Employment Status and Credit Cycles: An Extensive Margin Analysis in Heterogeneous Agent Life Cycle Models.

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Research question & Motivation

Research question:

- How does introducing employment risk (extensive margin of the labor market) that changes over the life cycle affect the household borrowing, saving, and interest rate dynamics?

Motivation:

- Employment risk along the extensive margin varies not only with business cycles, but also with age. This suggests that the extensive margin may have heterogeneous effects on borrowing, saving, and interest rate dynamics.
- Standard macro models either rely primarily on the intensive margin due to convenience or assume complete markets that eliminate unemployment risk, potentially understating the macroeconomic importance of employment risk.

Extensive Margin in RBC

Indivisible Labor and The Business Cycle, Hansen (1985):

- Addresses a key limitation in RBC theory by explaining why total hours worked fluctuate more than productivity.
- Modeled RBC with labor movement through the extensive margin.
- Did a variance decomposition for total hours worked in the US.

Variance Decomp

$$\text{var}(\ln T) = \text{var}(\ln E) + \text{var}(\ln H) + 2\ \text{cov}(\ln E, \ln H)$$

- var(ln(E)) = 55%
- var(ln(H)) = 20%
- 2*cov(ln(E),ln(H)) = 25%
- T total hours, E employed individuals, and H weekly hours are all percent deviation from trend (Quarterly HP filter $\lambda = 1600$).

Extensive Margin in NK Model

Gali et al. (2012):

- Introduced wage regidity, which is essential for generating realistic unemployment fluctuations in response to macroeconomic shocks.
- Demonstrates that real wage rigidity amplifies labor market volatility, helping the model match empirical evidence on unemployment.
- By adding unemployment as an observable variable, the "correct" measures of the output gap can be calculated.

Problems:

- Model primary goal was to study the labor market
- Brings household into a unit square of i labor types and j disutilities of work, but assumes full risk sharing. $C(i,j)_t = C_t$

Continuous Time Heterogenous Agents

Microeconomic Heterogeneity and Macroeconomic Shocks, Kaplan and Violante (2018):

- Examine how adding household heterogeneity caused by idiosyncratic productivity shocks influences the macroeconomic response to aggregate shocks.
- They looked at Representative Agent and Heterogeneous Agent models, up to the two-asset HANK.
- "The fact that labor market risk is mostly exogenous in current HANK models is a gaping hole in the framework."

Heterogeneous Agent Papers With the Extensive Margin

- **Krueger et al. (2016):** showed that unemployment risk changes consumption and saving dynamics.
- **Rendahl (2016):** demonstrated that fiscal policy is particularly effective when households face elevated job uncertainty.
- **Challe et al. (2017):** build a HANK model where aggregate demand is driven by fluctuations in precautionary savings due to endogenous employment.
- **McKay and Reis (2016):** highlight how unemployment insurance plays a critical role in dampening shocks when there is an extensive margin.
- **Ravn and Sterk (2017):** demonstrate how job uncertainty can endogenously generate demand-driven recessions.

Heterogeneous Agent Papers With the Extensive Margin Critiques

Critiques

- The Models are done in discrete time, which fails to capture the nuances of continuous employment transitions.
- Restrictive borrowing forcing agents to have zero assets. This misses the richness of how past borrowing or savings affect current saving and consumption decisions.
- Lack a fully specified life cycle framework, missing decisions households make based on the stage of life, and based on past employment paths. OLG framework allows for natural interagent borrowing and lending.

OLG literature

A Model of Secular Stagnation: Theory and Quantitative Evaluation, Eggertsson, Mehrotra, & Robbins (2019):

- Studies secular stagnation. Specifically, the binding zero lower bound (ZLB) occurs when the natural rate of interest is low and even negative.
- Use a similar framework to their overlapping generations (OLG) endowment economy to show how tightening borrowing constraints for the unemployed young agents affects household loans.

The Housing Boom and Bust: Model Meets Evidence, Kaplan, Mitman, and Violante (2019):

- Studies multiple shocks that generate fluctuations in equilibrium house prices with an OLG model.
- Use debt with a maximum payment-to-income ratio (PTI) and a minimum payment that forces amortization before retirement.

Labor Market Flow Dynamics

Reassessing the Ins and Outs of Unemployment, Shimer (2012):

- Analyzed quarterly data in a continuous-time framework and found that employment to unemployment transitions over a quarter are driven predominantly by the failure of recently separated workers to find new jobs, a dynamic that was not captured in prior discrete-time analysis.
- "Movements in the job finding probability account for 77 percent of fluctuations in the unemployment rate since 1948, rising to 90 percent after 1987."

What This Reasearch Adds

Extensive Margin in Continuous Time HA model:

- Allows for more realistic employment transition dynamics.
- Will create a precautionary motive.

Adding a lifecycle component:

- Capture unemployment rate variation across age groups, both in the steady state and impulse response functions.
- Captures precautionary savings motivations across different age groups.

What this allows us to see:

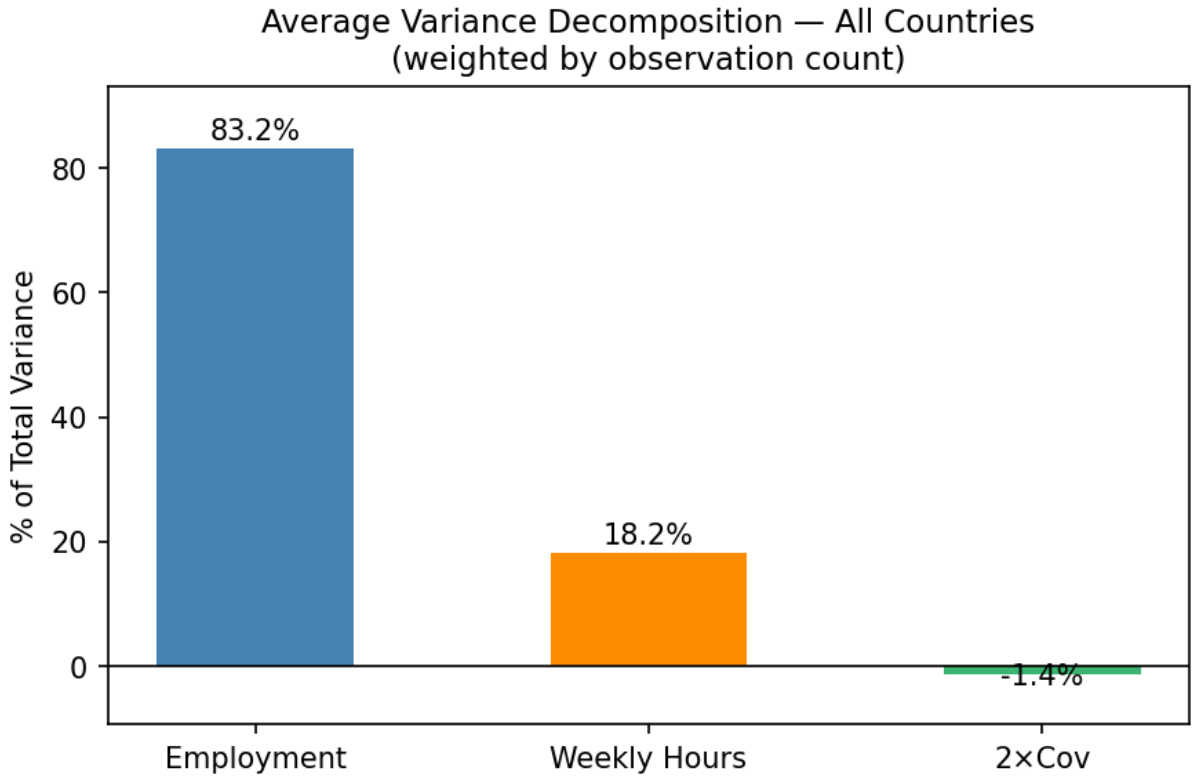
- This allows us to see how labor dynamics affect saving and consumption decisions.
- This gives us a deep dive into what drives household debt.

Data used

European data as a complement:

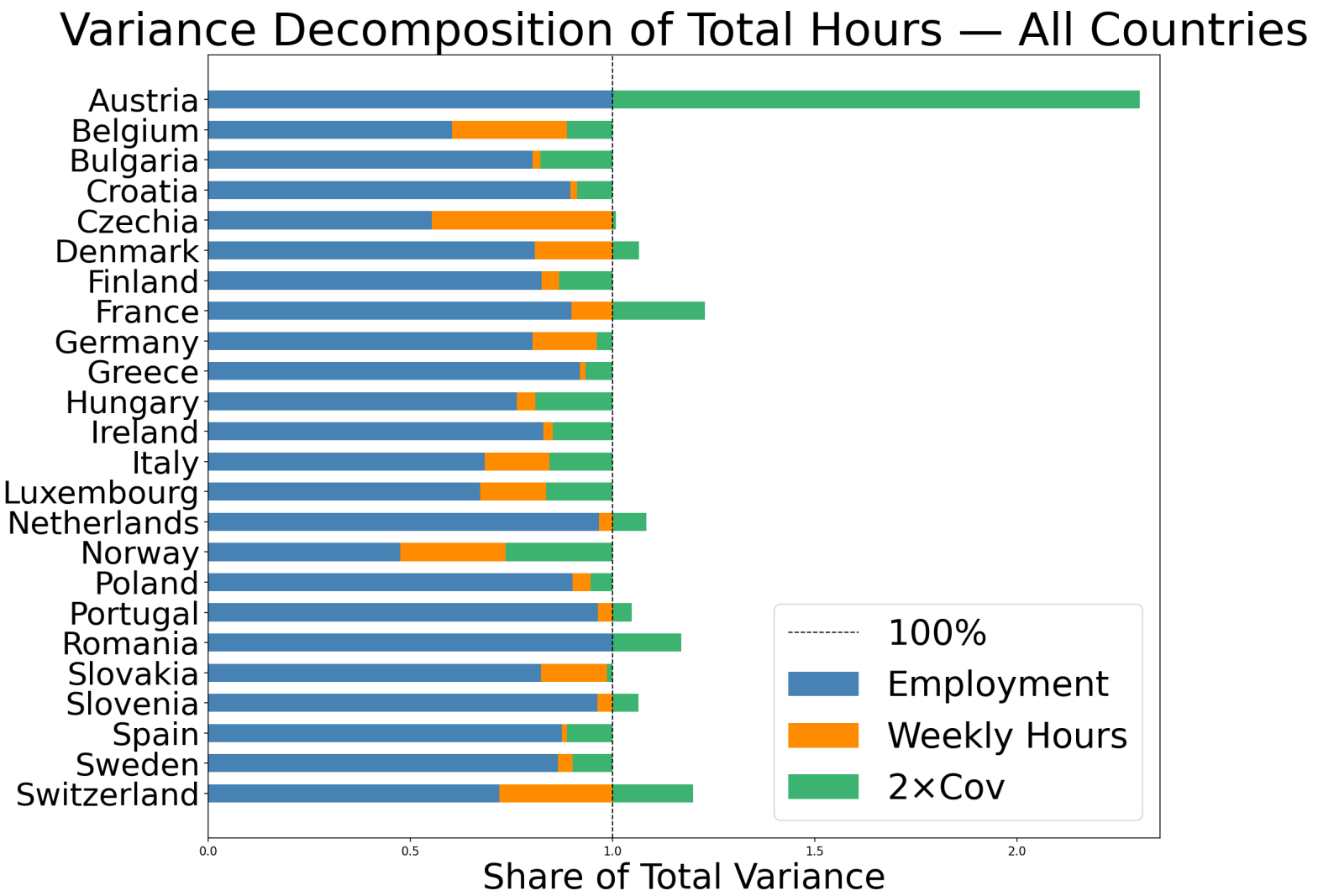
- Data is Quarterly from 1996 to 2019
- Greater cross-country variation that can be exploited for identification.
- The US lacks comprehensive state level household debt data, limiting the scope of within state debt analysis.
- European empirical evidence provides additional clarity by capturing a broader set of shocks and institutional differences that a single country study may miss.
- Specifically, Europe is ahead of the US by 10 to 20 years with their demographic cycle, and the PIGS (Portugal, Italy, Greece, and Spain) had public debt issues that the US hasn't yet faced, but is becoming more likely as its debt increases.

