h' Z_t + u_{t+h}.$$

- Z_t contains two lags of investment growth, GDP growth, real oil-price growth, inflation, the short rate, and both shock components, plus quarter indicators.
- Responses are scaled to the common median absolute shock, 1.43.
- Bands are pointwise 90% Newey–West intervals with $h + 1$ lags.

Back to Fact 1

Appendix: Regression behind Fact 2

For $K \in \{1, 3, 6, 12\}$ months, annualized future oil volatility is

$$F^V_{t,K} = \left(\frac{252}{N_{t,K}} \sum_{j=1}^{K} \sum_{d \in t+j} e_d^2 \right)^{1/2},$$

where e_d is the innovation from an AR(5) for daily real Brent returns. We estimate

$$F^V_{t,K} = \alpha_K + \beta_K |s_t| + \gamma_K F^V_{t-1,1} + u_{t,K}.$$

- s_t: monthly Baumeister–Hamilton oil-supply shock.
- Future windows exclude the shock month; the graph reports $5\widehat{\beta}_K$.
- Pointwise inference uses Newey–West standard errors with K lags.

Back to Fact 2

Appendix: Regression behind Fact 3 (France)

For energy-intensity group $g \in \{H, L\}$, let $i_t^g = 100 \log I_t^g$ and estimate

$$i_{t+h}^g - i_{t-1}^g = \alpha_h^g + \theta_h^{g,+} S_t^+ + \theta_h^{g,-} S_t^- + (\Gamma_h^g)' Z_t + u_{t+h}^g.$$

- Annual INSEE investment data; estimation sample 1978–2025, with horizons $h = 0, \ldots, 5$ years. Groups are fixed using 2015–2019 direct energy purchases relative to gross output: high intensity exceeds 5% (7 high- and 25 low-energy industries).
- Monthly supply shocks are summed within each year, then split: $S_t^+ = \max(S_t, 0)$ and $S_t^- = \max(-S_t, 0)$.
- Z_t Includes two annual lags of both groups' investment growth, GDP growth, real oil-price growth, CPI inflation, the short rate, and both shock components.

Back to Fact 3

Appendix: Different Horizons

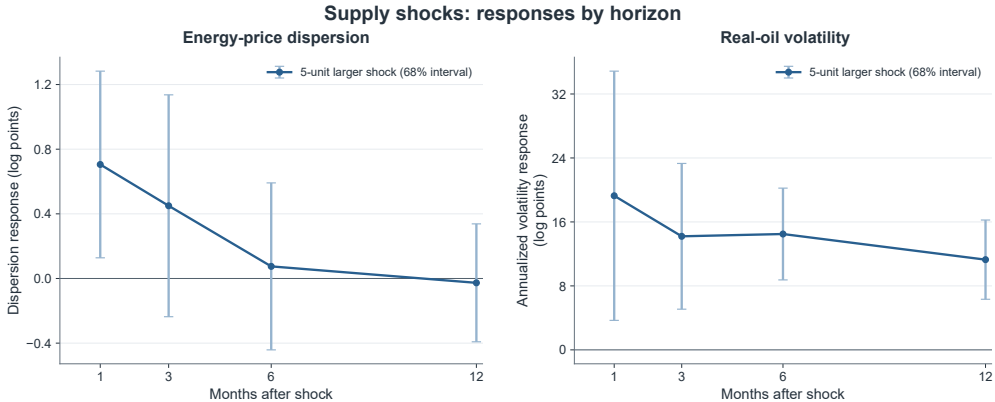


Figure 6: Supply-shock magnitude and EU10 energy-price dispersion.

A five-unit larger absolute supply shock raises EU10 energy-price dispersion, most strongly at short horizons.

