U.S. versus Europe: How Differential COVID-19 Policies Affect Inequality

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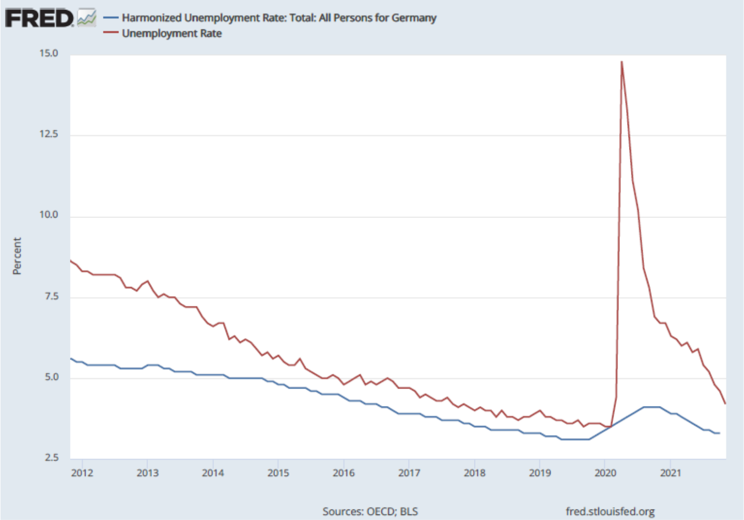
Motivation

- COVID-19 = a large negative (supply and/or demand) shock
  - restrictions on labor supply (Kocherlakota, 2020)
  - temporary decline in productivity (Gregory et al. 2020)
  - infection shock (Kapicka and Rupert, 2020)
  - skill loss shock hitting unemployed (Jackson and Ortego-Marti, 2020)
  - job loss (Bernstein et al. 2020)
  - preference shock (Ravenna and Walsh, 2021)
- Differential government fiscal policies across countries
  - *U.S.*:
    - mostly transfers via the unemployment insurance system
  - *Europe*:
    - mostly transfers to firms to support employers-employees

Stylized Fact



Previous COVID-19 Heterogeneous-Agent Literature

- **Previous COVID-19 literature with heterogeneous agents** (HA)
  - Bayer, Born, Luetticke and Müller (2020): *HANK*
  - Gregory, Menzio and Wiczer (2020): *HA + search*
  - Ravenna and Walsh (2021): *HANK + search*
  - Guerrieri et al. (2020): *HANK + multi-sector*
    - steady state; all shocks are MIT; no calibrated exercise

This paper: quantifies the effects of COVID-19 policies in a calibrated, *multi-sector*, large-scale *HANK* model with *search*

HANK Model with Directed Search

- **Households**
  - Two types of consumption goods (imperfect substitutes)
  - Two types of assets: liquid (bonds) and illiquid assets
  - Two borrowing constraints, one for each asset
  - Idiosyncratic shocks to productivity level
  - Directed job search
  - Submarkets indexed by workers' characteristics
- **Two production sectors**
  - Fixed shares of population in each sector
  - Downward-sloping demand
  - Sticky prices a la Rotemberg
  - TFP levels subject to sector-specific shocks
  - CRS with capital and labor
  - One sector is COVID vulnerable
- **Labor firm**
  - Posts a job in the chosen submarket
  - Exogenous separation
  - Free entry for firms

HANK Model with Directed Search (Cont.)

- **Mutual fund**
  - One asset: capital
  - Subdivision of capital between two sectors
  - Owns final good producers and job posting firms
- **Fiscal policy**
  - Balanced budget
- **Automatic stabilizers**
  - Unemployment benefits
  - Progressive income tax
  - Food stamps
- **Discretionary policy**
  - Government transfers to households (U.S.)
  - Government transfers to labor firms (Europe)
- Monetary policy
  - Taylor rule with ZLB

Previous COVID-19 HA Literature versus Present Paper

- **Previous literature:**
  - On-the-job search without capital
  - No aggregate risk
  - Low-order perturbation
  - State space includes a small number of distributional moments
- **Present paper:** addresses the above limitations by using deep learning
  - On-the-job search with two assets – capital and bonds
  - Aggregate risk shocks in the solution procedure
    – COVID-19 – a sector-specific TFP shock
    – (discretionary fiscal policy as MIT shocks)
  - Global nonlinear solutions
  - State space includes variables of **all** agents