Variance Decomposition

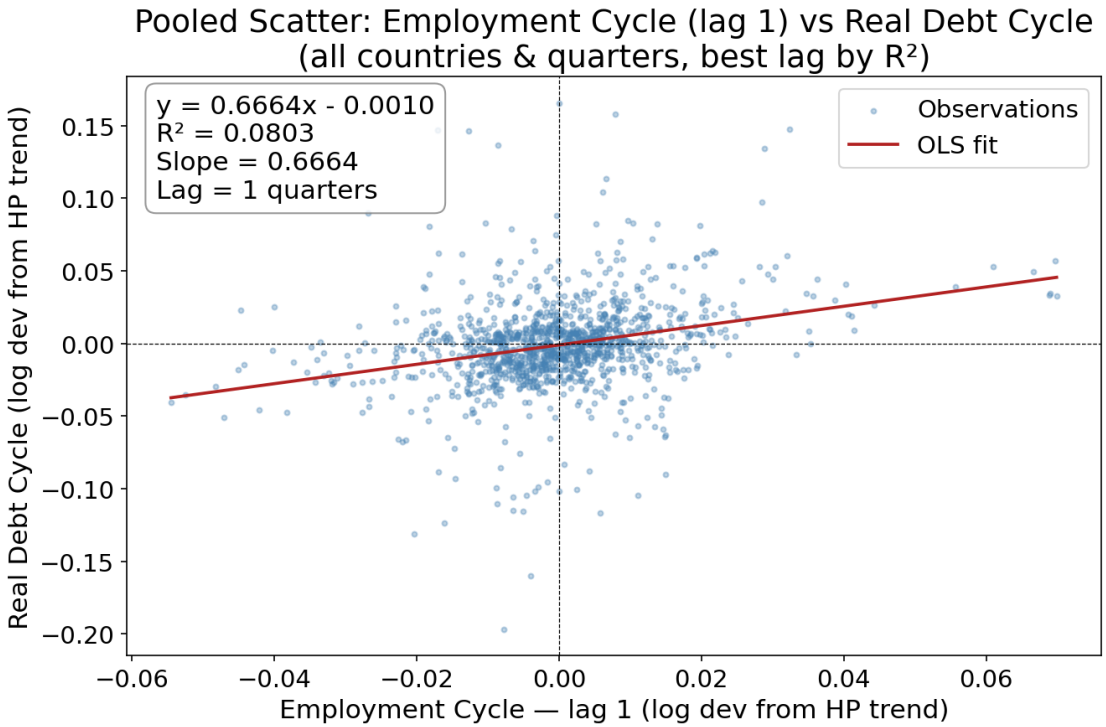


- Employment dominates total variance.
- correlation is barely negative because of Austria's negative covariance.

Variance Decomposition Within Country



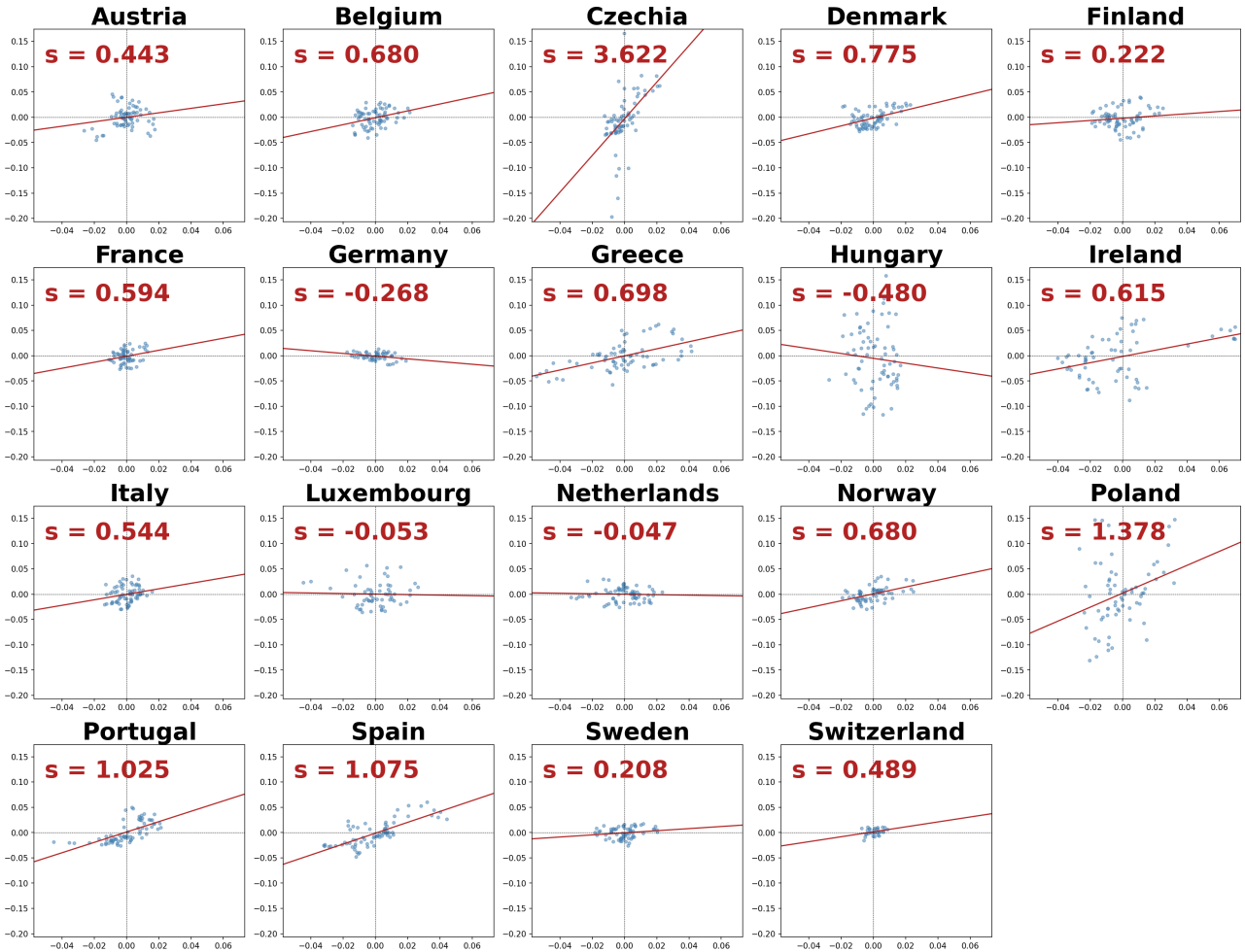
Employment vs Debt Aggregate



- There is a strong correlation between real detrended household debt and detrended unemployment lagged by one quarter/period.
- Unemployment was lagged due to its empirical significance.
- Detrending method follows the same framework as Hansen 1985

Employment vs Debt Country Specific

Employment Cycle (lag 1) vs Real Debt Cycle — By Country



Why Use The OLG Model

Big Picture view of OLG model

- The young agents will be employed or unemployed.
- The model is used to highlight what happens to loan demand when only the youth unemployment rises.
- Only youth unemployment was chosen to vary for model simplicity, and empirically it varies by more than the aggregate unemployment rate.

OLG Overview

Quick Details:

	Income	Borrowing/Dissaving	Consumption
Young Unemployed	+	0	+
Young Employed	++	+	+++
Middle Age Employed	+++++	− −	+++
Old Retired	++	+	+++

Borrowing

- There is a lifecycle consumption smoothing dynamic
- Borrowing constraint is based on income.
- Borrowing constraint is an exterior solution.

OLG Setup

- **Utility Function**

$$U_t^y = ln(C_t^y) + \beta ln(C_{t+1}^m) + \beta^2 ln(C_{t+2}^o)$$

- **Debt Constraint**

$$D_t = B_t(1 + r_t) = \gamma Y_t^y$$

- **Euler Equation**

$$\frac{1}{C_t^m} = \beta E_t(1 + r_t)\frac{1}{C_{t+1}^o}$$

OLG Setup cont.

- **Loan Demand**

$$L^d = \frac{\omega_t D^e + (1-\omega_t) D^u}{1+r_t}$$

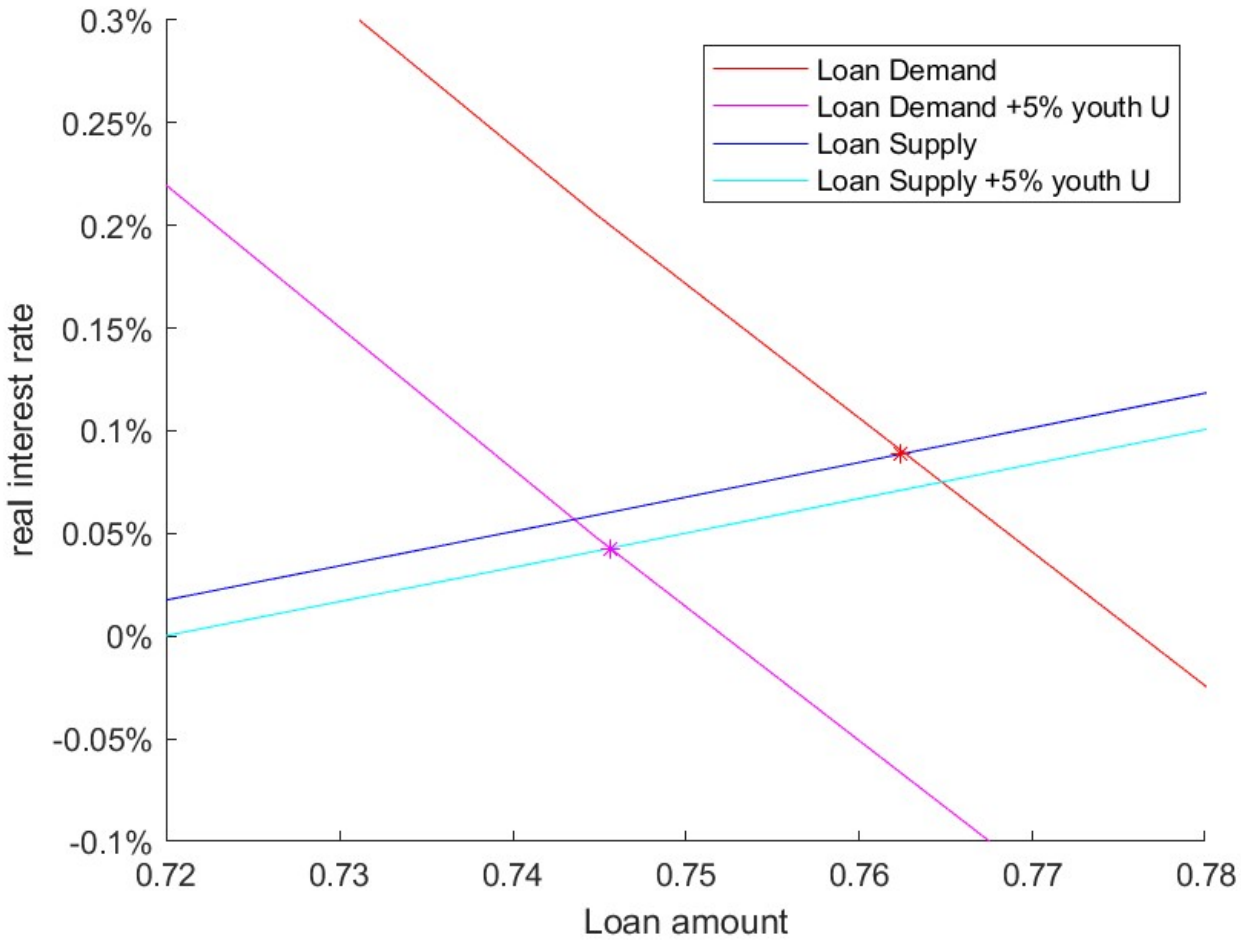
- **Loan Supply**

$$L^s = \left(\frac{\beta}{1+\beta}\right)\left(Y_t^m - \omega_{t-1} D^e - (1-\omega_{t-1}) D^u\right) - \left(\frac{1}{1+\beta}\right)\frac{Y_{t+1}^o}{1+r_t}$$

