Nonlinear Heterogeneous Impact of Net Worth Shocks

Cheng Ding, Tianhao Zhao

Emory University

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Introduction

- The wealth effect is a critical channel through which economic shocks propagate
  - Mian, Rao, and Sufi (2013); Mian and Sufi (2014) proposed *net worth shock* and the household balance sheet channel
- The presence of financial and nominal frictions can amplify the effects of net worth shocks and impede the recovery process
  - Financial friction: Collateral constraint
  - Nominal friction: Downward Nominal Wage Rigidity (DNWR)
- This paper:
  - Develops a tractable two-agent model to illustrate the how the interaction between the two frictions leads to non-linear heterogeneous impacts of net worth shock
  - Builds a novel county-level dataset (*CountyPlus*)
  - Empirically estimates and does inference on the non-linear heterogeneous effects using semi-varying coefficient local projections

Introduction

Related studies:

- Net worth shock and slow recovery:Bocola and Lorenzoni (2020); Guerrieri, Lorenzoni, and Prato (2020); Kaplan, Mitman, and Violante (2020a, 2020b); Mian et al. (2013); Mian and Sufi (2014) ...
- Financial, nominal frictions and their impact: Christiano, Eichenbaum, and Trabandt (2015); Schmitt-Grohé and Uribe (2016); Shen and Yang (2018) ...

Methodology:

- Local projections (LP) and heterogeneous effect estimation: Cloyne, Jordà, and Taylor (2023); Jordà (2005); Jordà, Schularick, and Taylor (2020) ...
- Estimation and inference of semi-varying coefficient model: Fan and Huang (2005); Fan, Zhang, and Zhang (2001); Hu (2024); Zhang, Lee, and Song (2002) ...

Introduction

Key findings:

- Negative net worth shock $\rightarrow$ higher precautionary savings and deleverage in response to tightened collateral constraints. DNWR $\rightarrow$ higher income uncertainty. The adjustment process is prolonged, leading to a persistent decline in consumption.
- Found significant heterogeneity in the impact of net worth shocks across counties, with the effect magnitude varying by the degree of local financial and nominal frictions.
- Suggested that the impact of net worth shocks can be non-linearly amplified when both collateral constraints and DNWR are binding.

Main contributions:

- Adds empirical evidence of how financial and nominal frictions affect the impact of net worth shocks.
- Proposes a tractable model to illustrate the amplification mechanism of the frictions.

A tractable two-agent model

- $t = 0, 1, 2, \ldots$, economy's state s^t, and aggregate housing productivity shock $u(s^t)$
- Two assets:
  - Housing wealth $h(s^t)$ of price $p(s^t)$
  - State-contingent claims $b(s^{t+1})$ of price $q(s^{t+1}|s^t)$
- Two agents:
  - **Expert** (borrower): enjoy consumption; produce consumption goods using their housing wealth $h(s^t)$ and household's labor $l(s^t)$; borrow state-contingent claims
  - **Household** (lender): enjoy consumption and housing; constantly supply 1 unit of labor; save in the state-contingent claims
- Two frictions:
  - The expert faces state-contingent collateral constraints: $b(s^{t+1}) \leq \theta p(s^{t+1}) h(s^t)$
  - DNWR: $w(s^t) \geq \delta w(s^{t-1})$ and $(1 - l(s^t))(w(s^t) - \delta w(s^{t-1})) = 0$

A tractable two-agent model

Expert's problem

$$V^b(s^t) = \max_{c(s^t),\{b(s^{t+1})\},h(s^t),l(s^t)} \log c(s^t) + \beta \mathbb{E} V^b(s^{t+1})$$

$$c(s^t) + p(s^t)h(s^t) = n(s^t) + \sum_{s^{t+1}} q(s^{t+1}|s^t)b(s^{t+1})$$

$$n(s^t) := p(s^t)h(s^{t-1}) + y(s^t) - b(s^t)$$

$$y(s^t) := Y(s^t) - w(s^t)l(s^t)$$

$$b(s^{t+1}) \leq \theta p(s^{t+1})h(s^t), \forall s^{t+1}$$

where

- $n(s^t) \geq 0$: net worth
- $Y(s^t) := Al^{\alpha}(s^t)[u(s^t)h(s^t)]^{1-\alpha}$

A tractable two-agent model

Household's problem

$$V^l(s^t) = \max_{c^l(s^t),\{a(s^{t+1})\},h^l(s^t)} c^l(s^t) + \gamma \log h^l(s^t) + \beta \mathbb{E} V^l(s^{t+1})$$

$$c^l + \sum_{s^{t+1}} q(s^{t+1}|s^t)a(s^{t+1}) + p(s^t)[h^l(s^t) - h^l(s^{t-1})] = w(s^t)l(s^t) + a(s^t)$$

A tractable two-agent model

- Housing market: $h(s^t) + h^l(s^t) = H, H \in \mathbb{R}$
- Bond market: $a(s^{t+1}) = b(s^{t+1}), \forall s^{t+1}$
- DNWR conditions:

$$w(s^t) \geq \delta w(s^{t-1})$$
$$(1 - l(s^t))(w(s^t) - \delta w(s^{t-1})) = 0$$

Scenario: Starts from an unbinding state. One-shot deviation where all $u_t \equiv 1$ except for u_1. The housing productivity shock u_1 is drawn from a distribution over the support $(0, \bar{u}]$.

