FROM MICRO TO MACRO: THE INFLUENCE OF FIRM HETEROGENEITY ON FOREIGN SHOCK TRANSMISSION

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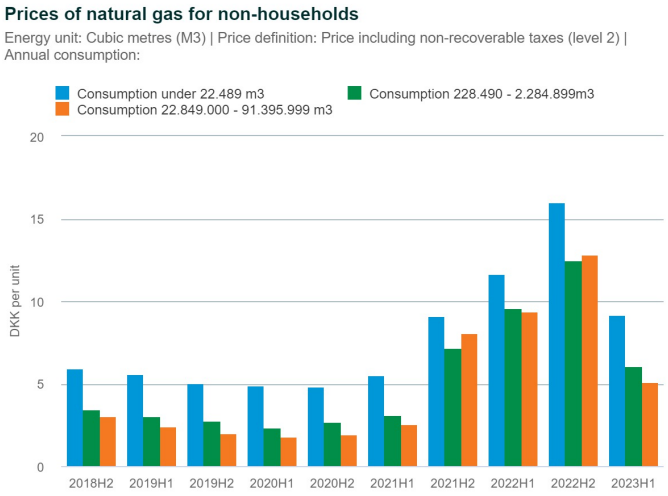
DREAM, February 2024

SPIKE IN NATURAL GAS PRISES IN DENMARK



Source: Statistics Denmark.

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- **When heterogeneity matters by and large unknown**

- **Question: How does firm heterogeneity affect the transmission of foreign supply shocks?**
  - When can the economy be represented using a representative firm?

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  - Building on prominent work on the importance of sectoral heterogeneity (**baqaee2019networks**; Baqaee and Farhi 2019)

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- **NK model of a small open economy**
  - **Novel:** sector **and** firm heterogeneity
  - 44 sectors calibrated to match Danish IO-tables
  - Continuum of heterogeneous firms in each sector calibrated to match firm-level data

RESULTS

- **Analytical results**
  - In frictionless benchmark heterogeneity **does not matter** for output/inflation response to supply shock
  - With labor adjustment costs heterogeneity **amplifies** output/inflation responses,
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- **General equilibrium**
  - GE CPI response to foreign supply shock **nearly doubles** with firm heterogeneity
  - Larger output response, dampened GDP and employment responses

RELATED LITERATURE AND CONTRIBUTIONS

- **Importance of firm heterogeneity**
  - Firm heterogeneity in GE (Di Giovanni, Levchenko, and Mejean 2024)
    - **Adjustment costs, improved identification, dynamic NK model**

- **Propagation of shocks through production networks**
  - Acemoglu et al. (2012), Acemoglu, Akcigit, and Kerr (2016), Atalay (2017), Carvalho and Tahbaz-Salehi (2019), Huo, Levchenko, and Pandalai-Nayar (2023), Antràs and Chor (2022), and Bonadio et al. (2023)
    - **Role of firm heterogeneity for IO propagation**

- **Empirical contributions**
  - Natural disasters (**meier2020covid**; **lafrogne2022supply**; Boehm, Flaaen, and Pandalai-Nayar 2019; Carvalho et al. 2021)
  - Shift share (Huneeus 2018; Huneeus, Kroft, and Lim 2021; Dhyne et al. 2021; Dhyne et al. 2022)
    - **We investigate supply shocks and heterogeneous dynamic responses**

ROADMAP

- Analytical Exposition
- Estimate effect of foreign supply shock on Danish firms
- Partial equilibrium model
- General equilibrium model

STYLIZED MODEL

STYLIZED MODEL

- Consider first a simple static model to show when firm **heterogeneity** matters for aggregate responses to foreign supply shock and when it does not
- Partial equilibrium only for now (take aggregate demand, prices of other firms and wages as constant)
- Generalise to larger, dynamic model and general equilibrium later