- **Interest Rate**

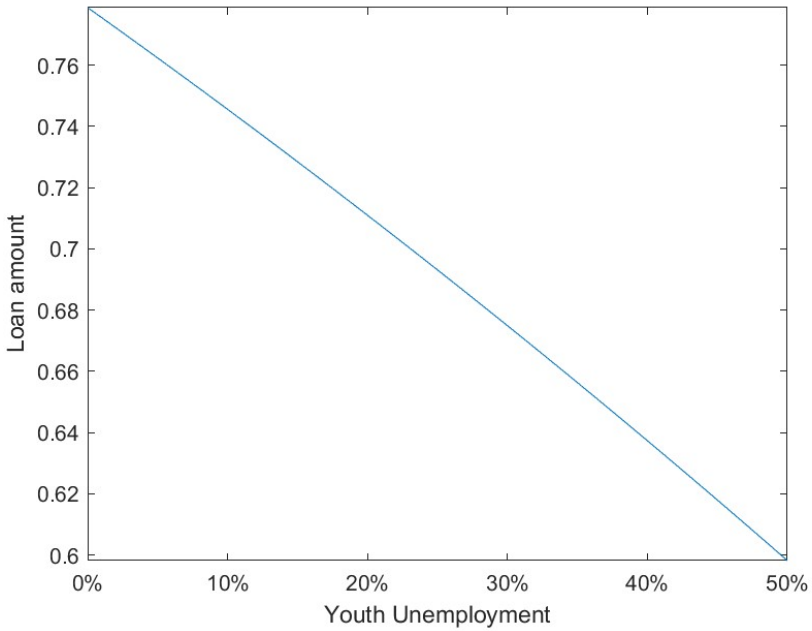
$$1 + r_t = \frac{(1+\beta)(\omega_t D^e + (1-\omega_t) D^u) + (\frac{1}{1+\beta}) Y_{t+1}^o}{\beta(Y_t^m - \omega_{t-1} D_{t-1}^e - (1-\omega_{t-1}) D_{t-1}^u)}$$

Results: Youth Unemployment's Comparative Static

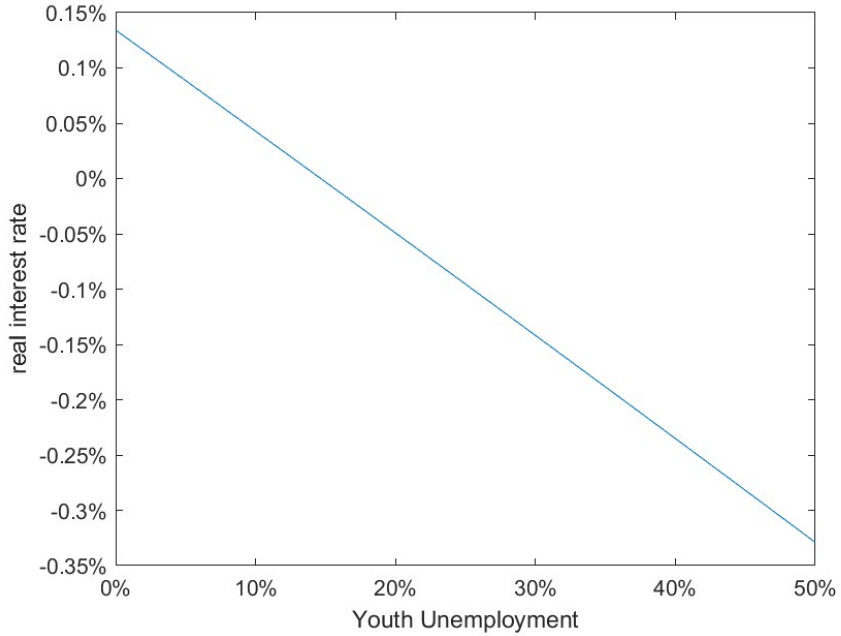


Notes: Highlights the effect of youth unemployment on loan demand and loan supply.

Results: Youth Unemployment on Total Loans and Interest Rate



Notes: The loan amount drops at higher employment rates.



Notes: Interest rates drop as youth unemployment goes up.

Why Use a HA Model

Big Picture View of HA Model

- Look at what happens when total hours worked is reduced through the extensive margin and the intensive margin after a negative total factor productivity shock.
- This model will enable us to examine loan supply in addition to loan demand because the HA model is a more comprehensive model that incorporates precautionary savings and unemployment across all age groups.

Deeper Dive:

- Age 20-74 with 11, 5-year age grids.
- Debt amortizes before requirement at 65 and maintains a payment-to-income ratio.
- Borrowing and lending is now based on 3 saving motives.

HA Overview

Quick Details:

- Discrete 3-axis grid with values based on asset level, employment status (employed/unemployed), and age (20 - 75 death).
- Income is set by age and employment status
- Unemployment/Social Security is 40% of the average wage income in equilibrium.
- The young agents borrow to boost consumption now, and middle-aged agents save to pay down debt and for additional consumption when they retire.

Asset Basics

- The unemployed cannot borrow, but must maintain existing payments out of their unemployment payments.
- There is a precautionary savings motive to hold positive assets. This allows agents to smooth consumption when they are unemployed.

HA Setup

- **Value Function**

$$\rho v(a,e,l) = \max_c \; u(c) + v_a'(a)\dot{a} + \sum_{e' \neq e} \lambda_{ee'}[v(a,e',l) - v(a,e,l)]$$

$$+ \sum_{l' \neq l} \lambda_{ll'}[v(a,e,l') - v(a,e,l)]$$

- **Budget Constraint**

$$c(a,e,l) = (wz_l h_e + u_e(1-e) + \pi_l)(1-\tau) + ra - s(a,e,l)$$

- **Kolmogorov Forward Equation**

$$\partial_t g_t(a,e,l) = \partial_a[s(a,e,l)g_t(a,e,l)] - g_t(a,e,l)\sum_{e' \in E} \lambda_{ee'} + \sum_{x \in E} \lambda_{xe} g_t(a,x,l)$$

$$- g_t(a,e,l)\sum_{l' \in L} \lambda_{ll'} + \sum_{x \in L} \lambda_{xl} g_t(a,e,x)t$$

HA Setup Continued

- **Asset Market Clearing Condition**

$$A(r) = 0 = \sum_e \int_l \int_a ag(a, e, l; r)\, da$$

- **Government Budget Clearing Condition**

$$gov\_surplus = 0 = \sum_e \int_l \int_a \tau_1(w(z_l h_{e,t}) + \pi_l)$$

$$- \sum_e \int_l \int_a u_e(1 - e)$$

Savings Motive

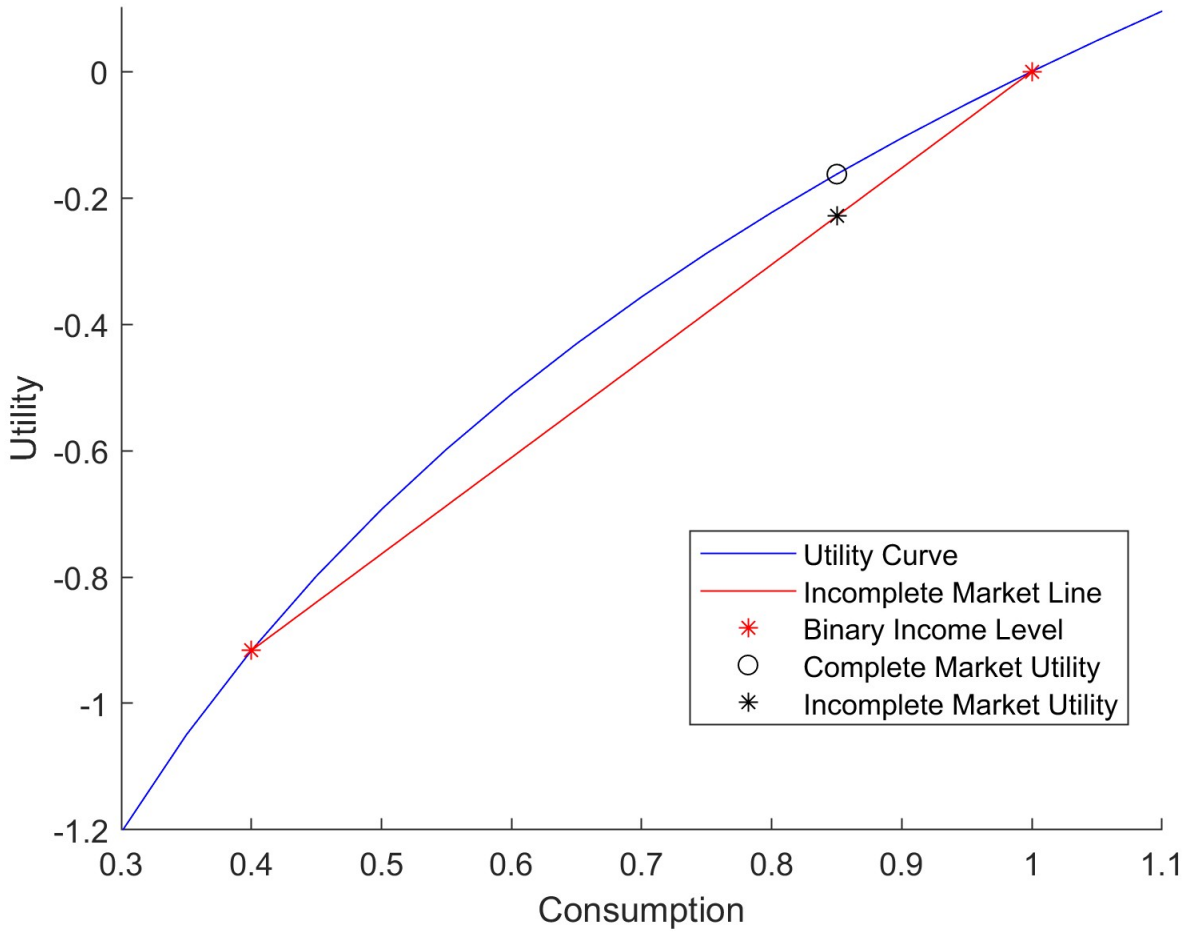
Three savings motives

- Intertemporal Savings Motive: savings concerning r and ρ.
- Smooth Consumption: smooth savings over the life cycle.
- Precautionary motive: occurs when the convexity of the marginal utility $u''' > 0$.

Effect of Unemployment increase

- The borrowing-constrained unemployed agents cannot smooth consumption.
- Agents at or around zero assets have a higher precautionary savings motive as the risk of unemployment becomes more likely with a longer unemployment duration.

Incomplete Markets



Notes: There is a motivation to self-insure when facing the same expected income when there is a range of possible incomes.

Asset Movement

- The amount of debt that can be taken out (negative asset level) is based on a payment-to-income ratio and a minimum debt payment that amortizes at retirement age.
- Payment to income PTI based on Quercia, R. G., McCarthy, G. W., & Wachter, S. M. (2003) value of .28.

$$pmt_t = .28 y_{e,l} e_e$$

- Minimum Payment amount

$$pmt_t = \frac{-a * r}{1 - (1 + r)^{65-l}}$$

- Assets at the time of death will be given to the new group of 20-year-olds as a bequest from dying grandparents to grandchildren.

Life Cycle Movement

- The income is based on the income by age in the 2013 report by the BLS. The data was fit with a parabola for simplicity.
- The dividend is based on the same methodology. All employed individuals get the same dividend income by age.
- There is forced retirement at age 65. Everyone provides a perfectly inelastic labor supply when below age 65.