A tractable two-agent model

Theorem (Persistent effect)

There exist a unique continuation equilibrium that depends on the states $(u_1, h_0, b_1(u_1))$. *In the continuation equilibrium, the collateral constraint is binding for a finite number of periods* J, *with* $J = 0$ *iff* $n_1(u_1) \geq \bar{n}_1 := \bar{p}\bar{h}(1 - \beta\theta)/\beta$, *where* $\bar{p}$ *and* $\bar{h}$ *are jointly determined by*

$$(1 - \beta)\bar{p} = \frac{\gamma}{H - \bar{h}} \tag{1}$$

$$\bar{p}(1 - \beta) = \beta(1 - \alpha)\bar{h}^{-\alpha} \tag{2}$$

A tractable two-agent model

Theorem (Non-linear heterogeneous effect)

There exist levels of the entrepreneur's financial friction parameter θ and the DNWR parameter δ, such that if

$$\frac{w_0}{n_0} \geq \frac{\alpha}{\delta(1-\alpha)} \left[1 + (1-\theta)(1-\alpha)(\frac{p_0 h_0^l}{\gamma} - 1)\right] \tag{3}$$

then, in equilibrium, the date 1 collateral constraint and DNWR both bind when u_1 is in a non-empty interval $[\hat{u}_0, u_0^*]$ where

$$u_0^* = \left(\frac{\delta w_0}{\alpha A}\right)^{\frac{1}{1-\alpha}} h_0^{-1} \tag{4}$$

$$\hat{u}_0 = \frac{n_0}{A(1-\alpha)h_0} \left(\frac{\delta w_0}{\alpha A}\right)^{\frac{\alpha}{1-\alpha}} \left[1 + (1-\theta)(1-\alpha)\left(\frac{p_0 h_0^l}{\gamma} - 1\right)\right] \tag{5}$$

, and the u_1 shock effects:

$$\frac{\partial c_1}{\partial u_1} > 0, \ \frac{\partial l_1}{\partial u_1} > 0, \ \frac{\partial p_1}{\partial u_1} > 0 \textit{ or } < 0 \textit{ or } = 0 \textit{ depends} \tag{6}$$

which are also non-linear functions of θ and δ. Formula

A tractable two-agent model

Comparative statistics

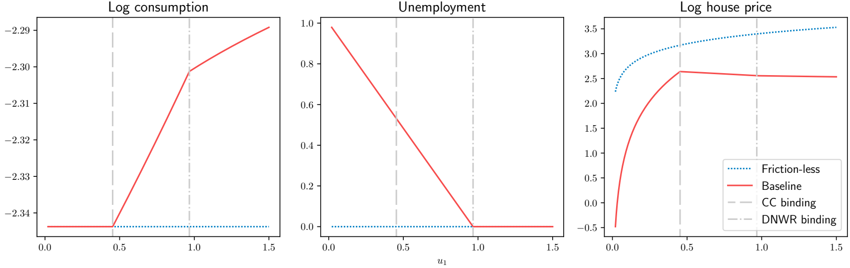


Figure: Baseline vs. Friction-less economy

Baseline scenario

Data: CountyPlus

- Build a new open-source panel data set *CountyPlus*
  - 03-19 yearly, 3058 US counties
  - 20+ public available data sources, fully replicable
  - `github.com/Clpr/CountyPlus`
- Covers: household balance sheet by asset Formula ; income and consumption Formula ; labor and housing market indicators; friction measures; demographics; ...
- Key variables:
  - Household net worth (wealth)
  - Consumption, unemployment and house price
  - `DENI`: home mortgage denial due to lack of collateral / total denials
  - `FWCP`: Fraction of Wage Cuts Prevented Formula
- Net worth shock is identified as:

$$x_{i,t} := \sum_{j \in \{S,B,H\}} s^j_{i,t-1} g^j_{t-1,t}$$

where i is county, S is equity, B is bond, H is housing wealth; $s^j_{i,t-1}$ is lag asset share in the balance sheet; and $g^j_{t-1,t}$ is the lag aggregate growth of asset prices.