STYLIZED MODEL

- Continuum of firms indexed by i. Firm i has production technology:

$$z_i = \left[\alpha_i^{\frac{1}{\phi}} m_i^{\frac{\phi-1}{\phi}} + (1-\alpha_i)^{\frac{1}{\phi}} \ell_i^{\frac{\phi-1}{\phi}} \right]^{\frac{\phi}{\phi-1}}$$

$$m_i = \left[\gamma_i^{\frac{1}{\vartheta}} \left(m_i^F \right)^{\frac{\vartheta-1}{\vartheta}} + (1-\gamma_i)^{\frac{1}{\vartheta}} \left(m_i^D \right)^{\frac{\vartheta-1}{\vartheta}} \right]^{\frac{\vartheta}{\vartheta-1}}$$

- With permanent heterogeneity in **firm size** z_i, **labor/materials** α_i and **imports** γ_i

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- With permanent heterogeneity in **firm size** z_i, **labor/materials** α_i and **imports** γ_i
- Firms face adjustment cost when adjusting labor:

$$\frac{\omega}{2} \left(\frac{\ell_i}{\bar{\ell}_i} - 1 \right)^2 \bar{\ell}_i$$

- and face CES demand curve $z_i = \varrho_i \left(p_i / P \right)^{-\epsilon^P} Z$

AGGREGATE RESPONSES TO FOREIGN SHOCK

- We consider a positive shock to import prices $dP^{M,F} > 0$ (adverse supply shock)
- Interested in response of aggregate output and prices $dZ = \int dz_i \, \mathrm{d}i, dP = \int dp_i \, \mathrm{d}i$

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- Interested in response of aggregate output and prices $dZ = \int dz_i \, \mathrm{d}i, dP = \int dp_i \, \mathrm{d}i$
- Compare response of model with heterogeneity (**HA**) in firm size and use of materials/labor/imports ($\mathbb{V}\mathrm{ar}(z_i) > 0, \mathbb{V}\mathrm{ar}(\alpha_i) > 0, \mathbb{V}\mathrm{ar}(\gamma_i) > 0$)
- ... with standard representative firm model (**RA**) that matches same aggregate allocation

AGGREGATE RESPONSES TO FOREIGN SHOCK - EQUIVALENCE

- **Result 1**: Assume arbitrary heterogeneity in firm size (z_i), material use (α_i) and imports (γ_i). If the adjustment cost on labor is zero, $\omega = 0$, then heterogeneity is irrelevant for the response of aggregate output and prices:

$$dZ^{HA} = dZ^{RA}$$
$$dP^{HA} = dP^{RA}$$

- Not too surprising given constant returns to scale + no frictions

HA-RA EQUIVALENCE

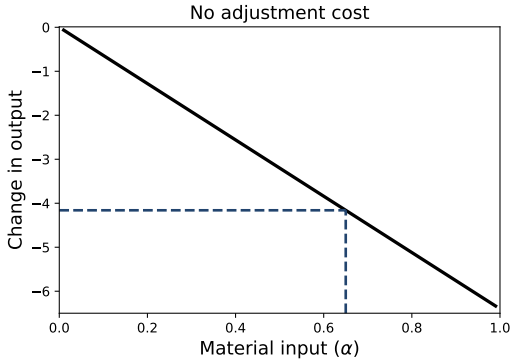
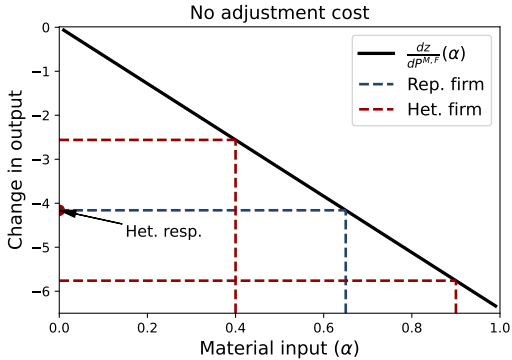