Firm Dynamics

- Labor used is the sum of on the productivity by age z_l times hours worked by all agents $h_{e,t}$.

$$N_t = \sum_e \int_l (z_l h_{e,t})$$

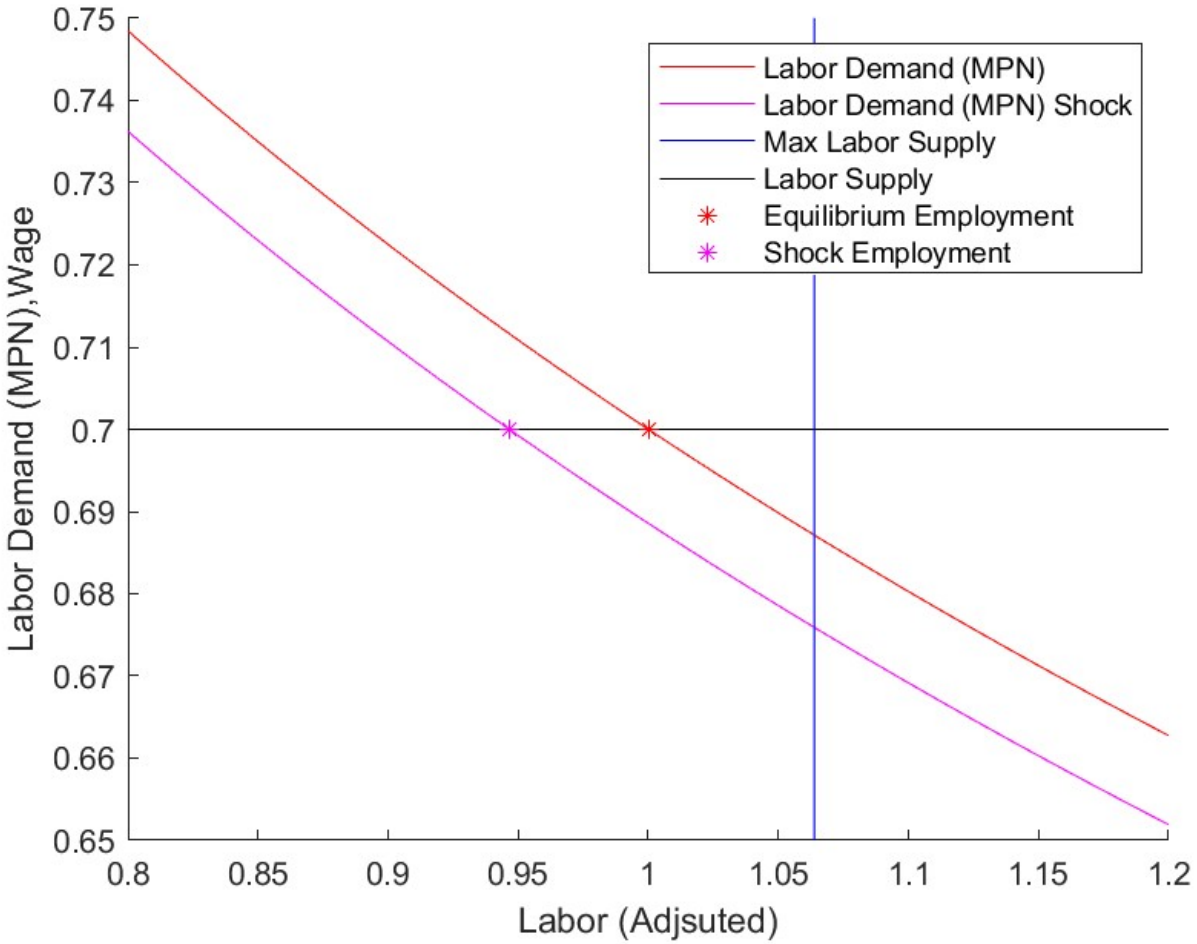
- Standard profit function exists with a fixed efficiency wage.

$$\pi_t = A_t (N_t)^{1-\alpha} - wN_t$$

- Labor demand is determined by

$$N_t = \left(\frac{A_t(1-\alpha)}{w}\right)^{\frac{1}{\alpha}}$$

Labor Market With Shock



Notes: Downward wage rigidity and a negative productivity shock drive unemployment. This is a divergence from when agents choose the hours they work.

Employment Movement

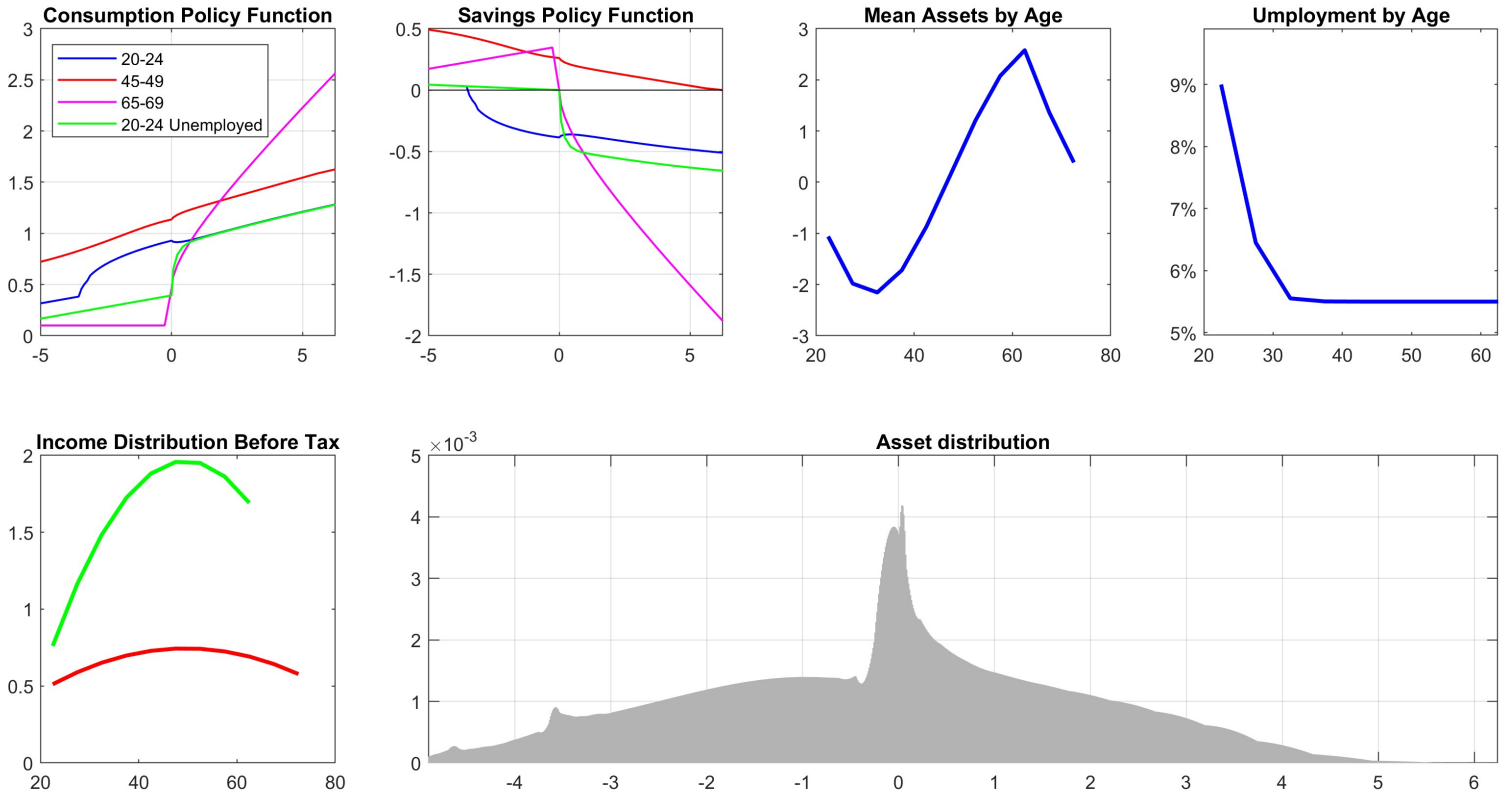
Employment Flows (Shimer 2012)

- From 1948 to 2010, the quarterly average of monthly hiring rates is 44 %. This corresponds to a 82 % quarterly hire rate.

Unemployment Dynamics used to enrich the model

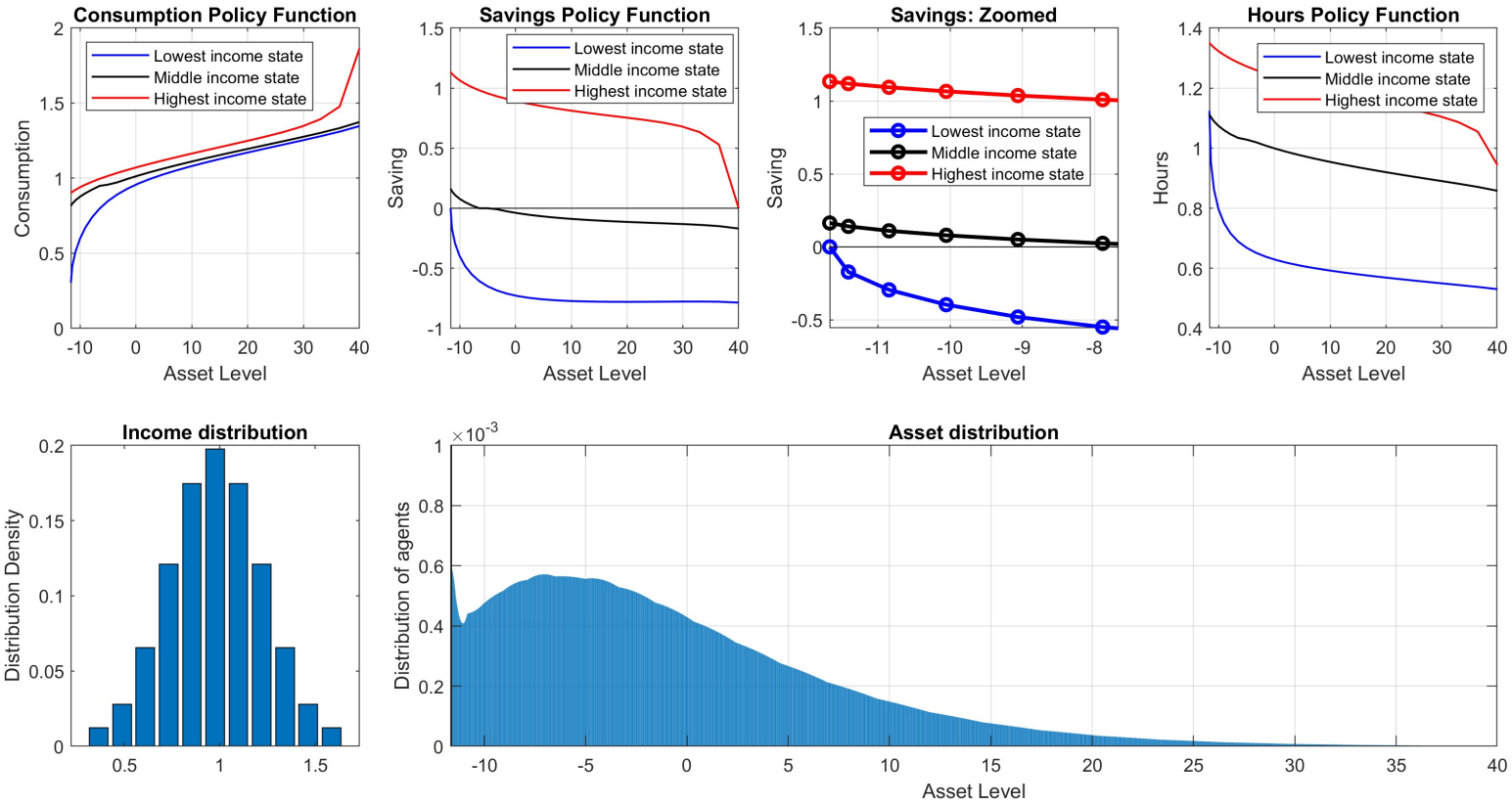
- The unemployment of 20-24 year olds is 1.5x total unemployment.
- 25-34 unemployment roughly matches the total unemployment rate.
- The separation rate is set to ensure that total unemployment matches the natural rate.
- The chance that 20 - 29 year olds exit employment is set to be higher.
- A portion of 20-year-olds will start employment by taking some of the jobs vacated from the retirement of 65-year-olds.

Steady State Dashboard



Notes: There is no missing middle. Mean assets by age show borrowing and savings behavior because realistic modeling of income and unemployment by age

Steady State Dashboard: Standard Huggett Model



Notes: Asset distribution suffers from the missing middle. Agents here choose how much they work.

