Inflation in Supply Chains: An Empirical Test of Production Network Models

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Introduction

- The COVID pandemic and high inflation have revived interest in assessing how input price increases propagate through supply chains.
- There has recently been a profusion of network modeling in Macro.
  - Network models predict how this passthrough should occur.
- But these models haven’t been subject to rigorous empirical testing.
- In our paper, we
  - Report findings on the speed and extent of price passthrough in supply chains
  - Discuss important dimensions of industry heterogeneity in passthrough
  - Provide a Calvo New Keynesian Model able to generate these facts.
  - Develop a new measure of core inflation fully stripping out the network effects of energy/food price movements.
Outline

1. Introduction & Literature
2. Empirical Strategy & Results
3. Results from Imperfectly-Flexible New Keynesian Model
4. Applications & Implications
5. Conclusion
Related Literature

- Seminal papers on production networks

- Industry shocks can have meaningful aggregate fluctuations

- Broader literature on production networks
Related Literature

- Empirical literature

- Closest related paper: Auer, Levchenko, and Saure (2019) [propagation of price movements across international borders]
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Data

- **BEA I/O Tables:** Every 5 years since 1967, the BEA has released 400-500 industry input-output tables of the US economy.
  - These represent interdependencies between industries.
  - The extent to which the output of industry $i$ is used as an input in industry $j$.

- **BLS PPI Series:** The BLS publishes monthly data on industry prices at a very granular level.
  - Beginning in the 1940s – few industries covered at first.
  - Coverage increases greatly over the course of the 1960s/70s.
Basic Idea

- Consider oil as an example.
- Oil is used throughout the economy – but mostly not directly.
  - Oil refineries directly purchase crude oil.
  - Petrochemical manufacturers purchase refined oil from refineries.
  - Plastic/foam producers purchase from petrochemical manufacturers.
  - Furniture manufacturers purchase from plastic/foam producers.
  - Etc.
- BEA input-output tables allow us to compute each industry’s total network cost share – direct and indirect – in oil.
  - If 20% of your costs are in crude oil and 30% are in a sector with a 50% crude oil share, then your network share is 35% ($= 20\% + 50\% \times 30\%$).
  - 20% in “first-order” exposure, 15% in “second-order” exposure.
Industries with Top Network Oil Exposures
Industries with Top 3rd-order Oil Exposures
Regression Approach: Case Studies

- We utilize the following regression specification:
  \[ \sum_{j=0}^{t} \Delta p_{i,j} = \lambda_t + \beta_t \text{NetworkShare}_{Z,i} + \epsilon_{i,t} \]

- Full passthrough would correspond to \( \beta_t = \Sigma \Delta p_{Z,j} \), where \( Z \) denotes the commodity of interest.
  - I.e., if there is a 1 log-point increase in the price of oil over some period, this should induce a \( \text{NetworkShare}_{Z,i} \) log-point increase in industry \( i \)'s prices.

- It is also possible to split network share into first-order and indirect:
  \[ \sum_{j=0}^{t} \Delta p_{i,j} = \lambda_t + \gamma_t \text{DirectShare}_{Z,i} + \theta_t \text{IndirectShare}_{Z,i} + \epsilon_{i,t} \]
Case Study: 1979 Oil Crisis
Case Study: 2014-15 Oil Shale Boom
Regression Approach

- The above specifications are well-suited for case studies. A more versatile approach not requiring an index period is

\[
\Delta p_{i,t} = \lambda_t + \sum_{j=-6}^{12} \beta_j \text{NetworkShare}_i \Delta p_{Z,j} + \epsilon_{i,t}
\]

- Here, \( \Sigma \beta = 1 \) corresponds to full passthrough.

- Here, too, it is possible to decompose the network share into direct (first-order) and indirect (residual network) shares.

- We also run a version of this specification where we instrument the oil price change with Kanzig’s (2021) series of exogenous OPEC shocks.
What’s in the Error Term?

- The industry wage, rental rate of capital, and TFP will be in the error term.
  - So, we should be concerned if any of these variables are correlated with the oil cost shock.
  - Note that the time FEs capture aggregate inflation, effects of monetary policy, changes in aggregate expected TFP, aggregate markup expectations, etc.

- The industry wage can be measured directly. Adding this to our regressions induces virtually no change in the results.

- Furthermore, we use the more exogenous Kanzig series of OPEC shocks to deal with worries about correlation with the other variables.
Monthly Passthrough – All Oil Price Variation
Monthly Passthrough – All Oil Price Variation
Monthly Passthrough – Kanzig Variation
Cumulated Passthrough Coefficients
Passthrough – Oil and All Other Commodities

![Graph showing pass-through for oil and non-oil commodities over time. The x-axis represents time, with negative and positive values, and the y-axis represents pass-through percentage. The graph includes data points for oil (red dots) and non-oil commodities (teal dots) with error bars indicating variability. The graph shows a significant drop in pass-through at around zero time, with a recovery period followed by stabilization.]
We have performed heterogeneity analysis on a variety of variables.
- Market concentration, average inventory size, average firm size, shock size, and frequency of price adjustment.

We only find evidence of any heterogeneity on the last of these.

Specifically, we use data from Pasten, Schoenle, and Weber (2017) on average frequency of price adjustment by industry.
- The authors computed these measures using restricted BLS micro data.
- Number of monthly price changes per good divided by the number of months the good is in the sample – aggregated to the industry level.