Data: CountyPlus

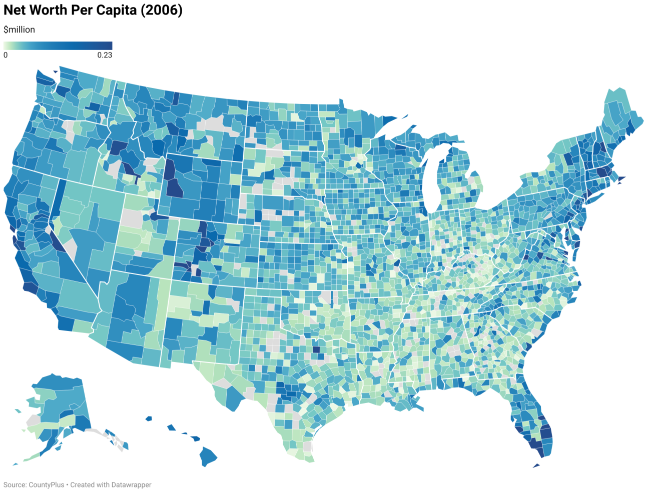


Figure: Geographical: Pre-crisis net worth

Data: CountyPlus

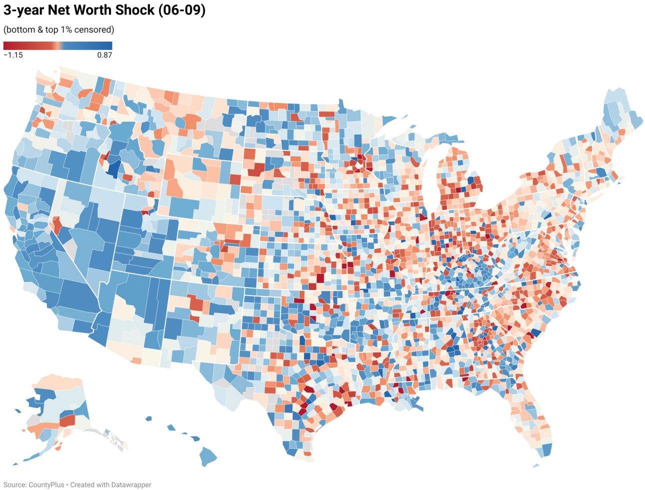


Figure: Geographical: Net worth shock during the Great Recession

Data: CountyPlus

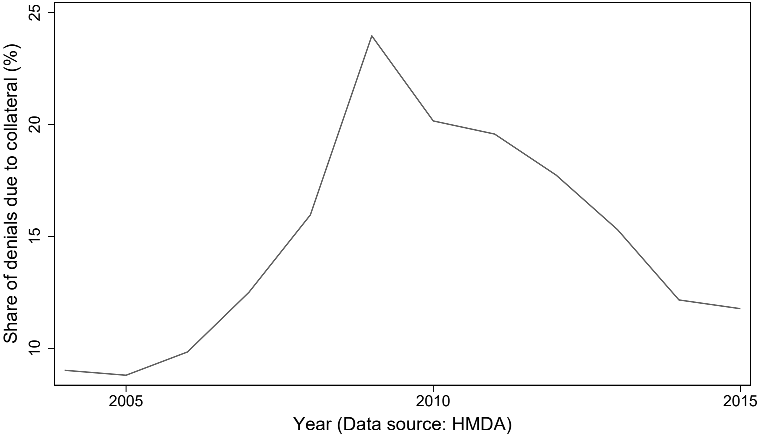


Figure: The aggregate extent of collateral constraint

Geographic: collateral constraint

Data: CountyPlus

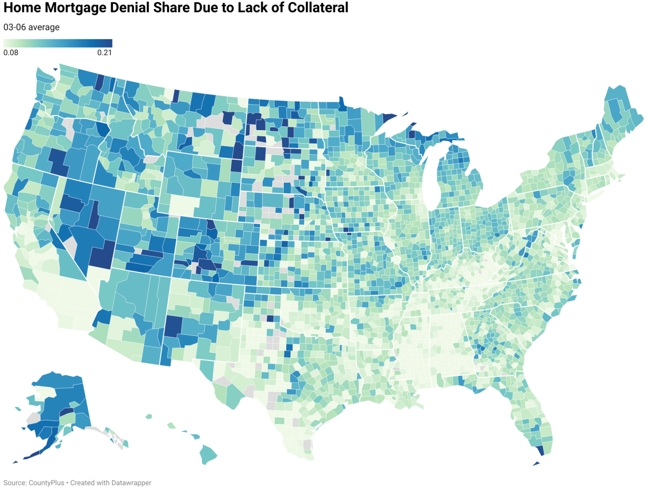


Figure: Geographical: Collateral constraint before the crisis

Data: CountyPlus

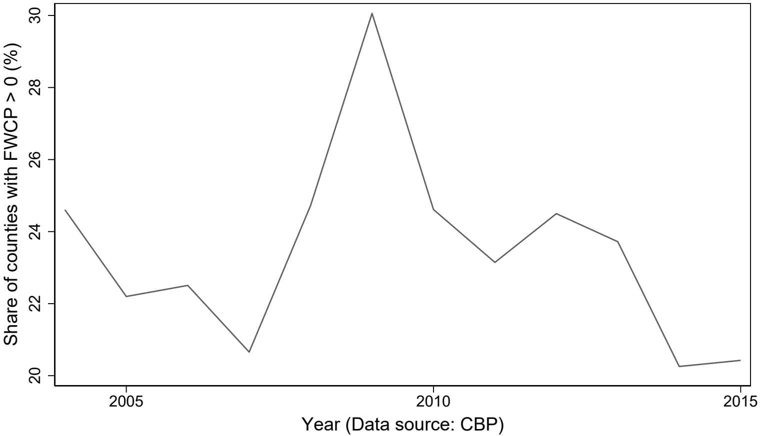


Figure: The aggregate extent of DNWR

Data: CountyPlus

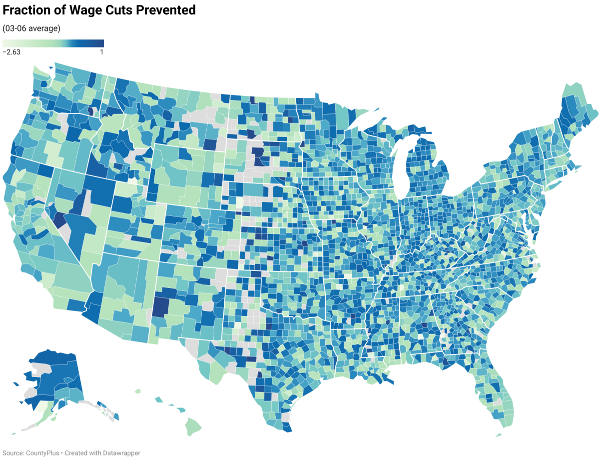


Figure: Geographical: DNWR before the crisis

Data: CountyPlus

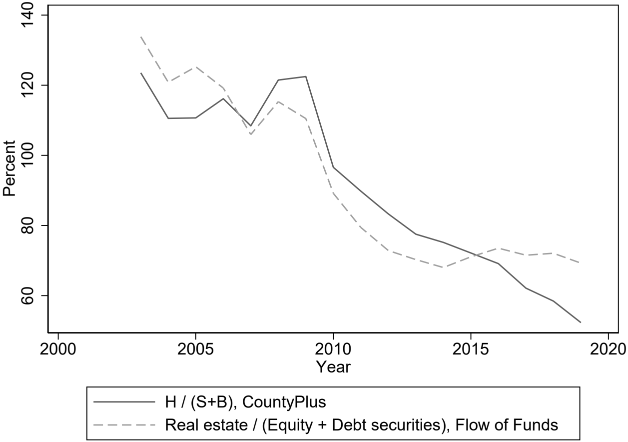


Figure: CountyPlus vs. Fed Flow of Funds

Baseline specification

- A semi-varying coefficient variant of the linear LP in Cloyne et al. (2023)