Intensive vs Extensive Margin vs Huggett Model

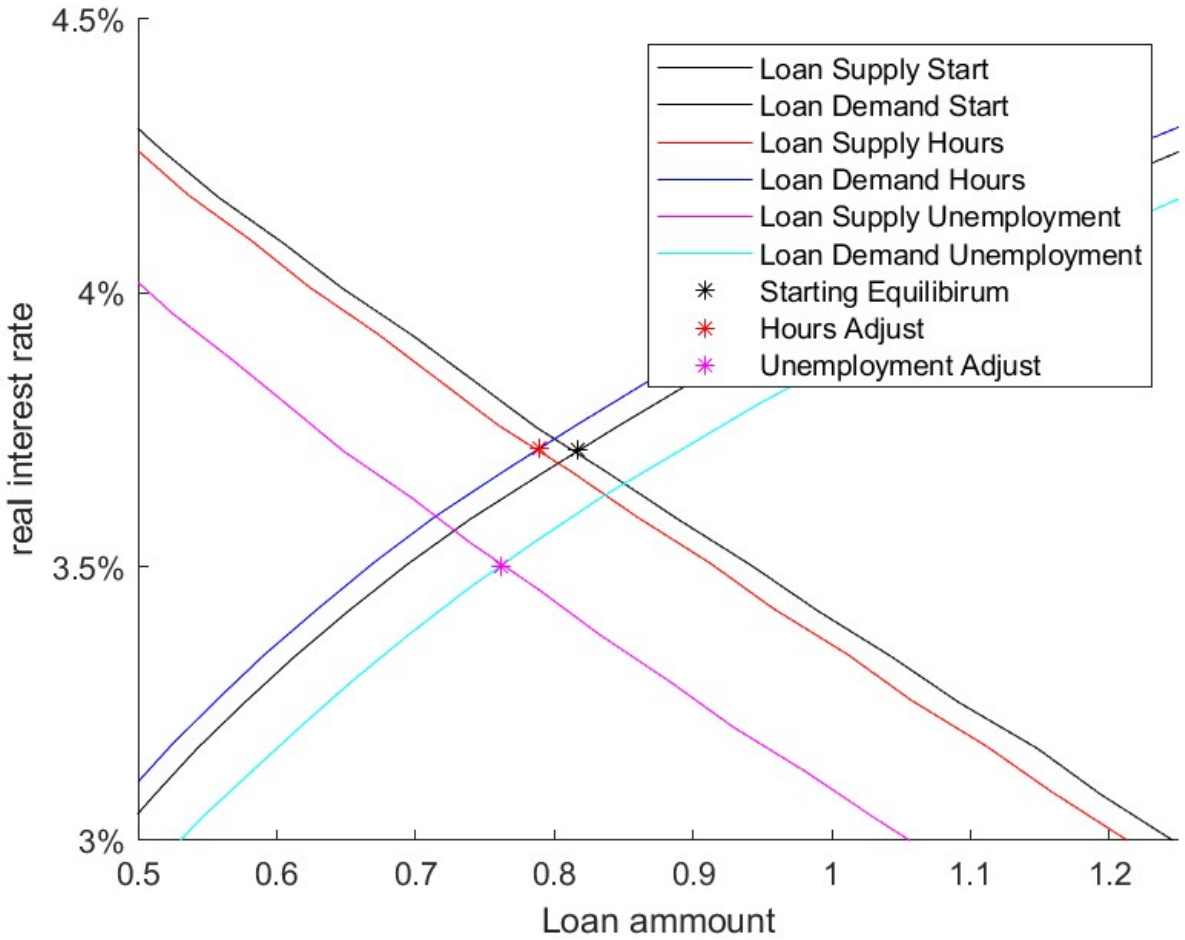
Intevsive vs Extensive Margin

- After a productivity shock, total hours worked drop.
- The two separate models will be used to see the difference in the outcome based on whether the time worked per working agent decreases or employment drops.
- This allows us to highlight differences between the two margins, not only in outcomes but also in loan demand and loan supply.

Huggett Model

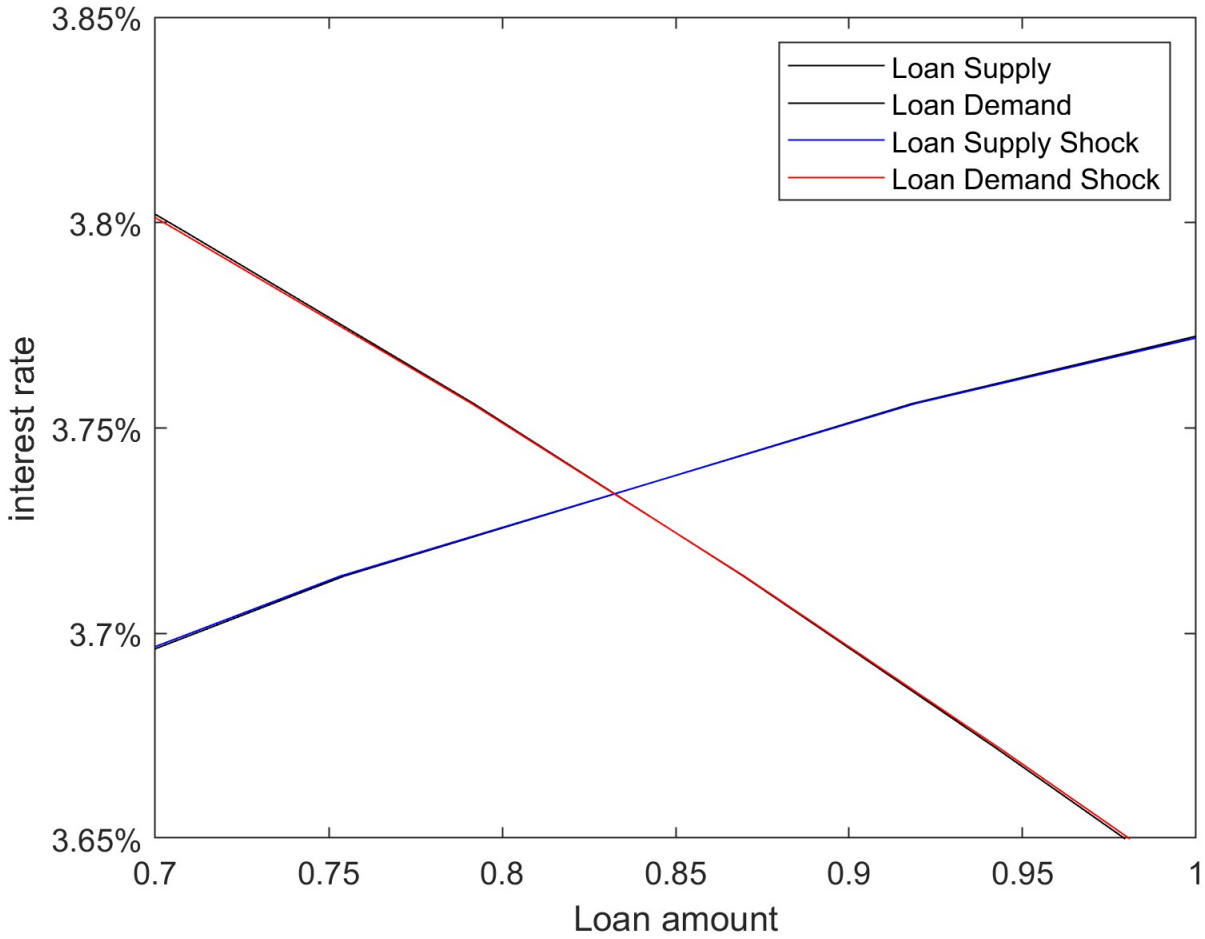
- The standard Huggett model is used to demonstrate that it fails to capture the interest rate and leverage phenomena without adding capital and making household loans quasi-business loans.
- Huggett model doesn't have significant changes in the precautionary savings motive.

HA Comparative Static



Notes: The extended margin has large effects on both the loan supply and loan demand.

HA Comparative Static Standard Huggett



Notes: Little to no effect in the comparative static for Huggett model.

Why Study HA IRF

Big Picture View of HA Model

- IRF allows us to compare the IRF to both a temporary and a permanent productivity shock in the intensive margin and extensive margin models.
- This will highlight the impact, if any, of incorporating employment risk on the saving and borrowing dynamics.

Outputs of Study:

- Real interest rates, household loans outstanding, percent of individuals borrowing constrained, hiring transition probabilities, and the unemployment rate.

IRF Methodology

Overall Methodology

- I use the Achdou, Han, Lasry, Lions, and Moll (2022) continuous-time approach to solve the model.
- The value function (HJB) is solved backward, and then the distribution is solved forward (KFE).

Labor Adjustment Cost

- This is added because transitioning employment instantaneously doesn't make sense.
- Lechthaler & Snower (2013) added quadratic labor adjustment costs to a new Keynesian model.

Solving the IRF

HJB and KFE

- HJB is solved backward, and KFE is solved forward.
- Three residuals: labor market, government budget, and asset residual are solved in order.

Effective Labor Determined by:

$$V = \max_{N_t} \int_0^\infty e^{-\rho t}(A_t(N_t)^{1-\alpha} - wN_t - \frac{\theta}{2}\dot{N_t}^2)\,dt \tag{1}$$

- Adjust labor usedthe , ensuring that the quantity of labor used equals firm's quantity demanded.
- Adjust the hiring rate in the Extensive Model.
- Adjust hours worked by agent in the Intensive Model.(N_t)

Solving the IRF cont.

Taxes

- Taxes depend on the production and the number of unemployed agents and can be solved after the labor market.
- This is solved using one iteration of a quasi-Newton method.

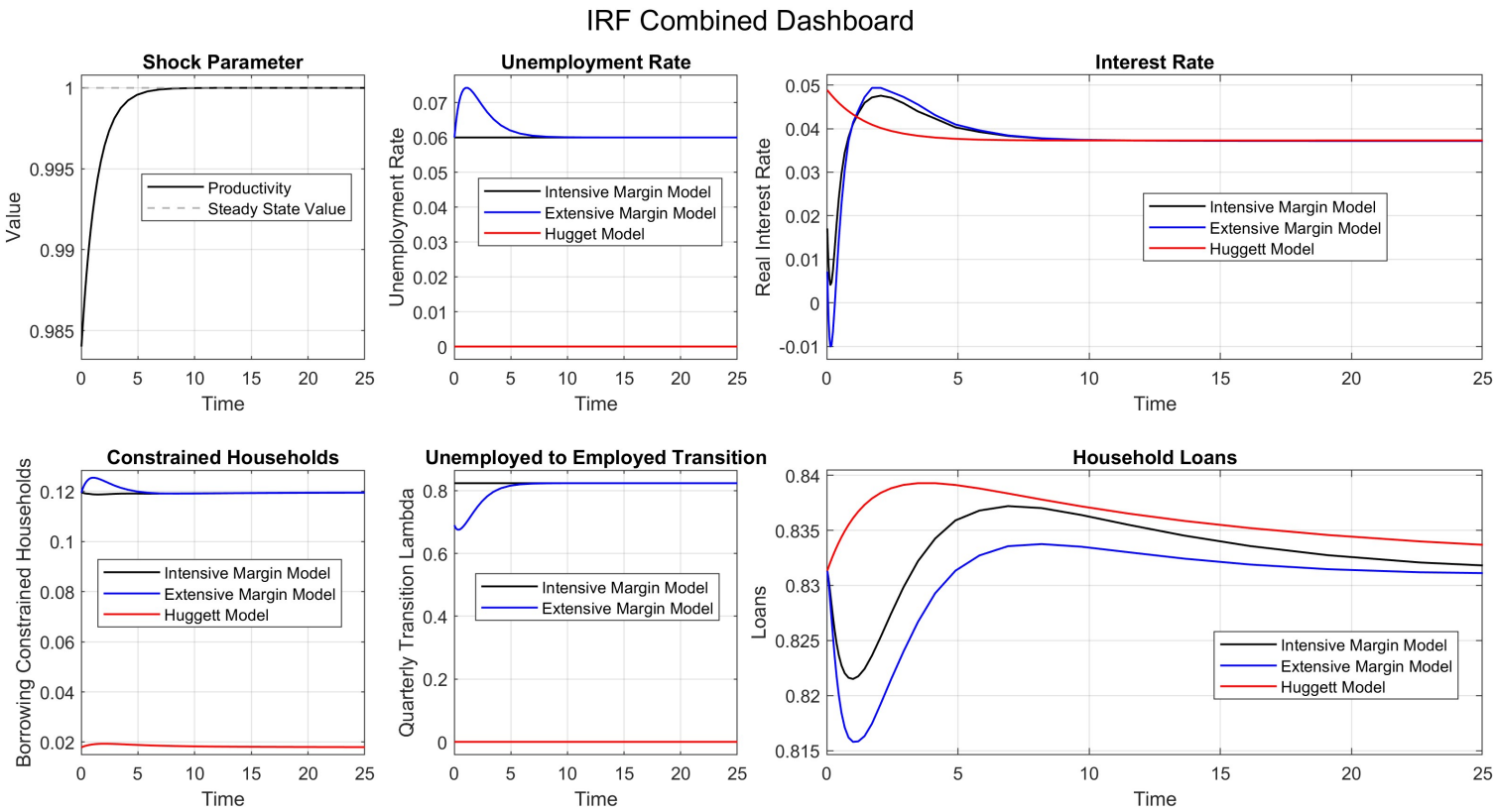
Interest Rate

- Interest rates have no effect on the labor market and taxes, so they can be solved independently after the labor market and government budget.
- Clear asset market A(t) = 0 at all time
- A smoothing function is used to smooth the interest rate path.
- Levenberg-Marquardt Gauss-Newton (LM-GN) method used