Figure: Output response by material intensiveness

HA-RA EQUIVALENCE



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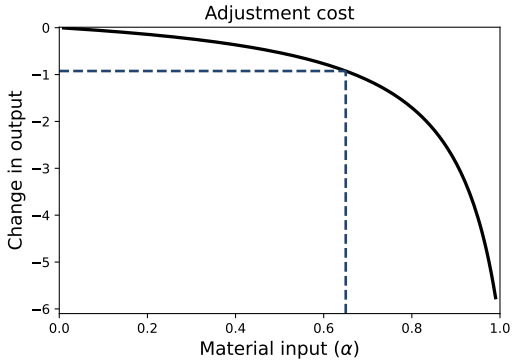
HETEROGENEITY AND AMPLIFICATION

- Consider now the role of adjustment costs, $\omega > 0$.
- **Result 2**: With positive adjustment costs, heterogeneity affects the response of aggregate production and prices. In particular:

$$
\begin{aligned}
dZ \propto & -\overline{\alpha}\overline{\gamma}\overline{z}dP^{M,F} \\
& - \frac{\overline{z}\overline{\gamma}\omega\left(\epsilon^P-\phi\right)\overline{\psi}+\overline{\alpha}\overline{z}\overline{\gamma}\omega^2\left(\epsilon^P-\phi\right)^2}{\overline{\psi}^2}\mathbb{V}\mathbf{ar}\left(\alpha_i\right)dP^{M,F} \\
& - \frac{\overline{\gamma}\overline{\psi}+\overline{\alpha}\overline{\gamma}\omega\left(\epsilon^P-\phi\right)}{\overline{\psi}}\mathbb{C}\mathbf{ov}\left(\alpha_i,z_i\right)dP^{M,F}
\end{aligned}
$$

- $\Rightarrow$ Heterogeneity ($\mathbb{V}\text{ar}\left(\alpha_i\right)>0, \mathbb{C}\text{ov}\left(\alpha_i,z_i\right)>0$) amplifies the response of output/ and prices.

ADJUSTMENT COSTS AND AMPLIFICATION



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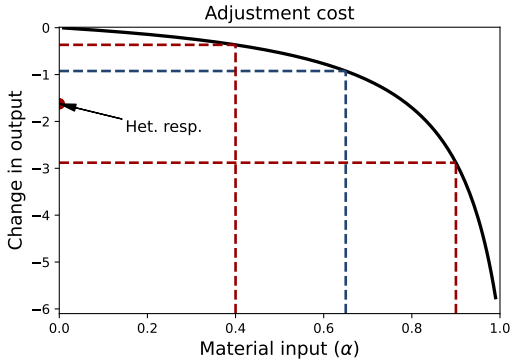

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LABOR AND VALUE-ADDED

- Heterogeneity **amplifies** output and price responses
- What about labor/Value-added?
- Opposing effects:
  - With heterogeneity the general responses get amplified (stronger response of L, VA)
  - But the firms that respond the most (i.e. high α) also rely less on labor (weaker response of L, VA)

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  - But the firms that respond the most (i.e. high α) also rely less on labor (weaker response of L, VA)
- Total effect of heterogeneity is ambiguous, but in the quantitative model we find a **dampening** effect (Di Giovanni, Levchenko, and Mejean (2024))

EMPIRICAL RESULTS

STYLIZED FACTS

- **Two key insights from stylized model**
  - Heterogeneity and no adjustment costs: Rep. and het. firm models **coincide**
  - Heterogeneity and adjustment costs: $\rightarrow$ **Amplification** in het firm model
    - Large firms rely on more easily adjustable inputs
    - Variance in material shares in itself sufficient to generate amplification

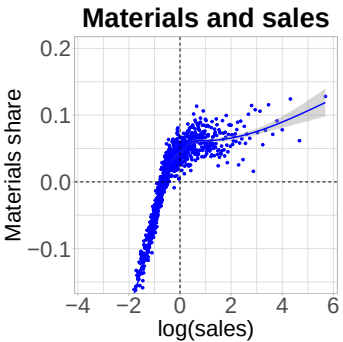
- **Requires three facts to hold true in Danish data**
  1. Within a sector, firms are heterogeneous
  2. Large firms respond more to foreign shocks
  3. Labor more costly to adjust than materials