▸ Back to Fact 2 ▸ Back to Dirspersion and Regions

Appendix: Both signs

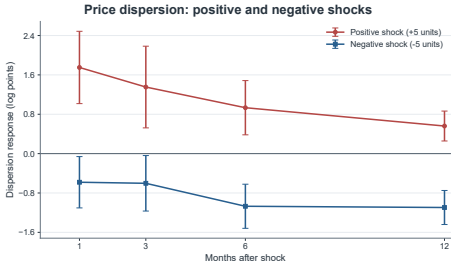


Figure 7: EU10 energy-price dispersion by shock sign.

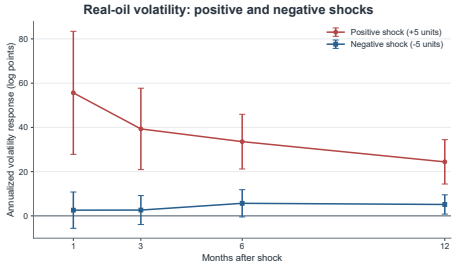


Figure 8: Real-oil volatility by shock sign.

Both signs raise subsequent price risk. Decreases raise volatility somewhat more.

Back to Fact 1

Appendix: Size nonlinearity

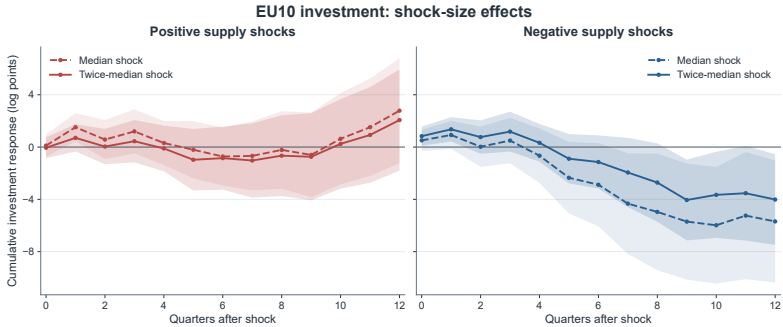


Figure 9: EU10 investment responses at the median and twice-median shock size.

EU10 investment at the median and twice-median shock magnitudes in a continuous threshold specification. The contraction after adverse shocks grows more than proportionally with size.

Back to EU investment

Appendix: Why regions

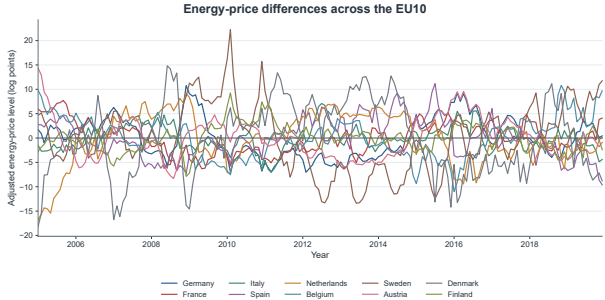
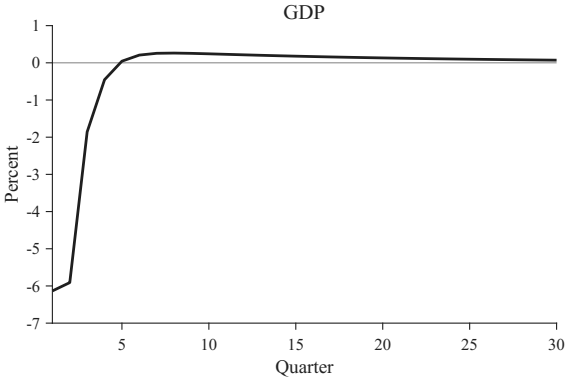


Figure 10: EU10 domestic energy-price residuals.