$$y_{i,t+h} = \alpha_h + x_{i,t} \cdot \beta_h(\Delta \mathbf{Z}_{i,t}) + \Delta \mathbf{Z}'_{i,t} \boldsymbol{\delta}_h + g(N_{i,t-1}) + \mathbf{W}_{i,t}\lambda_h + \iota_{i\in s} + \nu_t + \varepsilon_{i,t+h}$$

where

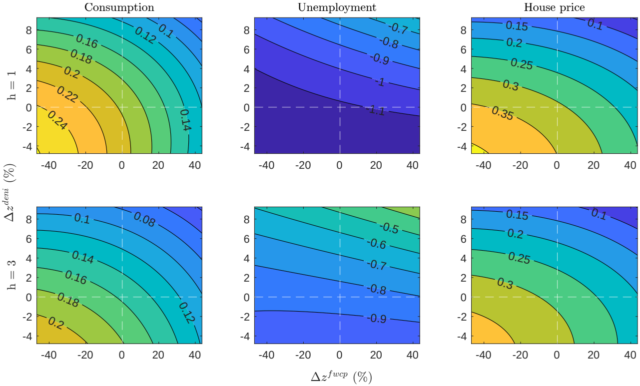
- $\Delta \mathbf{Z}_{i,t}$: DENI and FWCP deviation from the county's mean level
- $\beta_h(\Delta \mathbf{Z}_{i,t})$: effects of the net worth shock
- $h = 0, \ldots, H$: projection horizons
- $y_{i,t+h}$: outcomes
- $g(N_{i,t-1})$: a functional control of lagged net worth
- $\iota_{i\in s}, \nu_t$: state and year fixed effects

- Sieve estimator of global polynomial approximation:

$$\beta_h(\Delta \mathbf{Z}_{i,t}) \approx b_h^0 + b_h^1 \Delta z_{i,t}^{fwcp} + b_h^2 \Delta z_{i,t}^{deni} + b_h^3 \Delta z_{i,t}^{fwcp} \Delta z_{i,t}^{deni} + b_h^4 (\Delta z_{i,t}^{fwcp})^2 + b_h^5 (\Delta z_{i,t}^{deni})^2$$

- Outcomes: Log real consumption per capita; Unemployment rate; Log real house price index