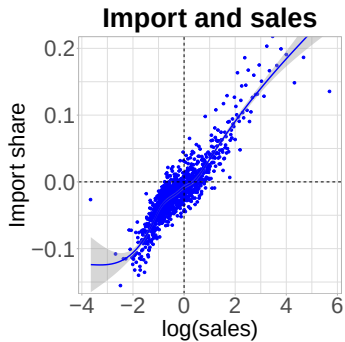
DATA

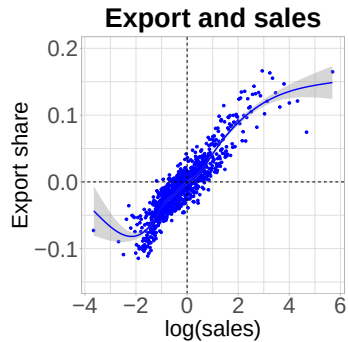
- **Danish firm-level data**
  - Private sector firms, time period 1999-2017
  - Restrict to at least five employees and positive sales (97,000 firms in total)
  - **Key:** Data include total firm-level goods *and* service trade $\rightarrow$ all sectors trade in our model
    - **Caveat:** Need country and product variation to construct instrument $\rightarrow$ estimations based on goods trade only

- **Danish sector-level data**
  - Firms divided into 44 sectors in total
  - Sector aggregates and IO-network obtained from IO-tables
    - Model consistent with national accounts

FACT 1: LARGE FIRMS MORE MATERIALS-, IMPORT-, AND EXPORT-INTENSIVE







ESTIMATION FRAMEWORK

- **Estimate the dynamic effect on several firm-level variables,** $\ln Y_{i,s,t+h}$

$$\ln Y_{i,s,t+h} = -\beta_S^h \ln S_{i,s,t}^{shock} - \beta_{S,het}^h \omega_{i,s,t-1} \ln S_{i,s,t}^{shock} + \lambda_D^h \ln D_{i,s,t}^{shock} + \kappa^h X_{i,s,t-1} + \eta_{i,s,t+h}$$

$$\eta_{i,s,t+h} = \delta_i^h + \delta_s^h \times \delta_t^h + \varepsilon_{i,s,t+h}$$

- $\beta_S^h, \beta_{S,het}^h$: **Average** and **heterogeneous** response to *negative* foreign supply shock
  - $\omega_{i,s,t-1}$: log-firm size relative to average
  - Scaled to deliver 10% increase in import prices
- $\ln S_{i,s,t}^{shock}$: Shift-share instrument as an exogenous shock to foreign supply Shift-share design
- $\delta_s^h \times \delta_t^h$: Sector-time fixed effects to control for GE effects $\rightarrow$ **PE response**

FACT 2: LARGE FIRMS MORE RESPONSIVE TO FOREIGN SHOCKS

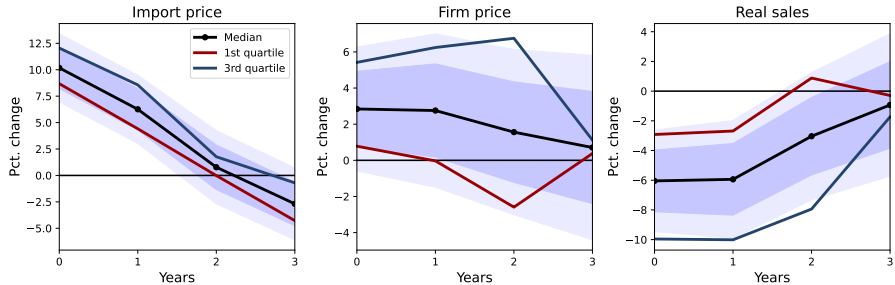
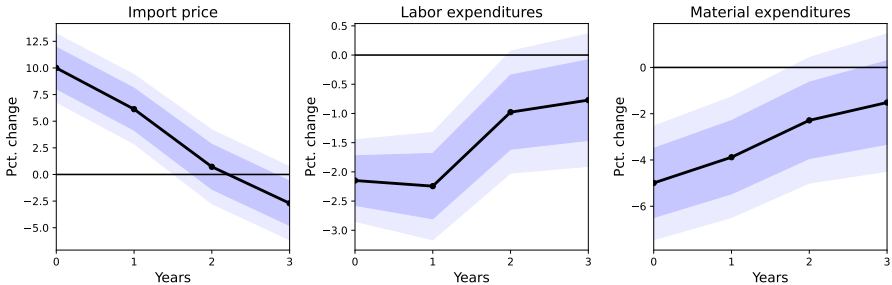