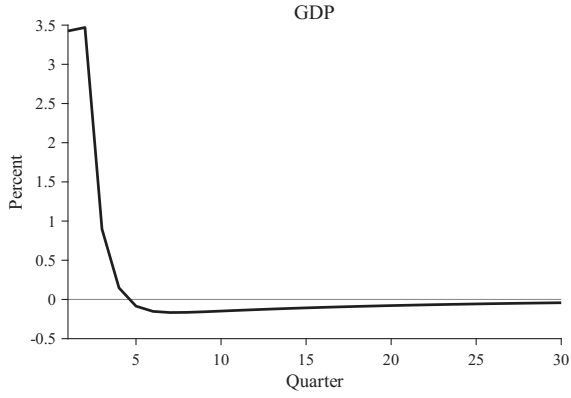
EU10 domestic energy-price residuals, 2005–2019, after country and month fixed effects and country-specific trends. Common oil events move all countries, but large country-specific residuals remain. That residual is the empirical counterpart of the regional oil-price draw ν_j.

Back to Oil prices and regions

Appendix: Direct GDP responses to joint shocks



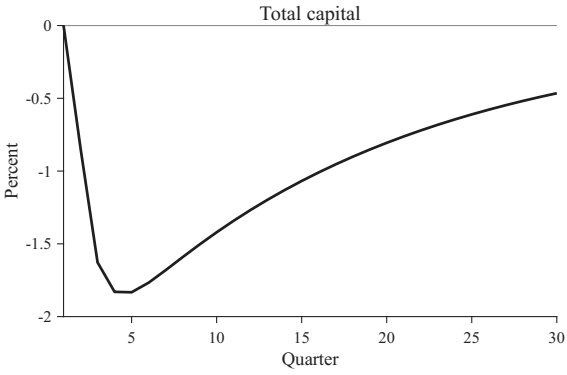
Price increase + dispersion



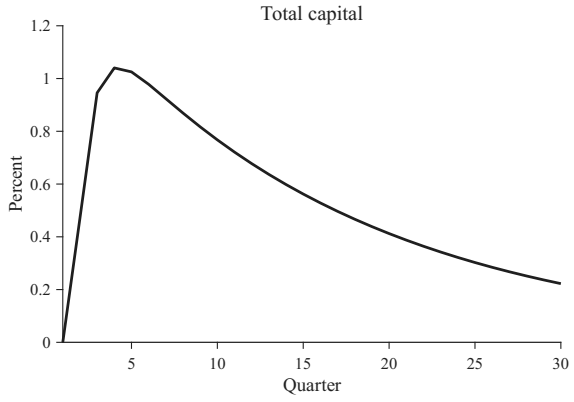
Price decline + dispersion

▸ Back to joint-shock asymmetry

Appendix: Direct capital responses to joint shocks



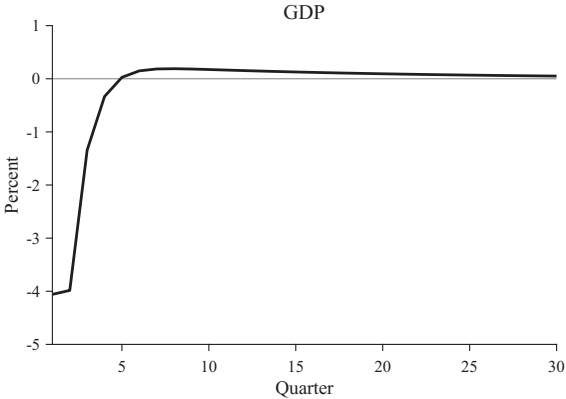
Price increase + dispersion



Price decline + dispersion

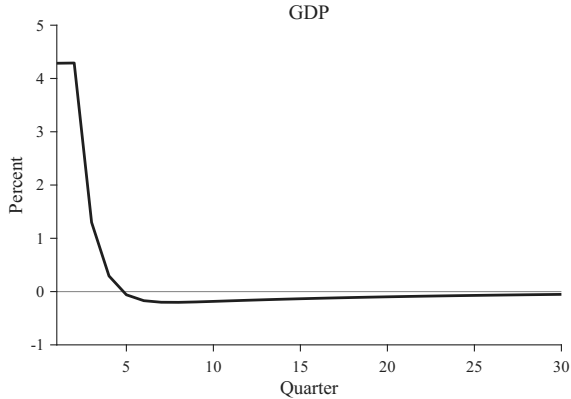
Back to joint-shock asymmetry

Appendix: Direct GDP responses to price shocks



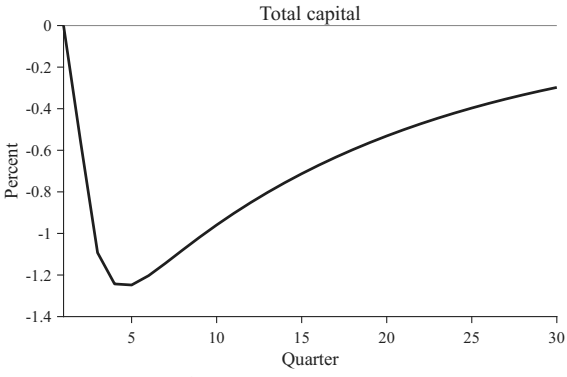
Oil-price increase

▸ Back to price-only asymmetry



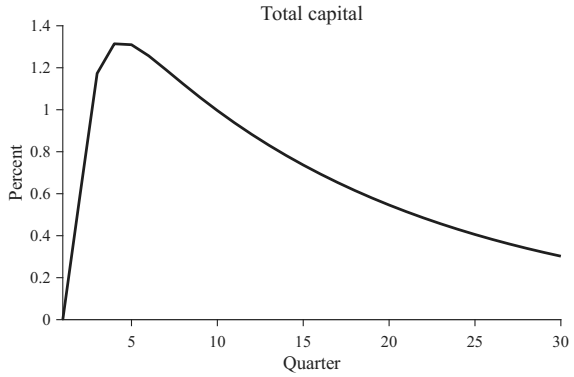
Oil-price decline