Smoothing Function:

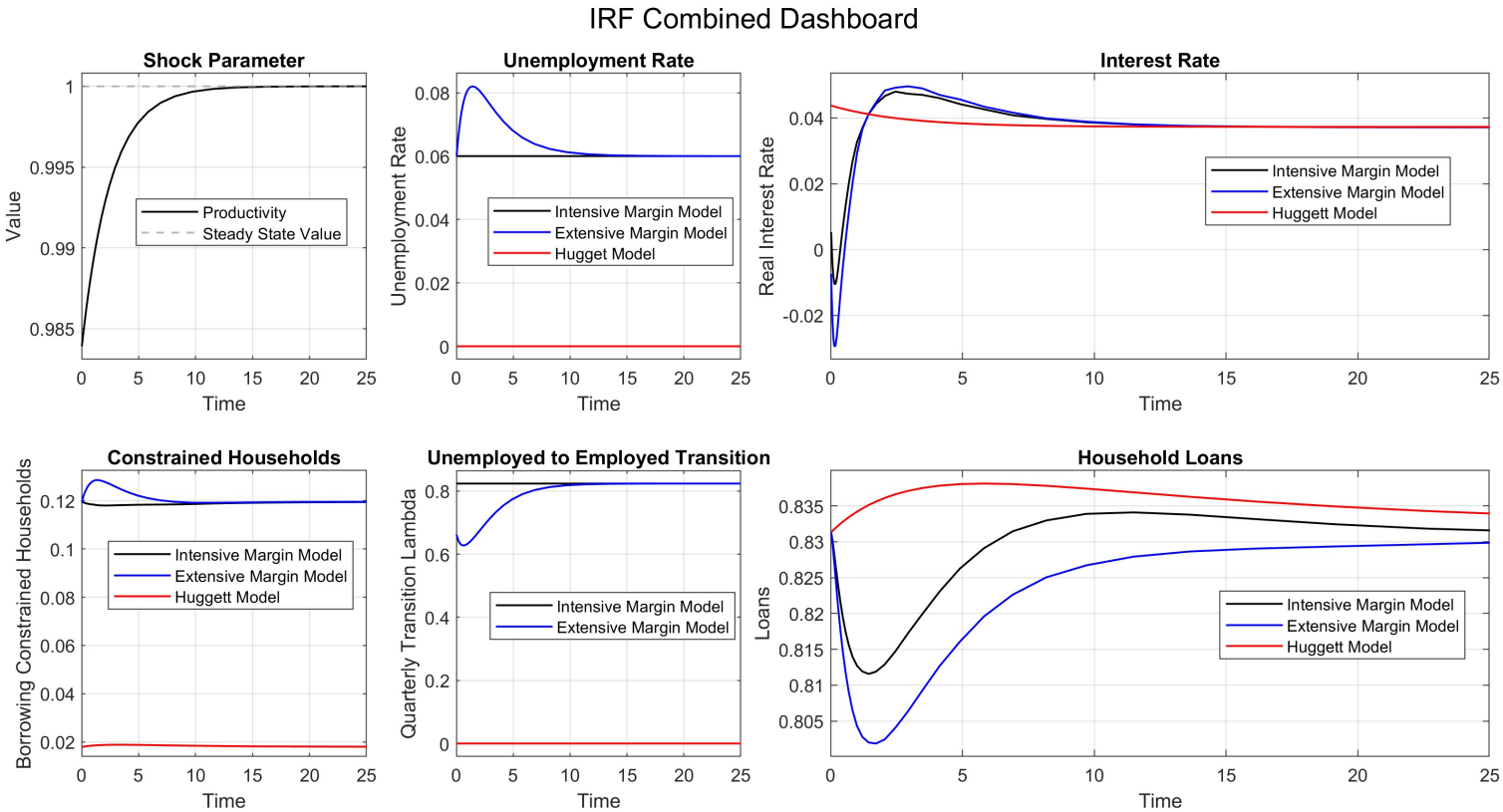
$$p(i) = \frac{x(i+1) - x(i)}{\Delta_f} - \frac{x(i) - x(i-1)}{\Delta_b}, \tag{2}$$

Temporary Negative Productivity Shock



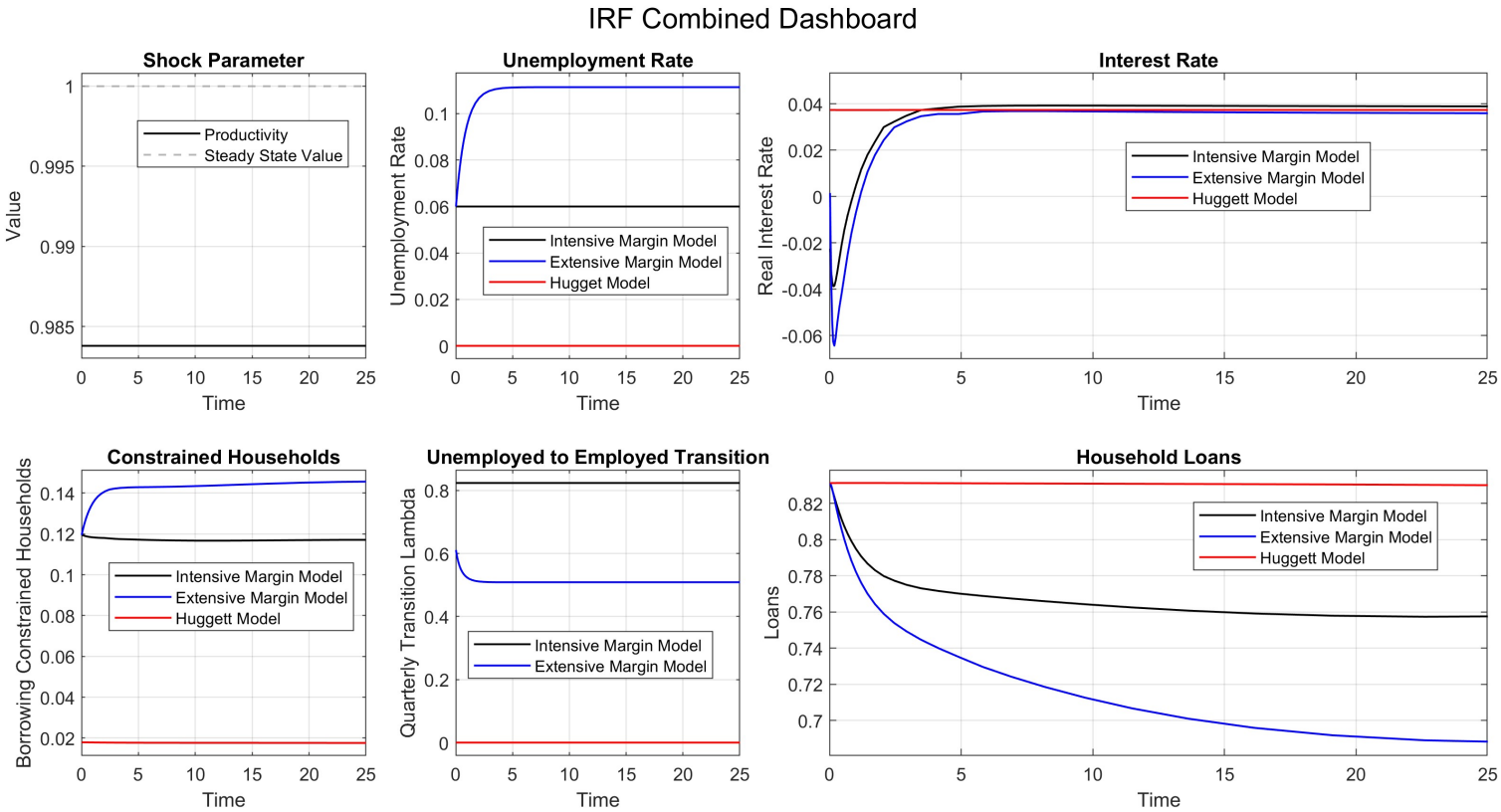
Notes: Large standouts are the interest rate paths with the Extensive Margin Model having the lowest bottom before both spike above the Huggett Model. Both the Extensive and Intensive Models have an initial contraction in household debt before increasing.

Higher Persistance Shock Productivity Shock



Notes: Increasing shock persistence to .9 creates the dynamics where the extensive margin does not overshoot the starting household loan value.

Permanent Negative Productivity Shock



Notes: Difference in leverage response is large and interest rates have persistant differences.

Empirical Overview

- Both vector autoregression (VAR) and Local Projection (LP) will be used to show how real-world data is impacted by a productivity shock
- The variables of study are all quarterly and are labor productivity, weekly hours worked, unemployment rate, and household debt.
- Weekly hours and the unemployment rate are both used to show the employment dynamics after a productivity shock.
- Household Debt was used because it is the most stable variable that can be compared to the theoretical models, as interest rates are deeply affected by default probabilities.

VAR Structure

- The VAR was calculated with a Cholesky decomposition of errors.
- The order of the Upper triangle was as follows: labor productivity, weekly hours, unemployment rate, and household debt.
- the VAR imposes an AR(1) on the productivity shock, and all other variables are lagged by 4 quarters.

VAR Formula

VAR formula:

$$(I - \Phi_1 L - \Phi_2 L^2 - \Phi_3 L^3 - \Phi_4 L^4) X_t = e_t \tag{3}$$

This is a reduced from VAR that forces labor productivity to be an AR(1)

Φ_1 layout $\begin{bmatrix} a_{11} & 0 & 0 & 0 \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix}$ $\Phi_{2,3,4}$ layout $\begin{bmatrix} 0 & 0 & 0 & 0 \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix}$

$$X_t = \begin{bmatrix} A_t : LaborProductivity \\ H_t : WeeklyHoursWorked \\ U_t : UnemploymentRate \\ B_t : RealHouseholdDebt \end{bmatrix}$$

VAR Error Terms

Cholesky Error Terms:

$$e_t = Bu_t$$

Matrix Form:

$$\begin{bmatrix} e_{1t} \\ e_{2t} \\ e_{3t} \\ e_{4t} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ b_{21} & 1 & 0 & 0 \\ b_{31} & b_{32} & 1 & 0 \\ b_{41} & b_{42} & b_{43} & 1 \end{bmatrix} \begin{bmatrix} u_{1t} \\ u_{2t} \\ u_{3t} \\ u_{4t} \end{bmatrix}$$

Local Projection

Local Projection:

- Impulse response functions by running a sequence of OLS regressions for different horizons (h).