Deep Learning Analysis of Maliar, Maliar, Winant (2019)

1. **HANK model**: $\begin{cases} E_{\epsilon}\left[f_1\left(X\left(s\right),\epsilon\right)\right]=0 \\ \dots \\ E_{\epsilon}\left[f_n\left(X\left(s\right),\epsilon\right)\right]=0 \end{cases}$

   s = state, $X\left(s\right)$ = decision function, ϵ = innovations.
2. Parameterize $X\left(s\right)\simeq\varphi\left(s;\theta\right)$ with a **deep neural network**.
3. Construct **objective function** for DL training

$$\min_{\theta}\left(E_{\epsilon}\left[f_1\left(\varphi\left(s;\theta\right),\epsilon\right)\right]\right)^2+\dots+\left(E_{\epsilon}\left[f_n\left(\varphi\left(s;\theta\right),\epsilon\right)\right]\right)^2\rightarrow 0$$

4. **All-in-one expectation** operator is a critical novelty:

$$\left(E_{\epsilon}\left[f_j\left(\varphi\left(s;\theta\right),\epsilon\right)\right]\right)^2=E_{\left(\epsilon_1,\epsilon_2\right)}\left[f_j\left(\varphi\left(s;\theta\right),\epsilon_1\right)\cdot f_j\left(\varphi\left(s;\theta\right),\epsilon_2\right)\right]$$

   with ϵ_1,ϵ_2 = two independent draws.
5. **Stochastic gradient descent** for training (random grids)
6. Google **TensorFlow** platform – software that leads to ground breaking applications (image, speech recognition, etc).

Household Consumption-Saving Problem

Stage 1. Given $\overline{C}_t$, choose a vector $\left(c_t^X, c_t^Z\right)$ maximizing total consumption

$$\max_{\left\{c_t^X, c_t^Z\right\}} \left[(1-\varepsilon)^{\frac{1}{\eta}} \left(c_t^X\right)^{1-\frac{1}{\eta}} + \varepsilon^{\frac{1}{\eta}} \left(c_t^Z\right)^{1-\frac{1}{\eta}}\right]^{\frac{\eta}{1-\eta}}$$

$$\text{s.t. } P_t^X c_t^X + P_t^X c_t^X \leq \overline{C}_t,$$

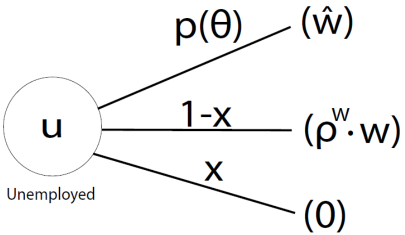
Stage 2. Given optimal $\left(c_t^X, c_t^Z\right)$, choose a utility-maximizing combination of consumption and assets subject to

$$\begin{aligned}
(1) \quad a' &= (1+r^m)\,a + i \\
(2) \quad \frac{b'}{R} &= b + y_{min} + (1+r^m)\,a + \varpi - c + \Psi\left(i, a\right) \\
(3) \quad a' &\geq 0, \quad b' \geq -\overline{b}
\end{aligned}$$

- $\varpi = \mathcal{W}^{\nu} \times \exp\left(\eta_\ell - \overline{\eta}_\ell\right) \times w$ *if employed* where $\nu =$ sector, $\mathcal{W}$ $=$ efficiency wage, $w =$ wage share and $\varpi_t = b_t^{ump}$ *if unemployed*

Unemployed Search Decision

Agent j searches in a submarket $(a'(j), b'(j), \hat{w}, \eta_\ell(j), \nu(j), \Sigma)$



θ : market tightness;
$p(\theta)$: job finding rate;
χ: probability of unemployment insurance expiring

Unemployed Search Decision

- Bellman equation:

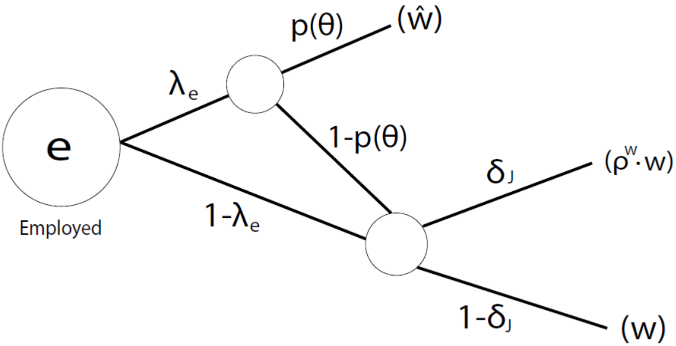
$$Q\left(w\left(j\right),\epsilon\left(j\right)=u,\ldots\right)=\max_{\hat{w}}\left\{p\left(\theta\right)EV\left(\hat{w},\epsilon'\left(j\right)=e,\ldots\right)+\left\{\left(1-\chi\right)EV\left(\rho^{w}w\left(j\right),\epsilon'\left(j\right)=u,\ldots\right)+\chi EV\left(0,\epsilon'\left(j\right)=u,\ldots\right)\right\}\times\left(1-p\left(\theta\right)\right)\right\}$$

subject to

$$q\left(\theta\right)\beta E\left[J\left(\hat{w},\ldots\right)\right]=k$$

- $\theta\left(a'\left(j\right),b'\left(j\right),\hat{w},\eta_{\ell}\left(j\right),\nu\left(j\right),\Sigma\right)$
- $q\left(\theta\right)$: job filling rate
- k: flow cost of posting a vacancy

Employed Search Decision



λ_e: probability of being chosen to look for a better job;
δ_J: probability of being hit by an exogenous separation shock and becomes unemployed

Employed Search Decision

- Bellman equation:

$$
\begin{aligned}
Q\left(w\left(j\right),\epsilon\left(j\right)=e,\ldots\right) = \\
\max_{\hat{w}}\left\{\lambda_e p\left(\theta\right) EV\left(\hat{w},\epsilon'\left(j\right)=e,\ldots\right)+\right. \\
\left\{\left(1-\delta_J\right) EV\left(w\left(j\right),\epsilon'\left(j\right)=e,\ldots\right)\right. \\
\left.\left.+\delta_J EV\left(\rho^w w\left(j\right),\epsilon'\left(j\right)=u,\ldots\right)\right\}\times\left(1-\lambda_e p\left(\theta\right)\right)\right\}
\end{aligned}
$$

subject to

$$
q\left(\theta\right)\beta E\left[J\left(\hat{w},\ldots\right)\right]=k
$$

Two Production Sectors

- Technology of a firm in sector ν

$$Y_t^v = \exp\left(\eta_{\theta,t}^{\nu} - \overline{\eta}_{\theta}^{v}\right)\left(K_{t-1}^{v}\right)^{\alpha}\left(H_t^v\right)^{1-\alpha}$$

H_t^v : efficiency labor; K_{t-1}^v : capital; $\exp\left(\eta_{\theta,t}^{\nu}\right)$: TFP level

- AR(1) process for TFP

$$\eta_{\theta,t}^{\nu} = \rho^{\theta,v}\eta_{\theta,t-1}^{v} + \sigma_{\theta}^{v}\varepsilon_{\theta,t}^{v}, \qquad \varepsilon_{\theta,t}^{v} \sim \mathcal{N}(0,1)$$

- Downward sloping demand

$$Y_t^v = \varepsilon\left(\frac{P_t^v}{P_t}\right)^{-\eta} Y_t$$

- Profit

$$(1-\tau_t)\frac{P_t^v}{P_t}Y_t^v - mc_t^v Y_t^v$$

Job Posting Firm

- Profit

$$D_t^{J,\nu} = \mathcal{W}_t^{\nu} \exp\left(\eta_{\ell,t} - \overline{\eta_\ell}\right)(1 - w_t) + \tau_t^J$$

- The value of a firm

$$J(a, b, w, \eta_\ell, \nu, \Sigma) = D^{J,\nu} + (1 - \delta_J)(1 - \lambda_e p(\theta)) \beta E J\left(a', b', w, \eta'_\ell, \nu, \Sigma'\right)$$