Appendix: Direct capital responses to price shocks



Oil-price increase

▸ Back to price-only asymmetry



Oil-price decline

Appendix: Positive and negative price paths

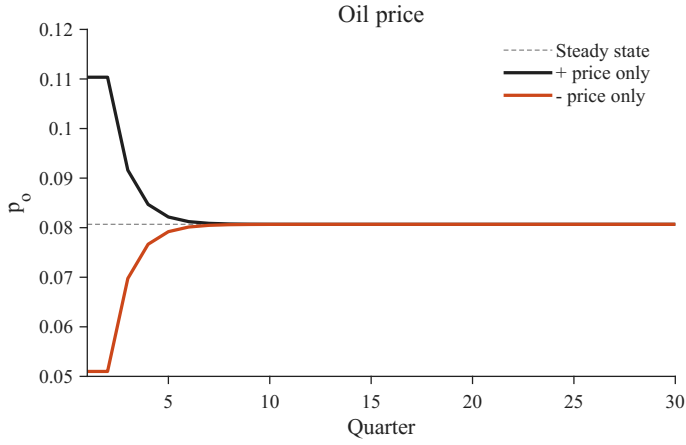


Figure 11: Price paths for the comparison without a dispersion shock.

▸ Back to Source of asymmetry

Dispersion in a simple two sector model

- The oil intensities are 0.175 and 0.025.
- Their average is the one-firm intensity, 0.10.
- Equal CES weights and elasticity 0.75 mix the two goods.
- The final-good price is 1, and each firm takes its own sectoral price as given.

Percent change	High energy	Low energy	Aggregate
Output	−32.2%	−25.0%	−29.1%
Capital	−42.6%	−33.7%	−36.2%

Table 6: Changes of a simple two sector model. Aggregate capital is the sum of the two stocks.

The gap in responses is modest

Oil per unit of capital is **seven times larger** in the high-energy sector. The output declines differ by 7.2 percentage points, and the capital declines by 8.9.