$$y_{t+h} = \alpha_h + \beta_h s_t + \gamma_h x_t + v_{t+h}$$

α_h constant, β_h Reaction to shock, and $\gamma_h x_t$ control variables

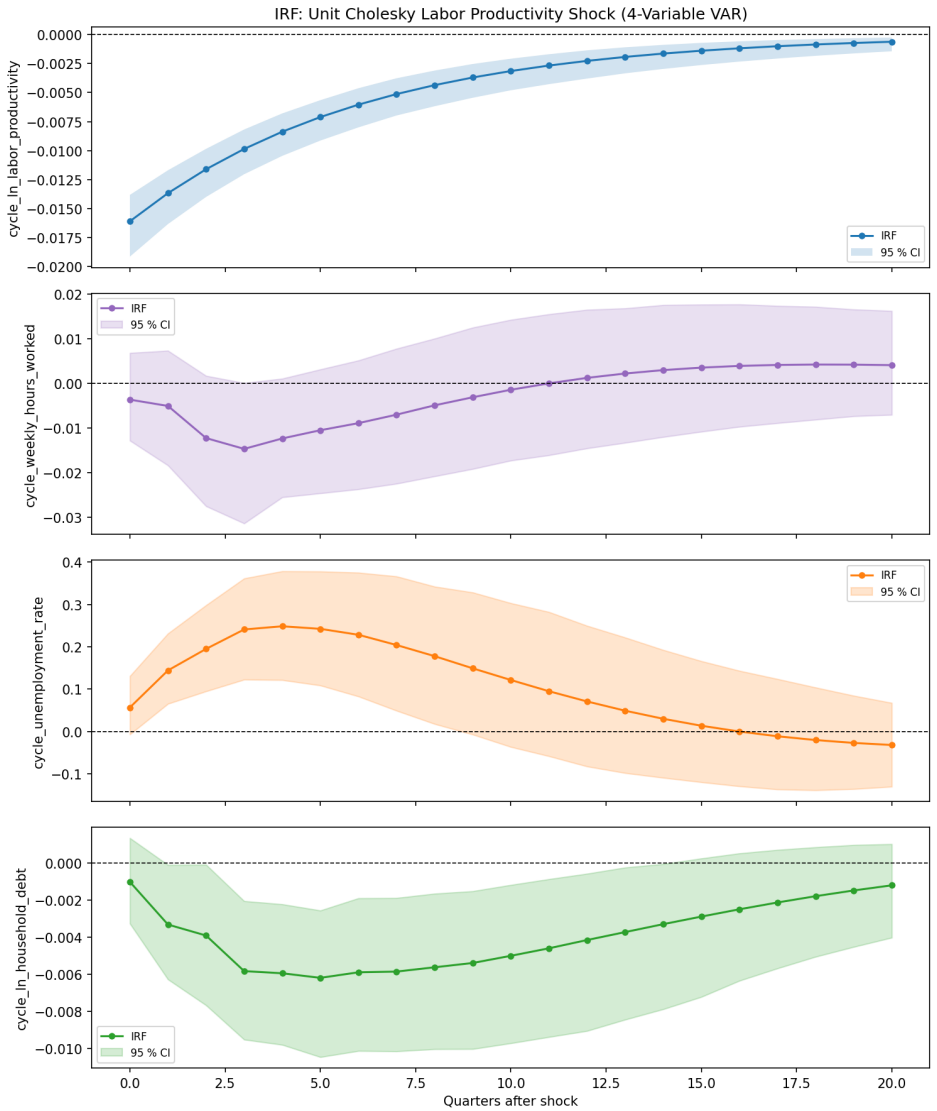
- Residual MA(h) Error Term:

$$v_{t+h} = u_{t+h} + \psi_1 u_{t+h1} + ... + \psi_h ut$$

VAR

VAR shows the following:

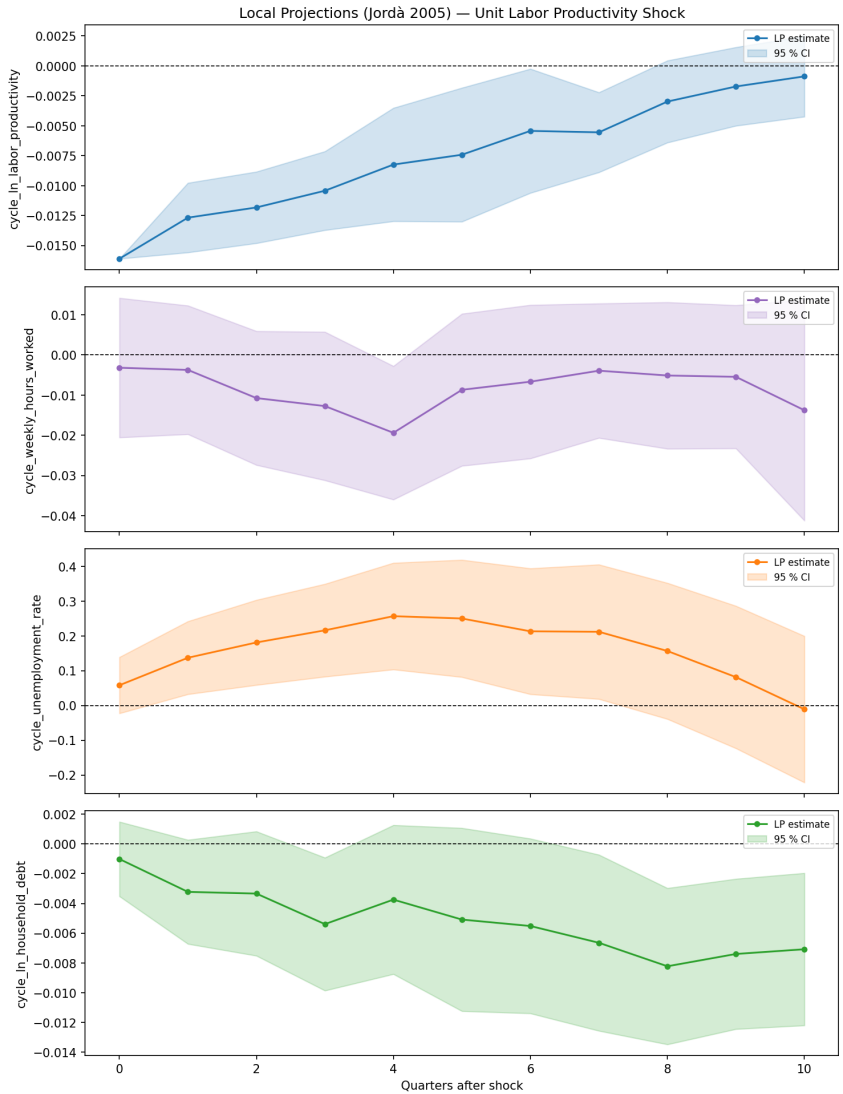
- Ln detrended productivity follows an AR(1) structure and shows the difference in log levels.
- Weekly hours worked don't move significantly.
- The UR increases significantly.
- Ln detrended real debt decreases significantly.



LP

LP broadly follows the VAR findings:

- Ln detrended productivity now moves freely.
- Weekly hours has minimal movement.
- The UR increases significantly.
- Ln detrended real debt decreases significantly over time.



Split Countries to Look at Difference

Why countries are split

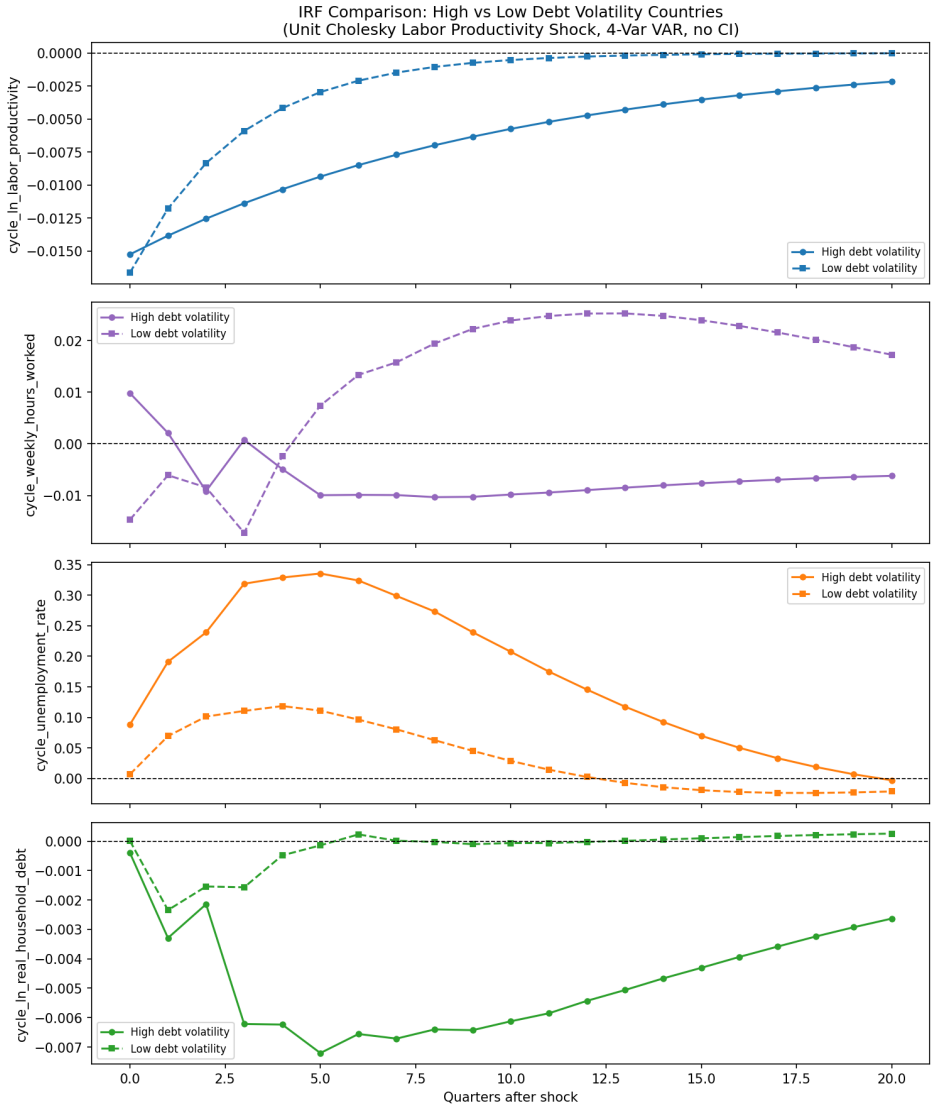
- Countries are split to see if there are significant differences in the IRF based on the splits