Figure: Heterogeneous Impulse-Responses to Negative Foreign Supply Shock

FACT 3: EVIDENCE ON SLUGGISH LABOR RESPONSE



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PARTIAL EQUILIBRIUM MODEL

HETEROGENEOUS FIRM MODEL

- Heterogeneous firm model as before **plus**:
  - Heterogeneity in sales destination (exports/no exports)
  - Domestic production network (firms in sector *i* source materials from all other domestic sectors)

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- Calibrate het. in firm-level material/labor shares, import shares, export shares, and firm size to dispersion and correlations with firm size in Danish data **for each sector**

Table: Example of targeted moments

Firm Size z_i	**Material Share** α_i	**Import Share** γ_i	**Export Share** ξ_i
$\mathbb{E}\, z_i$	$\mathbb{E}\, \alpha_i$	$\mathbb{E}\, \gamma_i$	$\mathbb{E}\, \xi_i$
$\mathbb{V}\mathrm{ar}(z_i)$	$\mathbb{V}\mathrm{ar}(\alpha_i)$	$\mathbb{V}\mathrm{ar}(\gamma_i)$	$\mathbb{V}\mathrm{ar}(\xi_i)$
$\mathrm{Skew}(z_i)$	$\mathbb{C}\mathrm{ov}(\alpha_i, \ln z_i)$	$\mathbb{C}\mathrm{ov}(\gamma_i, \ln z_i)$	$\mathbb{C}\mathrm{ov}(\xi_i, \ln z_i)$

IRF MATCHING

- Estimate relatively high labor adjustment cost ($\phi^L \approx 10$, and standard demand elasticity $\epsilon^P = 9.6$). Adjustment cost on materials estimated to be 0

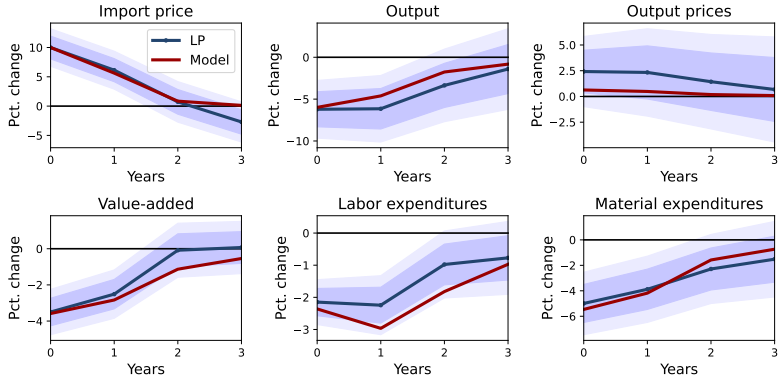


Figure: Impulse Responses to a Supply Shock vs. Model Fit

FIT OF HETEROGENEOUS RESPONSES

- Model also fits responses across firm size distribution even without explicitly targeting those moments