▸ Back to Dispersion in main model

Appendix: Pure dispersion-shock path

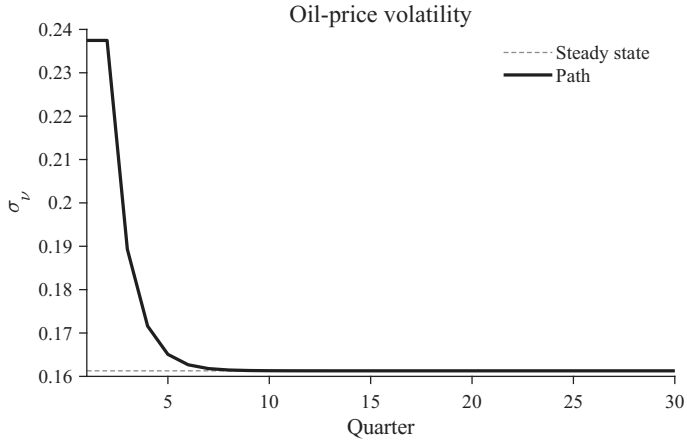
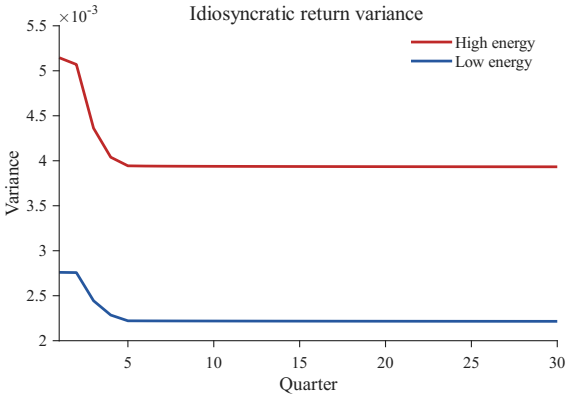


Figure 12: Dispersion path with the mean oil price held fixed.

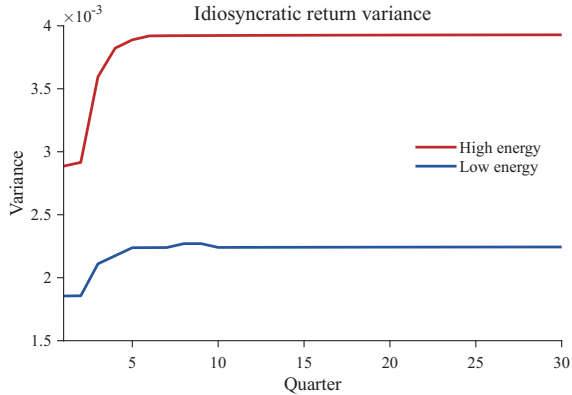
▸ Back to Dispersion effect

Appendix: Sectoral return variance after price shocks

Idiosyncratic return variance is reported separately for each sector.