- In equilibrium,

$$q(\theta) \beta E J(a, b, w, \eta_\ell, \nu, \Sigma) = k$$

Government

- A balanced government budget in each period

$$\int \mathcal{W}_t^{\nu(j)} \exp\left(\eta_{\ell,t}(j)\right) \rho^w w_t(j) \mathcal{I}_{\{\epsilon(j)=u\}} dj + y_{\min}$$
$$+ \int \tau^J(j) \mathcal{I}_{\{\epsilon(j)=u\}} dj = \int_h \tau_t Y_t^X(h)\, dh + \int_h \tau_t Y_t^Z(h)\, dh$$

- $y_{\min}$: transfers to households; τ^J : transfers to firms
- We plan to extend to unbalanced budget

Impulse Response Functions

- Koop's et al. (1996) methodology
- In the figures,
    - "Relative":

$$\frac{X^{innovation} - X^{no\_innovation}}{X^{no\_innovation}} \times 100$$

    - "Absolute":

$$\frac{X^{innovation} - X^{no\_innovation}}{number\ of\ simulations} \times 100$$

Impulse Response Functions (IRF)

- **No-innovation** series:

  "No TFP shock in COVID-vulnerable sector" **plus** *"No Transfers"*

- 3 **innovation** series, each of which has

"A TFP shock in the COVID vulnerable sector"

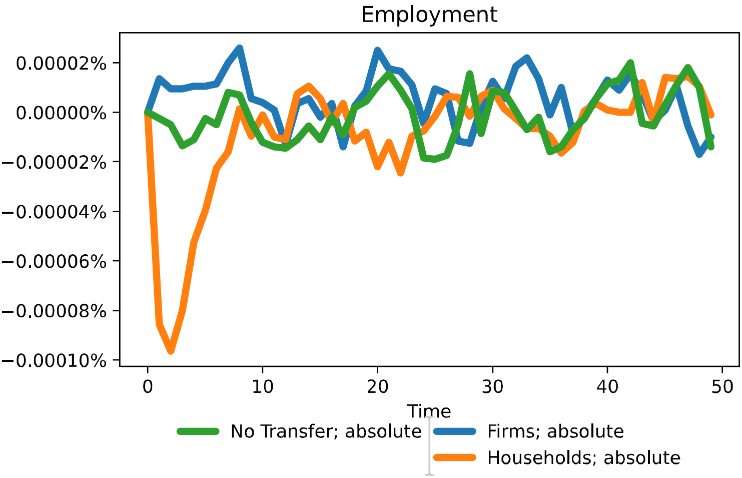
plus

1. "*No Transfer*": no additional transfers to households or firms
2. "*Households*": transfers to households
3. "*Firms*": transfers to firms

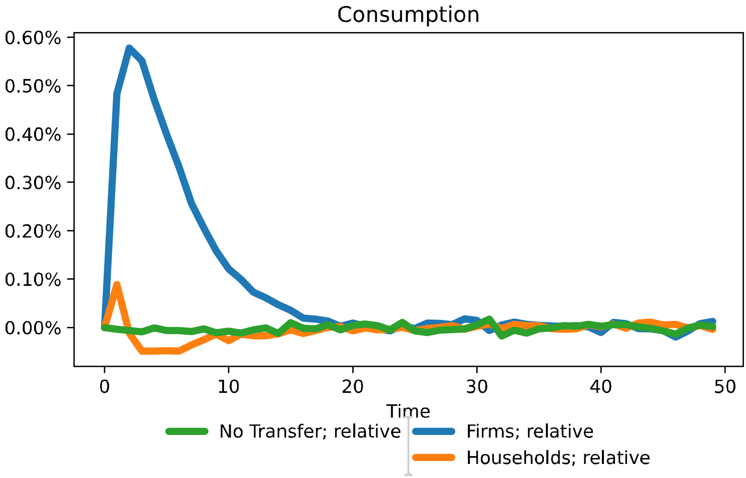
Model's Solution and IRF

- Model's period: 1 month
- 200 agents (100 in each sector)
- "*TFP shock in the COVID vulnerable sector*":
    - a 1 standard deviation negative shock
- "*Households*":
    - y_{min} increases by a factor of 5 in the first period and then decays by a factor of .5 each period
- "*Firms*":
    - τ^J increases from 0 to $4y_{min}$ in the first period and then decays by a factor of .5 each period