Countries Split by the following Groups

- Household Debt Variance
- Household Debt to GDP

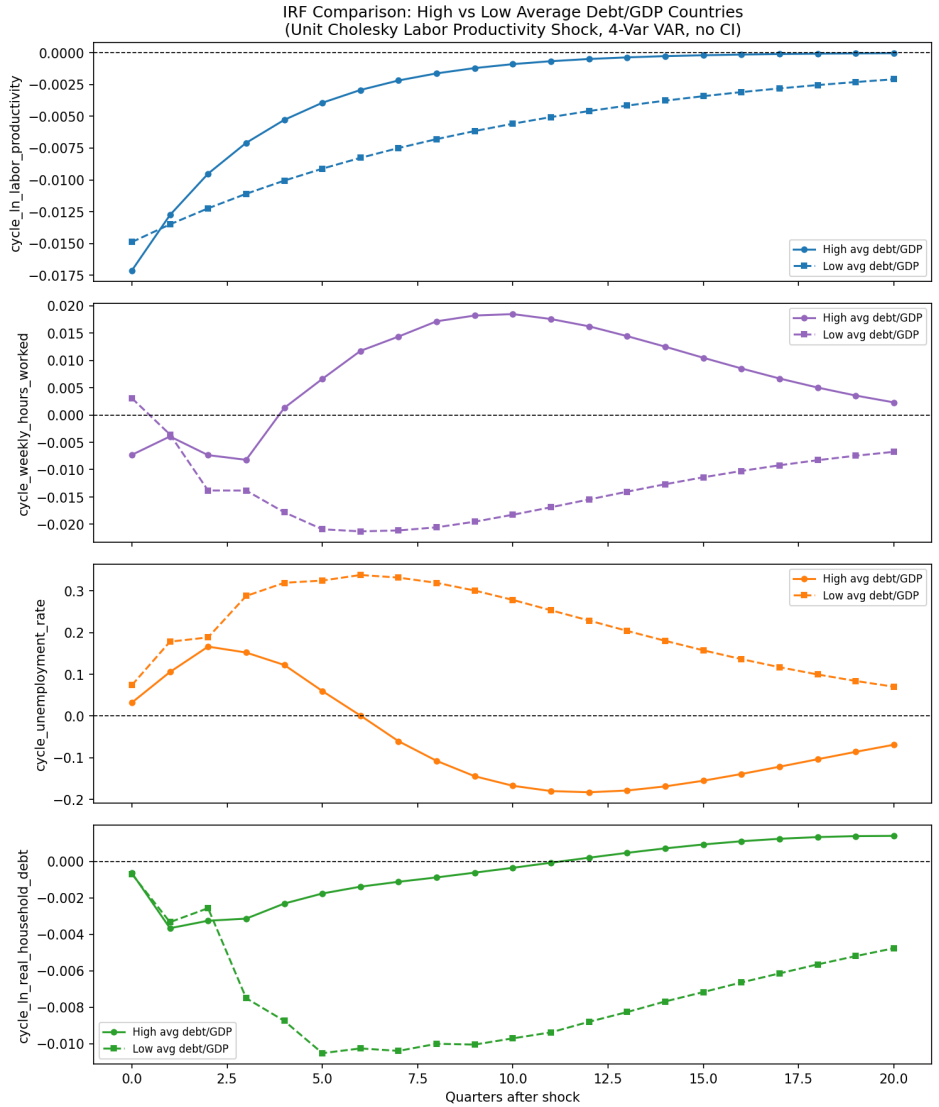
VAR Household Debt Volatility

- The countries are split based on the variance in cyclical real debt.
- The median variance 0.003472.
- High debt volatility countries (8): Czechia (var = 0.023705), Finland (var = 0.005124), Greece (var = 0.009867), Hungary (var = 0.019311), Italy (var = 0.004194), Poland (var = 0.012563), Portugal (var = 0.009483), and Spain (var = 0.010687)
- Low debt volatility countries (8): Austria (var = 0.001450), Belgium (var = 0.002750), Denmark (var = 0.002155), France (var = 0.000897), Germany (var = 0.000374), Ireland (var = 0.001910), Norway (var = 0.000353), and Sweden (var = 0.000665).



VAR High vs Low Household Debt/GDP

- The countries are split by on mean debt to GDP ratios.
- Median loans-to-GDP: 51.0
- High average household debt/GDP countries (8): Denmark (mean = 107.8), France (mean = 51.6), Germany (mean = 56.9), Ireland (mean = 78.6), Norway (mean = 78.5), Portugal (mean = 74.3), Spain (mean = 65.6), and Sweden (mean = 71.6).
- Low average debt/GDP countries (8): Austria (mean = 50.1), Belgium (mean = 49.8), Czechia (mean = 21.5), Finland (mean = 50.5), Greece (mean = 45.9), Hungary (mean = 22.6), Italy (mean = 34.9), and Poland (mean = 26.7).



Empirical Findings

- The empirical responses to productivity shocks show that the movement in the unemployment rate is significant, and weekly hours are not. They also show that real household loans are significantly affected by productivity shocks.
- Countries with high cyclical unemployment variation have similar productivity shocks, but the persistence is longer.
- This means that countries that experience persistent shocks have larger increases in unemployment, and therefore larger decreases in household loan balances.

Conclusion

- Most economic models adjust labor along the intensive margin and have complete markets, so they lack realistic precautionary motives.
- Hansen 1985 shows the extent of the extensive margin in the US, and this paper shows the extent in Europe.
- By having the extensive margin of the labor market in a life cycle model, household debt begins to react more similar to the empirical IRF.
- This paper documents a hole in the current literature.

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Lack of ability to spend and borrow from external sources

Forbes Article: 63% Of Americans Don't Have Enough Savings To Cover A $500 Emergency

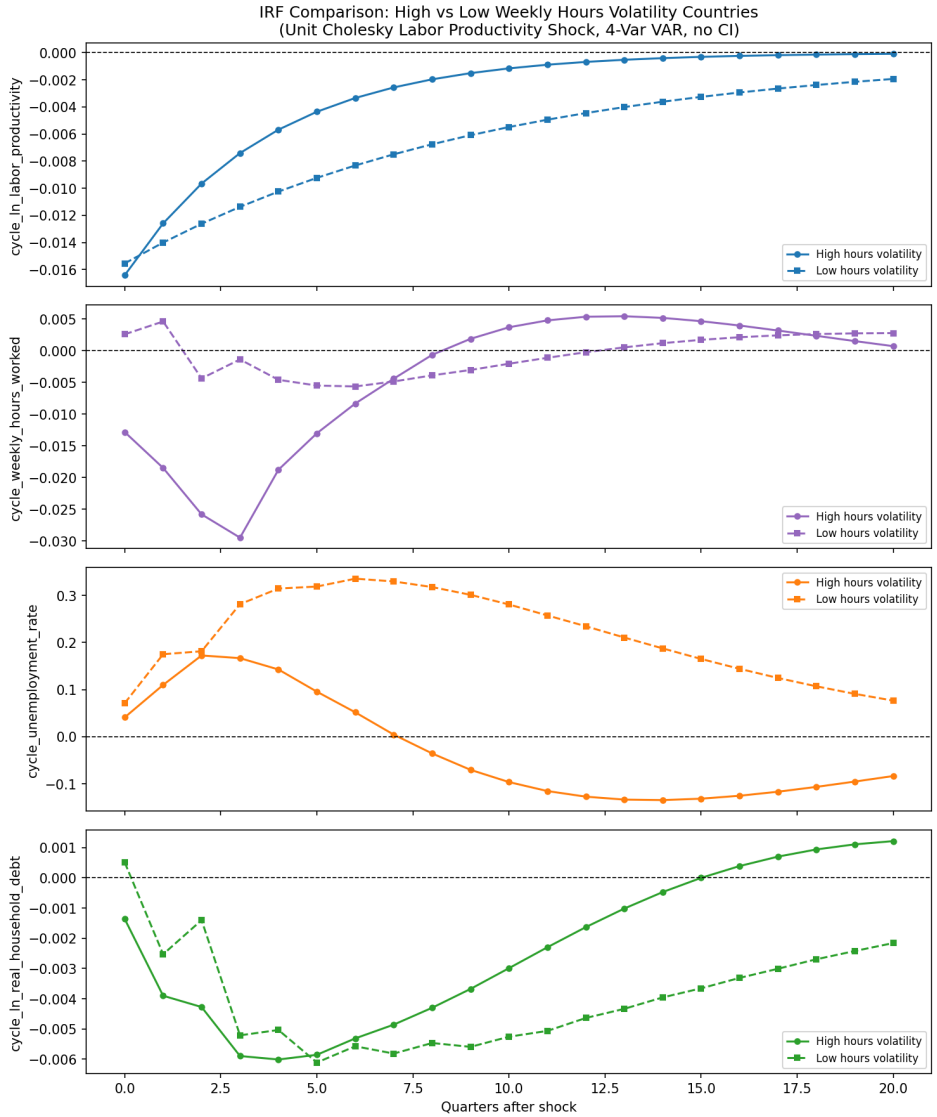
- This model simplifies all assets into one account, where in reality, individuals might have loans and a positive savings account.
- This is limited because most people don't have that much money in an extra savings account.

Liberty Street Economics: 18 percent of borrowers were using at least 90 percent of their available credit

- Credit cards allow people to smooth consumption even if they are in debt.
- This is limited because a good number of individuals are already at or near their credit card limit.

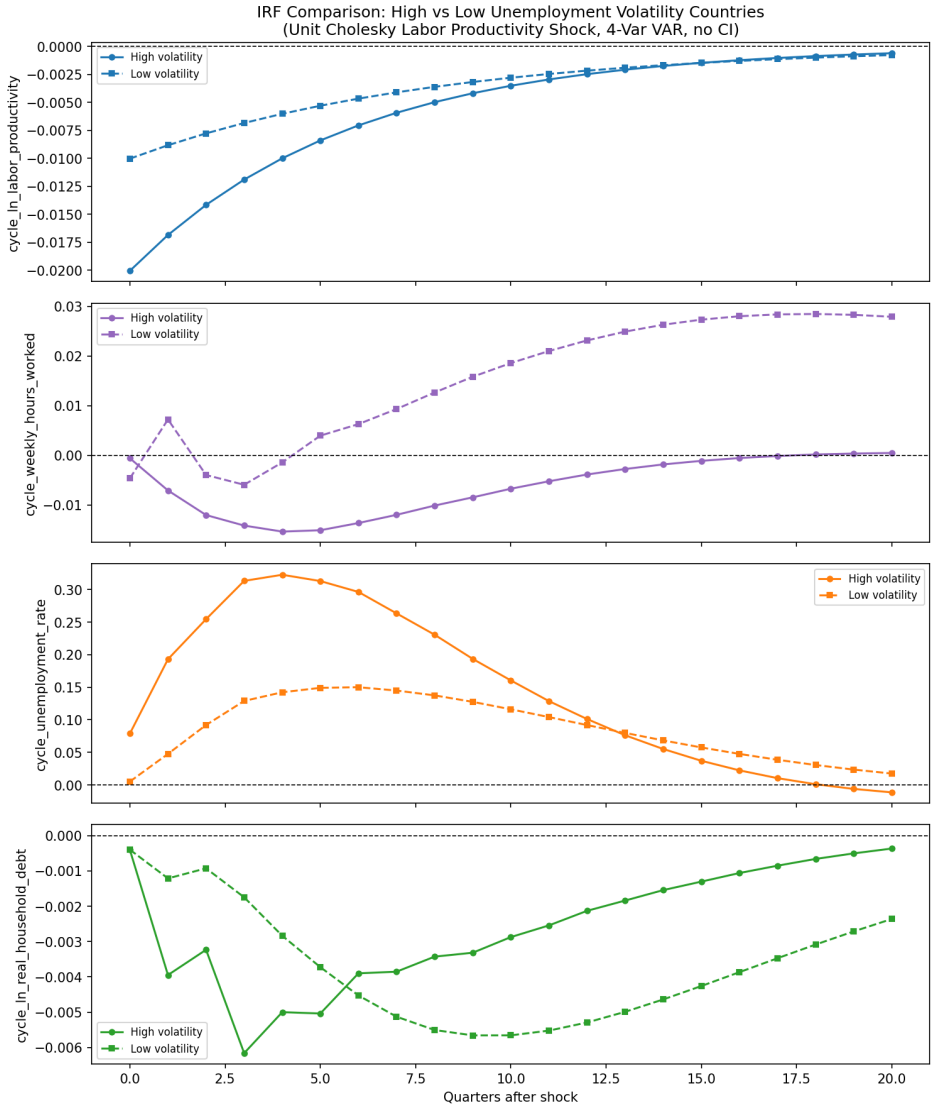
VAR Weekly Hours Variance

- The countries are split based on variance in weekly hours worked.
- The median variance: 0.061210.
- High hours volatility countries (8): Austria (0.750629), Czechia (0.132484), Denmark (0.156413), France (0.093829), Ireland (0.180871), Italy (0.168787), Portugal (0.061698), Spain (0.061316).
- Low hours volatility countries (8): Belgium (0.061104), Finland (0.016763), Germany (0.030801), Greece (0.056951), Hungary (0.043921), Norway (0.023075), Poland (0.036172), Sweden (0.014668).



VAR Unemployment Variance

- The countries are split based on the variance in the UR.
- Median variance: 2.1049.
- High UR volatility countries (8): Czechia (var = 3.6749), Greece (var = 41.3019), Hungary (var = 2.6149), Ireland (var = 7.0445), Italy (var = 2.1902), Poland (var = 5.4764), Portugal (var = 9.2806), and Spain (var = 24.5391).
- Low UR volatility countries (8): Austria (var = 0.3378), Belgium (var = 0.7696), Denmark (var = 2.0195), Finland (var = 0.7927), France (var = 0.3304), Germany (var = 0.0593), Norway (var = 0.3614), and Sweden (var = 0.7271).



Interest Rate Optimization

Levenberg-Marquardt

$$F_{aug} = [F; sqrt(\lambda_s) * Ps]; \tag{4}$$

$$J_{aug} = [J; sqrt(\lambda_s) * R]; \tag{5}$$

$$H = J'_{aug} * J_{aug} + \mu * eye(nT); \tag{6}$$

$$g = J'_{aug} * F_{aug}; \tag{7}$$

$$dx = -H^{-1} * G; \tag{8}$$