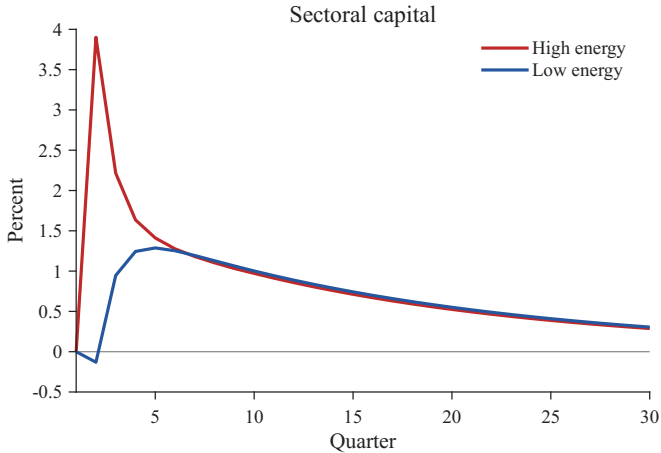
Oil-price increase



Oil-price decline

▸ Back to price-shock returns ▸ Back to price-shock liquidation

Sectoral response of an only negative price shock

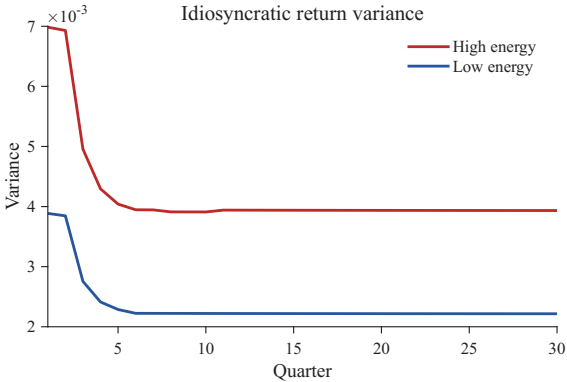


Sectoral capital response

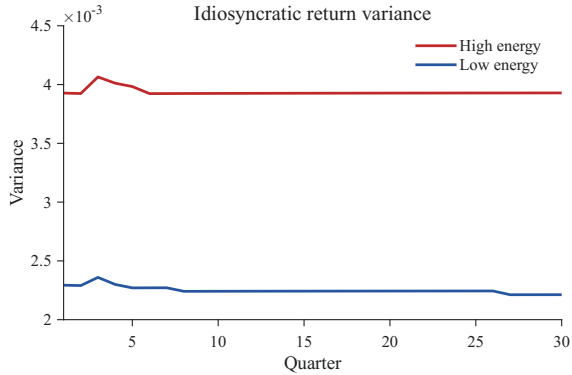
Back to Fact 3

Appendix: Sectoral return variance after joint shocks

Idiosyncratic return variance is reported separately for each sector.



Price increase + dispersion



Price decline + dispersion

▸ Back to joint-shock returns

▸ Back to joint-shock liquidation

Appendix: firm first-order conditions

Let $\varrho_f = (\rho_f - 1)/\rho_f$ and $Y_{js}^g = Z_{js}^{1/\varrho_f}$. Then

$$\frac{\partial Y_{js}^g}{\partial O_{js}} = (1-\phi_s)\alpha_{0,s}(Y_{js}^g)^{1/\rho_f} O_{js}^{-1/\rho_f}, \qquad \frac{\partial Y_{js}^g}{\partial T_s} = \phi_s(Y_{js}^g)^{1/\rho_f} T_s^{-1/\rho_f}.$$

Liquidation wedges μ_A (revenue) and μ_B (obligations) enter expected FOCs. For land,

$$\mathbb{E}_j\left[(1+\mu_{A,js})p_{js}\frac{\partial Y_{js}^g}{\partial T_s} - (1+\mu_{B,js})q_T\right] = 0.$$

With $\zeta_{js}^* = D_{js}/(p_{js}Y_{js}^g)$,

$$\mu_{B,js} = \frac{C_{\text{liq}}(1-\delta)K_s f_\zeta(\zeta_{js}^*)}{p_{js}Y_{js}^g}, \qquad \mu_{A,js} = \zeta_{js}^*\mu_{B,js}.$$

Back to Firm problem

Appendix: household details

Period utility

$$u(C, n) = \frac{C^{1-\sigma}}{1-\sigma} - \frac{n^{1+\gamma}}{1+\gamma},$$

with CES C over normal consumption and household oil. Budget

$$x + \left[1 + \kappa_d d^2 + \kappa_s d^2 (\theta - \theta_e^0)^2\right] W = a + w_j z n + \tau_T.$$

d is the diversified share; θ is the sectoral tilt inside that account. Next period's wealth is the return on the concentrated familiar firm and the diversified sectoral claims. Interior θ equalizes marginal-utility-weighted sectoral returns, net of the familiarity cost.