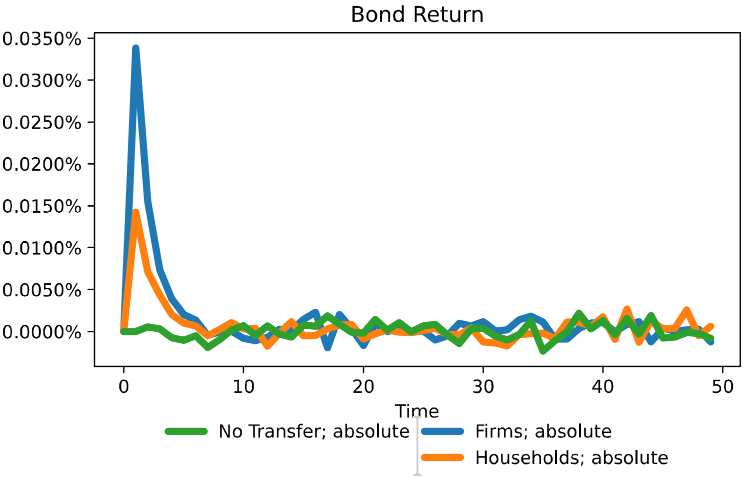
Employment


Employment
0.00002%
0.00000%
−0.00002%
−0.00004%
−0.00006%
−0.00008%
−0.00010%
0
10
20
30
40
50
Time
No Transfer; absolute
Firms; absolute
Households; absolute

Consumption

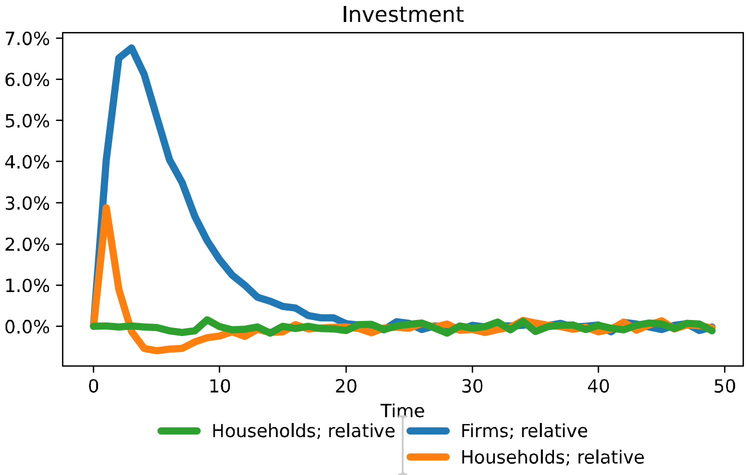


Bond Return



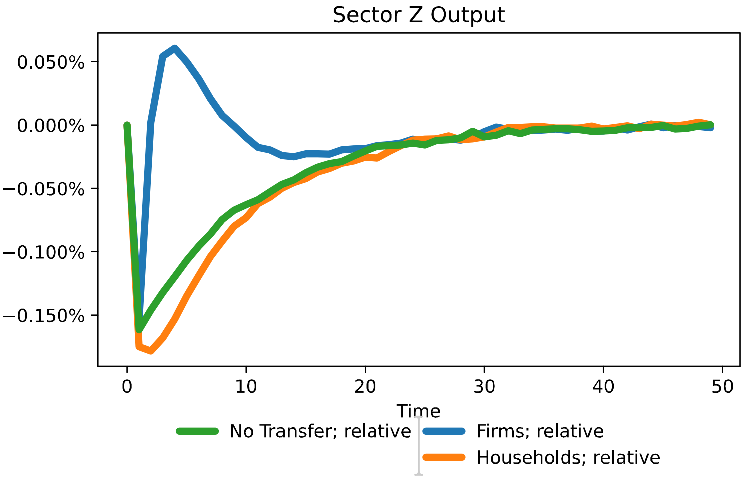
Bond Return
0.0350%
0.0300%
0.0250%
0.0200%
0.0150%
0.0100%
0.0050%
0.0000%
0
10
20
30
40
50
Time
No Transfer; absolute
Firms; absolute
Households; absolute