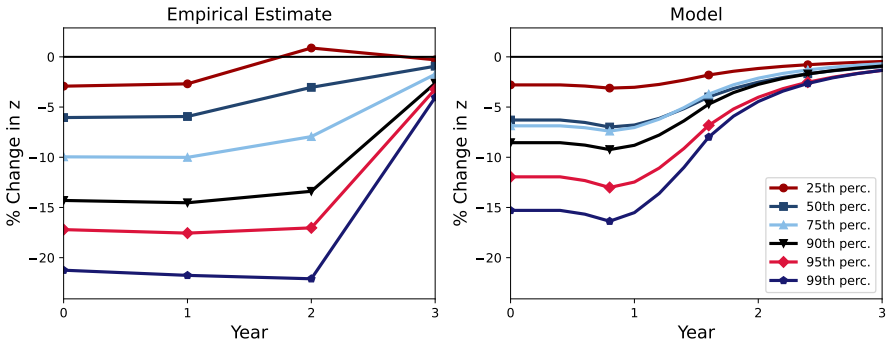
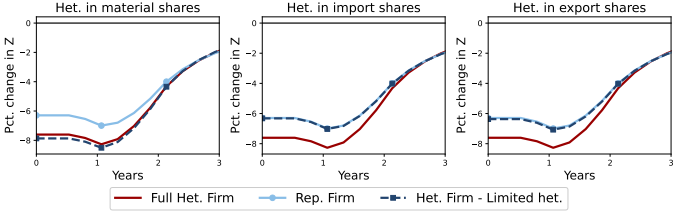


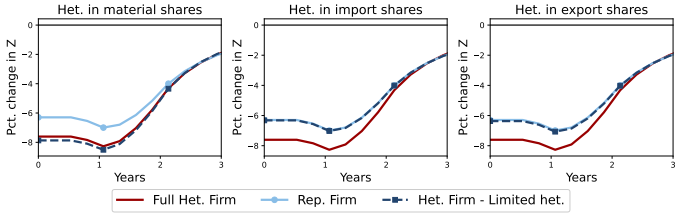
Figure: Heterogeneous Impulse Responses to a Supply Shock: Empirical vs. Model

PARTIAL EQUILIBRIUM: HETEROGENEITY VS. REP FIRM



(a) Response of Output

PARTIAL EQUILIBRIUM: HETEROGENEITY VS. REP FIRM



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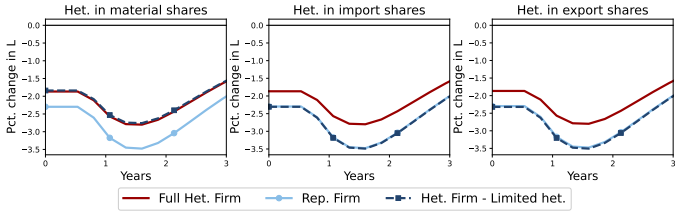

(b) Response of Labor

GENERAL EQUILIBRIUM MODEL

GENERAL EQUILIBRIUM MODEL

- **Heterogeneous firms (model from PE)**
  - Sector and firm heterogeneity
    - **Key:** Heterogeneous size, materials, imports, and export shares
  - Use parameters estimated in the IRF matching

- **Representative consumers**
  - Consume domestic and foreign goods
  - Labor supply set at the union level
  - Sticky wages from Rotemberg adjustment cost on wages (Erceg, Henderson, and Levin (2000))

- **Foreign economy**
  - Exogenous to Danish firms (small open economy assumption)
  - Free capital flows
  - Fixed exchange rate