Same data we will use to calibrate the imperfectly-flexible model.
Heterogeneity: Frequency of Price Adjustment

Baseline, Below-Median Price Rigidity

Baseline, Above-Median Price Rigidity

IV, Below-Median Price Rigidity

IV, Above-Median Price Rigidity

Cumulated Coefficients, 1-Year Horizon
Heterogeneity: Size of Shock
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Model Results by Industry

Log Price Increase from a 1 Log Point Oil Price Increase for top 3% price response industries

Industry Description
- Air transportation
- Asphalt paving mixture and block manufacturing
- Asphalt shingle and coating materials manufacturing
- Carbon and graphite product manufacturing
- Electric power generation, transmission, and distribution
- Natural gas distribution
- Other basic organic chemical manufacturing
- Other petroleum and coal products manufacturing
- Petrochemical manufacturing
- Petroleum refineries
- Plastics material and resin manufacturing
- Synthetic rubber and artificial and synthetic fibers and filaments manufacturing

Price Change
Month from shock
Regression Approach

- We test whether these model IRFs hold up in the data:

\[ \Delta p_{i,t} = \lambda_t + \sum_{j=0}^{K} \beta_j \frac{\partial \Delta P_{i,t}}{\partial \Delta P_{oil,t-j}} + \epsilon_{i,t} \]

- \( \beta_j = 1 \) for all \( j \) if the model’s predictions hold true.
  - As before, note that time FEAs capture aggregate inflation, effects of MP, changes in aggregate expected TFP, aggregate markup expectations, etc.
Empirical Fit – NK Model

All Oil Variation

Kanzig Variation
What if we add the assumption that firms are not forward-looking?
- They believe the optimal reset price tomorrow will be the same as the optimal reset price today.
- Unlike the preceding model, they do not account for expected future cost changes.
- Unlike a fully-flexible price approach, not every firm gets to reset prices in every period (frequency of price adjustment still matters).

Does this function equally well to the preceding full, rational-expectations NK model?
Empirical Fit – Are Firms Forward-Looking?

All Oil Variation

Kanzig Variation

Fit Estimate (Null = 1)

Myopic Pricing
Pass-through in Data Relative to Model for Shocks Realizing 0-2 Periods Earlier

Rational Expectations Gap
Pass-through in Data Relative to Model for Shocks Realizing 0-2 Periods Earlier
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Forward Guidance

- Firms do appear to be forward-looking.
  - If they foresee being hit by a cost shock in the future, they will adjust their prices accordingly.

- The fact that passthrough of indirect cost shocks is slower than direct shocks is partially because more downstream firms tend to have lower frequency of price adjustment.
  - Not just that they’re further downstream and shocks take time to filter through the supply chain.

- Suggests forward guidance may have bite in the goods market.
A New Measure of Core PCE

- The official measure of Core PCE Inflation excludes a few categories from total PCE Inflation.
  - “Food and beverages purchased for off-premises consumption”, “Gasoline and other energy goods”, and “Electricity and gas utilities”

- But, as we’ve shown throughout this talk – this leaves oil (and other commodities) entangled throughout the production network.
  - The influence of price movements of oil and other commodities is still (partially) present in Core PCE inflation.

- We can compute network oil (and network commodity) inflation to fully remove these influences and develop new measures of Core PCE
# Predictability of Core PCE with Network Oil Inflation

<table>
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<th>Dependent Variable: Core PCE Inflation</th>
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<th>(2)</th>
<th>(3)</th>
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<tbody>
<tr>
<td></td>
<td>All Variation</td>
<td>Kanzig Variation</td>
<td>All Variation</td>
<td>Kanzig Variation</td>
</tr>
<tr>
<td>Total Network Oil Inflation</td>
<td>0.232***</td>
<td>0.119***</td>
<td>0.232***</td>
<td>0.119***</td>
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<tr>
<td></td>
<td>(0.058)</td>
<td>(0.040)</td>
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<td>Direct Oil Inflation</td>
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<td></td>
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<td></td>
<td>(0.077)</td>
<td>(0.050)</td>
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<tr>
<td>Indirect Oil Inflation</td>
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<td>0.208**</td>
<td>0.221***</td>
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<td>R-Squared</td>
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<td>0.0711</td>
<td>0.1133</td>
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<td>Observations</td>
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<td>300</td>
<td>300</td>
<td>300</td>
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</tbody>
</table>
PCE Inflation minus Network Oil

Contribution of Oil Prices to Inflation

Industry panel changes in 1963 and 1997 are designated by vertical lines. Bars denote Paasche and Laspeyres bands. Error bars in 2021 are creating using the 2019 IO table as a stand-in for 2021 because the 2021 IO table is not yet published.
PCE Inflation minus Network Commodities

Industry panel changes in 1963 and 1997 are designated by vertical lines. Bars denote Paasche and Laspeyres bands. Error bars in 2021 are created using the 2019 IO table as a stand-in for 2021 because the 2021 IO table is not yet published.
Quarterly Version

Contribution of Commodity Prices to Inflation

Bars denote Paasche and Laspeyres bands.
Error bars in 2021 are created using the 2019 IO table as a stand-in for 2021 because the 2021 IO table is not yet published.
Conclusion

- Passthrough of commodity shocks throughout the network is gradual – occurring over six months – but full.
  - This result appears quite general.
  - True for specific large oil shocks, for Kanzig’s (2021) series of OPEC-driven oil price variation, for all oil price variation, and for all commodity price variation.

- Evidence of heterogeneity on frequency of price adjustment.
  - Only heterogeneity we’ve found (so far) that appears to matter.

- We create an imperfectly-flexible NK model calibrated with frequency of price adjustment, which approximates the data well, allowing for prediction of the effects of future commodity shocks.

- We develop a new core PCE that fully strips out commodity inflation.
Thank You!