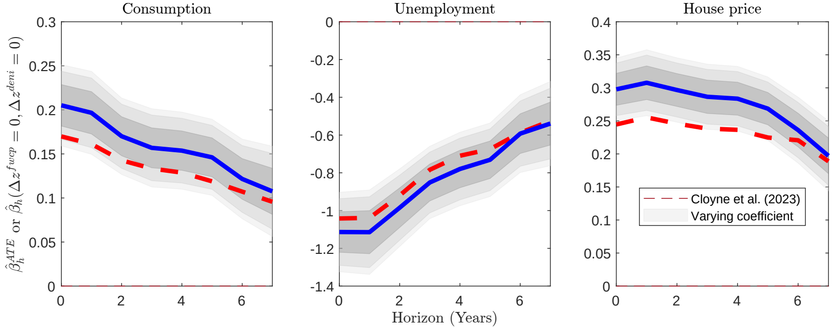
Baseline estimates of $\beta_h(\Delta\mathbb{Z}_{i,t})$



Notes: 1. The control variable $\mathbf{W}_{i,t}$ includes total housing units, share of housing wealth in household net worth, share of tradable sector employment in total employment, and share of construction sector employment in total employment. 2. The function $g(N_{i,t-1})$ is approximated by a cubic polynomial. 2. The regression is weighted by total population of each county, and the standard errors are clustered at state level. 3. The sample size used in each horizon's estimation varies from 12208 to 22784 where about 1700 counties with constructed consumption data are included, and the time spans from 2004 to 2019. 4. State and year fixed effects are controlled. 5. The scales of *FWCP* and *DENI* are in digits while they are visualized as percentage points in the figure.

Other horizons | Robustness: Degree selection | Robustness: Sensitivity analysis | Robustness: Local linear estimator

Baseline estimates of $\beta_h(\Delta\mathbb{Z}_{i,t})$



Notes: 1. The blue solid line is the point estimate of $\hat{\beta}_h(\Delta z^{fwcp}=0, \Delta z^{deni}=0)$ in the varying coefficient model. The gray shaded areas are the corresponding confidence interval in which t-testings are performed for points $\hat{\beta}_h(\Delta z^{fwcp}=0, \Delta z^{deni}=0)$. 2. The red dashed line is the point estimate of $\hat{\beta}_h$ in the linear LP model, as a contrast to our varying coefficient model estimates. 3. The two models share the same control variable set, standard error cluster and weights.

Figure: Baseline vs. Linear LP, at the average county

Baseline estimates of $\beta_h(\Delta \mathbb{Z}_{i,t})$

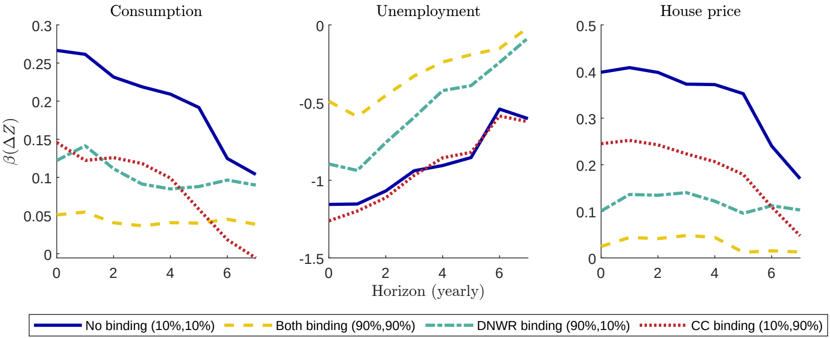


Figure: Point estimates by case

Baseline vs. Linear LP

- Baseline specification

$$y_{i,t+h} = \alpha_h + x_{i,t} \cdot \beta_h(\Delta \mathbf{Z}_{i,t}) + \Delta \mathbf{Z}'_{i,t} \boldsymbol{\delta}_h + g(N_{i,t-1}) + \mathbf{W}_{i,t}\lambda_h + \iota_{i\in s} + \nu_t + \varepsilon_{i,t+h}$$

- Linear LP with linear heterogeneous effects (Cloyne et al., 2023)

$$\begin{aligned} y_{i,t+h} = & \alpha_h + x_{i,t}\beta_h + x_{i,t}\Delta \mathbf{Z}'_{i,t} \begin{bmatrix} \gamma_h^{fwcp} \\ \gamma_h^{deni} \end{bmatrix} + \Delta \mathbf{Z}'_{i,t}\boldsymbol{\delta}_h \\ & + g(N_{i,t-1}) + \mathbf{W}_{i,t}\lambda_h + \iota_{i\in s} + \nu_t + \varepsilon_{i,t+h}, h = 0, \dots, H \\ \Delta \mathbf{Z}_{i,t} := & (\Delta z_{i,t}^{fwcp}, \Delta z_{i,t}^{deni})' = \left(\mathsf{fwcp}_{i,t} - \overline{\mathsf{fwcp}}_i \quad \mathsf{deni}_{i,t} - \overline{\mathsf{deni}}_i\right)' \end{aligned}$$