Back to Household problem

Appendix: Why sectoral exposure?

Empirical motivation

- Familiarity predicts concentrated investment in nearby and better-known assets (Huberman, 2001).
- Employer-stock holdings link labor income and financial wealth to the same firm or sector (Benartzi, 2001).
- Information advantages can generate persistent portfolio home bias (Van Nieuwerburgh and Veldkamp, 2009).

Modeling implication

- Employment sector e determines the household's familiar individual-firm position.
- Diversification d removes idiosyncratic firm risk only at a cost; the sectoral tilt θ is also costly away from the familiar sector.
- Consequently, firm-level downside risk affects required returns and aggregate capital supply rather than being diversified away.

Huberman (2001); Benartzi (2001); Van Nieuwerburgh and Veldkamp (2009); Bhamra and Uppal (2019). Back to Household problem

Appendix: EU employment and output shares

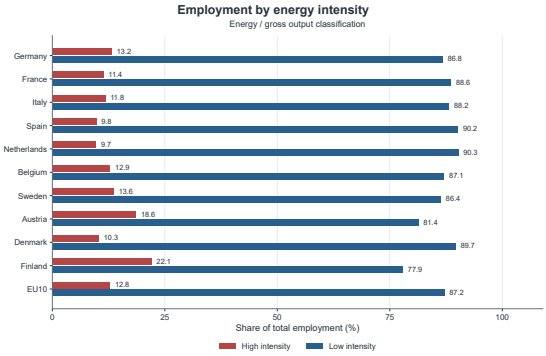


Figure 13: EU employment shares by energy-intensity group.

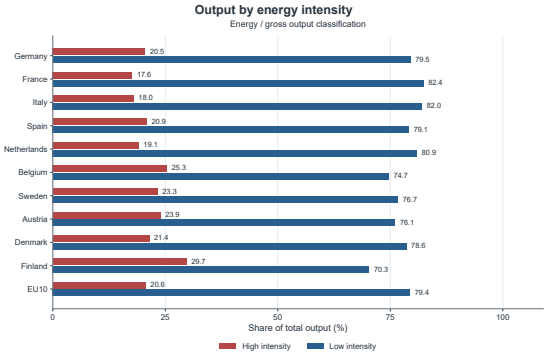


Figure 14: EU gross-output shares by energy-intensity group.

High-energy employment is targeted at 0.175. The final-good weight $\omega = 0.20$ is the high-energy share in the 2015–2019 EU industry classification (energy purchases relative to gross output).

▸ Back to Calibration

Appendix: why an almost-nonlinear method?

Sequence-space / local linear

- Fast.
- Linearize around steady state.
- Misses liquidation, portfolio corners, and sign/size dependence.

Full nonlinear MIT

- Keeps global nonlinearities.
- Repeated full-horizon solves.
- Slow in this HANC.

Compromise

Nonlinear policies conditional on beliefs, plus local on-impact derivatives only for small within-period clearing corrections.

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Appendix: level-k fixed point

Let B^k be belief paths, $\mathcal{S}$ the nonlinear policy operator, and $\mathcal{C}$ forward clearing.

$$P^k = \mathcal{S}(B^{k-1}), \qquad X^k = \mathcal{C}(P^k, B^{k-1}), \qquad B^k = \mathcal{M}(B^{k-1}, X^k).$$

- Level 0: steady-state paths plus the announced oil/volatility path.
- Each later level re-solves household and firm policies backward, then distributions and markets forward.
- Convergence: $B^\star = X^\star$.

A first-order transition would suppress the dependence of liquidation, portfolio corners, and risk-adjusted investment on the sign and size of the shock.

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Appendix: what is exact and what is local

- Anticipated household and firm policies remain nonlinear.
- On-impact response banks correct only small contemporaneous market-clearing gaps.
- If return-induced wealth revaluation is large, the distribution transition is rebuilt from realized returns.

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