GE RESPONSES

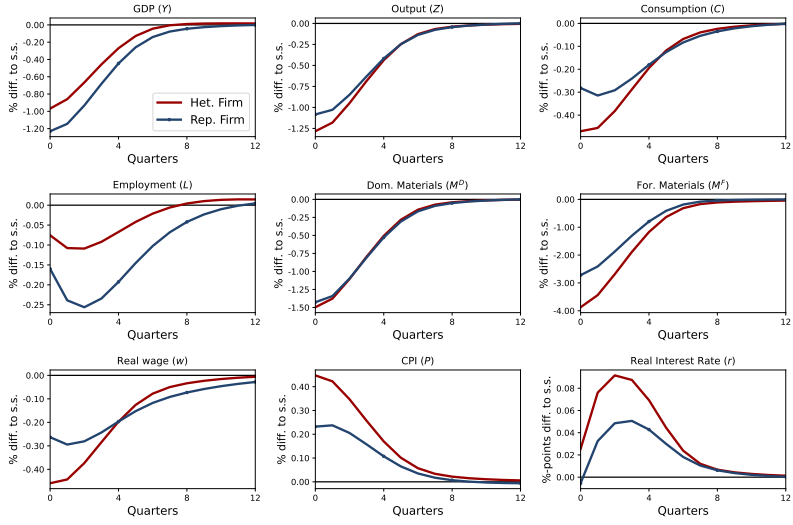

Figure: General Equilibrium Responses to Foreign Supply Shock With and Without Firm Heterogeneity

SOURCES OF AMPLIFICATION

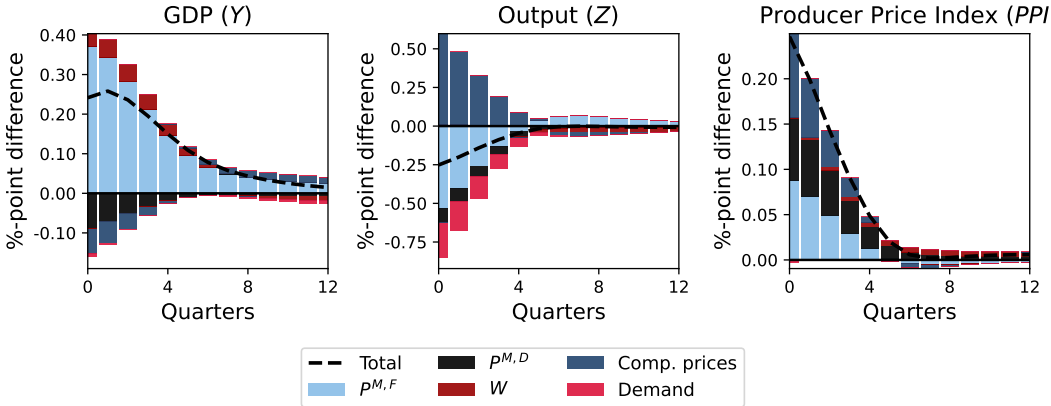

Figure: Sources of Amplification From Firm Heterogeneity

Note: This Figure decomposes the difference in response between the baseline model and the model with only sectoral heterogeneity into contributions from the various firm inputs.

CONCLUSION AND IMPLICATIONS

- **Investigate the role of firm heterogeneity in transmitting foreign shocks**
  - Heterogeneity in size, material shares, import shares, export shares
  - Adjustment costs on labor

- **Firm heterogeneity not sufficient to generate amplification in output and price response**
  - ... but considerable amplification of response to shocks when adjusting inputs is costly

- **Implies that aggregate models**
  - overestimate the GDP response (even without adjustment costs)
  - underestimate the price and output response when adjustment costs are present

APPENDIX

EXOGENOUS FOREIGN SUPPLY SHOCK

- Back
- **Apply shift-share instruments to obtain exogenous variation**
  - Exogenous shock to foreign supply (changes in productivity, production capacity, etc)

$$\ln S_{i.s,t}^{shock} = \ln \sum_{p,c} \mu_{i,c,p,t-1}^{IM} S_{c,p,t}^{EX} \tag{1}$$

- $\mu_{i,c,p,t-1}^{IM}$ is firm-specific share of imports from country c, product p
- $S_{c,p,t}^{EX}$ is foreign supply to all countries except Denmark

- **Exogeneity of shifters (Borusyak, Hull, and Jaravel 2022)**
  - *Randomly assigned*: Shifters exogenous to the Danish firm
  - *Instrument validity*: Sufficiently many independent shocks with low exposure (48,070 unique markets, serves on average 5 Danish firms)
  - *Instrument relevance*: Individual firms exposed to relatively few markets (median firm import from 8 markets)