Baseline vs. Linear LP

Figure: Linear heterogeneous effects by linear LP

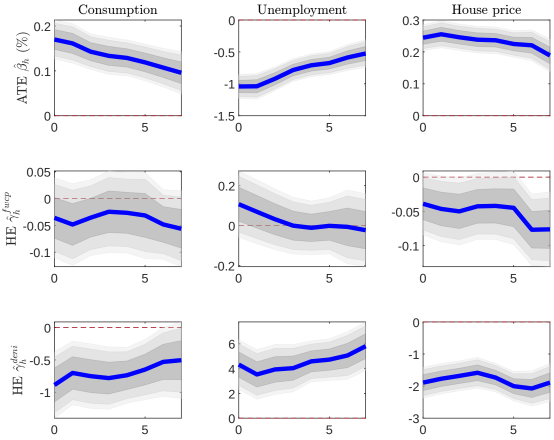


Figure: Horizon (yearly)

Inference on the non-linearity and friction interaction

- The non-linearity of heterogeneous effects and friction interaction is tested by an F-test
- $H_0 : 0 = b_h^3 = b_h^4 = b_h^5$

Horizon	0	1	2	3	4	5	6	7
Consumption	8.403 *** (.000)	8.641 *** (.000)	6.127 *** (.000)	5.289 *** (.001)	5.627 *** (.001)	7.282 *** (.000)	5.286 *** (.001)	4.002 *** (.008)
Unemployment	5.919 *** (.001)	3.874 *** (.009)	2.551 * (.054)	2.963 ** (.031)	3.453 ** (.016)	3.292 ** (.020)	2.532 * (.056)	1.627 (.181)
House price	24.967 *** (.000)	23.961 *** (.000)	22.215 *** (.000)	21.083 *** (.000)	22.661 *** (.000)	19.744 *** (.000)	14.116 *** (.000)	11.973 *** (.000)

***: $p < 0.01$, **: $p < 0.05$, *: $p < 0.1$

- The F-test suggests significant non-linear heterogneous effects and the interaction between collateral constraint and DNWR

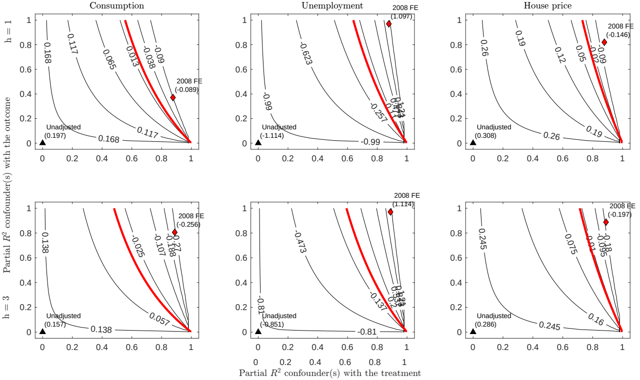
Robustness: Profile Likelihood Ratio test | Recall: polynomial approximation

Thank you

Latest version of this paper: `https://clpr.github.io/pages/research.html`

Appendix: Sensitivity Analysis

framework of Cinelli and Hazlett (2020)

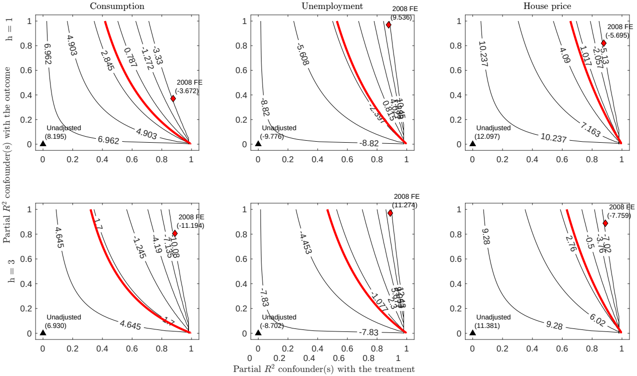


Notes: 1. The horizontal axis denotes $R^2_{D\sim Z|\mathbf{X}}$, the vertical axis denotes $R^2_{Y\sim Z|D,\mathbf{X}}$. 2. The dark triangle mark at the origin denotes the baseline ATE point estimate in which the value is labelled in the parenthesis. 3. The red diamond mark denotes the point estimate if there is confounder(s) as strong as the benchmark covariate (2008 year fixed effect); The new point estimate is labelled in the parenthesis. 4. The red thick curve marks the zero line. Point estimates beyond this line means sign flips.