Investment

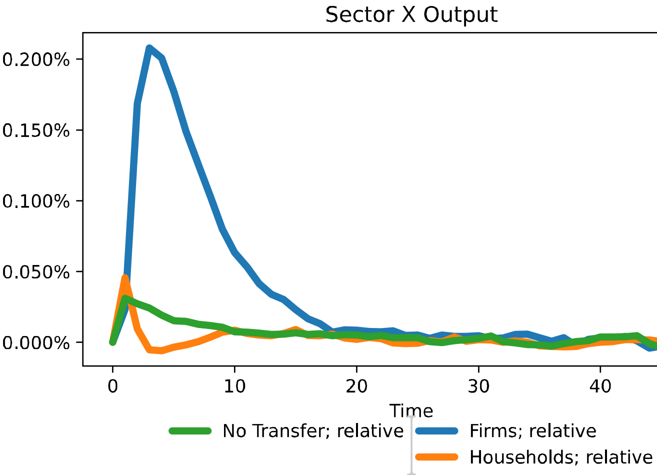


Investment
7.0%
6.0%
5.0%
4.0%
3.0%
2.0%
1.0%
0.0%
0
10
20
30
40
50
Time
Households; relative
Firms; relative
Households; relative

Output in the COVID Vulnerable Sector



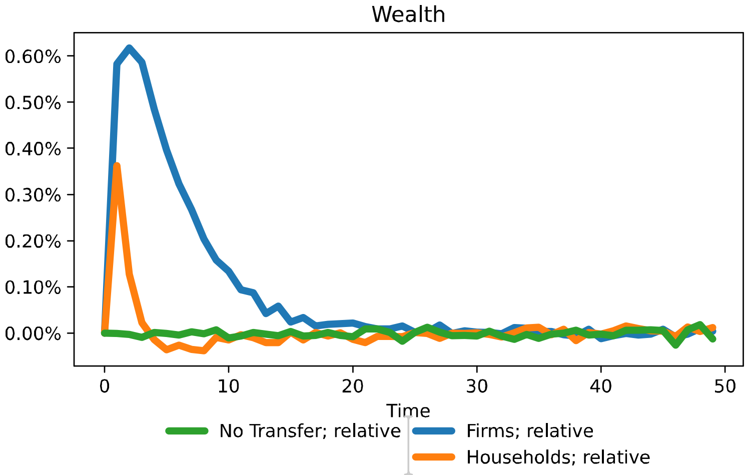
Output in the COVID Robust Sector



Wage Share

Wage Share
0.0100%
0.0050%
0.0000%
−0.0050%
0
10
20
30
40
50
Time
No Transfer; relative
Firms; relative
Households; relative

Wealth



Wealth
0.60%
0.50%
0.40%
0.30%
0.20%
0.10%
0.00%
0
10
20
30
40
50
Time
No Transfer; relative
Firms; relative
Households; relative

Conclusion

- The type of transfers used is important for how output responds to TFP shock in one sector:
  - with the firm transfers, output in the COVID-vulnerable sector starts increasing almost immediately, after the initial drop
- The responses of employment and wage share differ between firm and household transfers
- All effects are significantly larger for firm transfers than for household transfers
- Preliminary results for the real economy are promising
- Need to solve the full new Keynesian model

Thank you!

Krusell and Smith (1998) versus the Present Paper

- **Krusell and Smith** (1998) use a reduced state space:
  X_i (*variables of agent* i, *aggregate moments*)
  $\Rightarrow$ few state variables
- **The present paper** uses the full state space:
  X_i (*variables of all agents*, *distributions*)
  $\Rightarrow$ hundreds of state variables

How do we deal with such a large state space?

1. Neural network automatically performs the model reduction – it learns to summarize information from many inputs into a smaller set of hidden layers.
2. Neural network deals with ill conditioning – it learns to ignore collinear and redundant variables.