Figure: Point estimate of the ATE against potential confounders

Go back to: baseline estimates

Appendix: Sensitivity Analysis



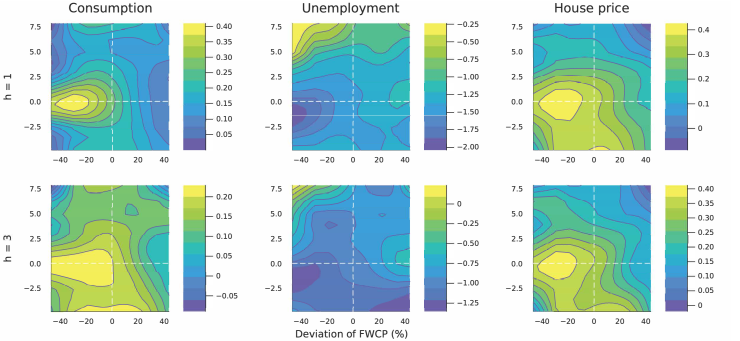
Notes: 1. The horizontal axis denotes $R^2_{D\sim Z|\mathbf{X}}$, the vertical axis denotes $R^2_{Y\sim Z|D,\mathbf{X}}$. 2. The dark triangle mark at the origin denotes the baseline ATE t-value in which the value is labelled in the parenthesis. 3. The red diamond mark denotes the t-value if there is confounder(s) as strong as the benchmark covariate (2008 year fixed effect); The new value is labelled in the parenthesis. 4. The red thick curve marks the 1.96 critical line. Point estimates beyond this line means not rejecting the H_0.

Figure: t-value of the ATE against potential confounders

Go back to: baseline estimates

Appendix: Local linear estimator

- Using the estimation procedure in Zhang et al. (2002)



Notes: 1. The horizontal axis of each panel denotes Δz^{fwcp} in percentage points, the vertical axis denotes Δz^{deni} in percentage points. 2. The cross of the white dashed lines denote the point $\hat{\beta}(0, 0)$. 3. The contour plot is created by a piece-wise linear interpolation of $\hat{\beta}$ over the along-each-dimension $10\% \sim 90\%$ quantile ranges of Δz^{fwcp} and Δz^{fwcp}. 4. The quantile reference grid knots are chosen by every 5% quantile such that there are $17 \times 17 = 289$ knots. 5. The distance for the kernel function is Euclidean distance where both reference variables are normalized to $[0, 1]$ in order to eliminate the impact of scales. 6. The bandwidth selection is done by the plug-in estimator in Yang and Tschernig (1999).

Go back to: baseline estimates

Appendix: Profile Likelihood Ratio test

- Using the PLR test by Fan and Huang (2005)
- H_0: if the overall treatment effect β is dependent on Δz^{fwcp} and Δz^{deni} and the baseline model is correctly specified, then it equals to the estimates from the linear LP model

Horizon	Consumption	Unemployment	House price
0	3230.96***	328.46***	1596.15***
	(0.1503)	(0.1503)	(0.1503)
1	2921.63***	355.91***	1166.61***
	(0.1504)	(0.1504)	(0.1504)
2	3345.83***	1301.31***	1230.62***
	(0.1504)	(0.1504)	(0.1504)
3	3069.98***	1684.84***	1127.61***
	(0.1504)	(0.1504)	(0.1504)
4	2615.89***	1605.61***	589.91***
	(0.1504)	(0.1504)	(0.1504)
5	2264.8***	1829.66***	770.64***
	(0.1503)	(0.1504)	(0.1504)
6	1886.03***	1837.51***	841.8***
	(0.1503)	(0.1503)	(0.1503)
7	1630.81***	1799.62***	935.84***
	(0.1502)	(0.1502)	(0.1502)

where the number with stars are the generalized likelihood ratio statistic T_0, the number in parenthesis is δ_n the degree of freedom of the asymptotic $\chi^2_{\delta_n}$ distribution, the other asymptotic parameter $r_K \approx 0.51579$ for our Gaussian kernel.

Go back to: F-test

Appendix: Full figure of baseline estimates

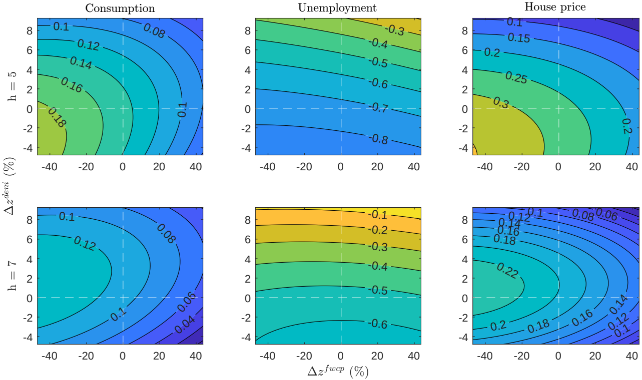
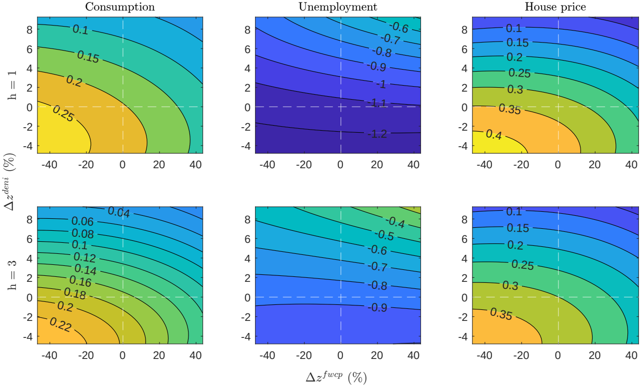


Figure: Baseline estimates (Horizon $= 5, 7$)

Go back to: baseline estimates

Appendix: Degree selection

- $\beta_h(\Delta \mathbf{Z}_{i,t})$ expanded to the 3rd order:



Go back to: baseline estimates

Appendix: More about the dataset

- Net worth: $NW_{it} = S_{it} + B_{it} + H_{it} - D_{it}$
- Stock and bond holding:

$$S_{i,t} = \frac{\text{County dividend income}_{i,t}}{\sum_j \text{County dividend income}_{j,t}} \times \text{National total equity of household}_t$$

$$B_{i,t} = \frac{\text{County interest income}_{i,t}}{\sum_j \text{County interest income}_{j,t}} \times \text{National total debt security of household}_t$$

- Household debt

$$D_{i,t} = \text{Household debt-to-income ratio}_{i,t} \times \text{AGI}_{i,t}$$

where i is county index and t is year index, AGI is adjusted gross income.

Appendix: More about the dataset

- Housing wealth

$$H_{i,t} = \frac{\text{Total housing units}_{i,t}}{\text{Average housing units per house}} \times \text{Median house value}_{i,2019} \times \frac{\text{HPI}_{i,t}}{\text{HPI}_{i,2019}} \tag{7}$$

where the average housing units per house is 1.8

Go back to: Data

Appendix: More about the dataset

- spirit of Zhou and Carroll (2012)
- Sales tax data from local department of revenues: 27 states, 1700 counties

$$C_{i,t} = \text{PCE}_{s,t} \times \text{Population}_{s,t} \times \frac{\text{Sales tax revenue}_{i,t}}{\sum_{j \in s} \text{Sales tax revenue}_{j,t}}$$

- The measurement error due to tax rates is adjusted using county and state average tax rates.
- Currently available states (sorted by FIPS code):

  1 Alabama, 4 Arizona, 5 Arkansas, 6 California, 8 Colorado, 12 Florida, 17 Illinois, 18 Indiana, 19 Iowa, 22 Louisiana, 27 Minnesota, 29 Missouri, 31 Nebraska, 32 Nevada, 36 New York, 37 North Carolina, 38 North Dakota, 39 Ohio, 42 Pennsylvania, 45 South Carolina, 47 Tennessee, 49 Utah, 50 Vermont, 51 Virginia, 55 Wisconsin, 56 Wyoming.

Go back to: Data

Appendix: More about the dataset

- methodology of Holden and Wulfsberg (2009)
- **Idea**: true nominal wage distribution vs. constructed notional rigidity-free distribution
- Notional distribution: all county-industry pairs with upper 25% wage growth in a given year
- Fraction of Wage Cuts Prevented:

$$\text{FWCP}_{i,t} = 1 - p_{i,t}/\tilde{p}_{i,t}$$
$$\tilde{p}_{i,t} := \frac{\#\{Z_{i,t} < 0\}}{N_t^{\text{top } 25\%}}$$
$$p_{i,t} := \frac{\#\{\Delta w_{j,i,t} < 0\}}{N_{i,t}}$$

where $Z_{i,t}$ is the rigidity-free wage growth from the notional distribution of county i in year t; $\Delta w_{j,i,t}$ is the true wage growth of industry j

Go back to: Data

Appendix: Baseline scenario for illustration

Table: Baseline parameters

Parameter	Definition	Value
β	Utility discounting factor	0.9
α	Labor income share	0.7
δ	Parameter of DNWR	0.99
θ	Collateral constraint as LTV ratio	0.8
A	Technology level	1
$\bar{\nu}$	Steady state LTV ratio	0.79
γ	Housing preference	0.8
H	House supply	30

Going back to: Comparative stats

With the presence of collateral constraint and DNWR, the partial effects of net worth n_1 wrt the shock u_1 is:

$$n_1'(u_1) = n_0 \left[\frac{1}{1 - \frac{\gamma}{p_0 h_0^l}} - \theta \right]^{-1} (1-\alpha)^2 A h_0^{-\alpha} \cdot (l_1^{\alpha} u_1^{-\alpha} p_t^{-1}) (\alpha \varepsilon_1^l - \alpha + 1 - \varepsilon_1^p)$$

$$\varepsilon_1^l := \frac{u_1}{l_1} l_1'(u_1), \varepsilon_1^p := \frac{u_1}{p_1} p_1'(u_1)$$

where ε_1^l is the shock elasticity of employment, and ε_1^p is the shock elasticity of house price.

- by case:

$$\varepsilon_1^l = \begin{cases} 0, \text{DNWR not binding} \\ 1, \text{DNWR binding} \end{cases} \qquad \varepsilon_1^p = \begin{cases} 1-\alpha, \text{CC not binding} \\ < 1-\alpha \text{ conditionally, if only CC binding} \\ < 1, \text{Both binding} \end{cases}$$

Going back to: Proposition

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