Resolving the Missing Deflation Puzzle

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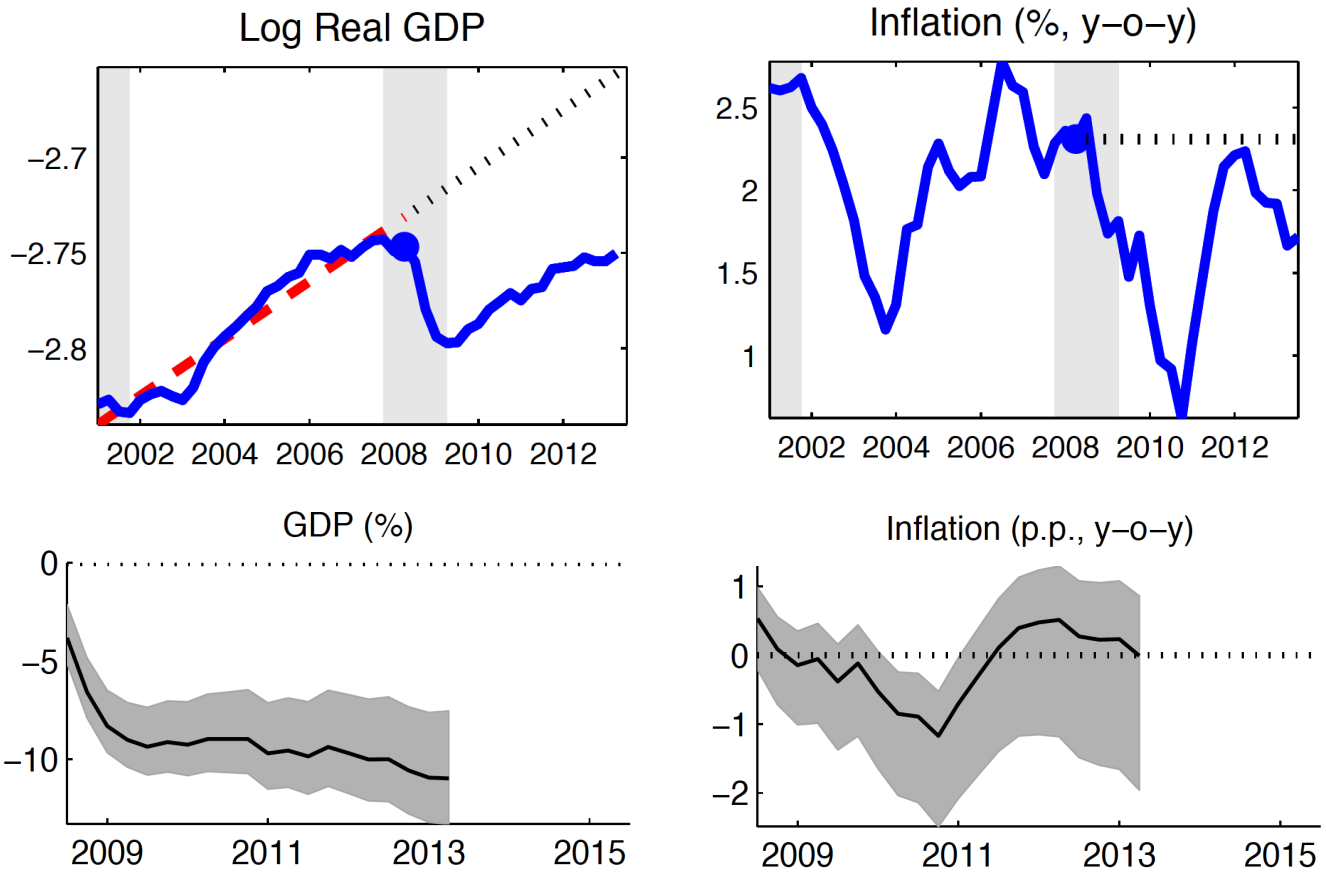
Motivation

- Key observations during the Great Recession:
  - Extraordinary contraction in GDP but only small drop in inflation.



Source: Christiano, Eichenbaum and Trabandt (2015, AEJ: Macro)

Motivation

- Small drop in inflation referred to as the "missing deflation puzzle":
  - Hall (2011), Ball and Mazumder (2011), Coibion and Gorodnichenko (2015), King and Watson (2012), Fratto and Uhlig (2018).

- John C. Williams (2010, p. 8): "*The surprise [about inflation] is that it's fallen so little, given the depth and duration of the recent downturn. Based on the experience of past severe recessions, I would have expected inflation to fall by twice as much as it has*".

Motivation

- Recent work emphasizes role of financial frictions to address the missing deflation puzzle:
  - Del Negro, Giannoni and Schorfheide (2015), Christiano, Eichenbaum and Trabandt (2015), Gilchrist, Schoenle, Sim and Zakrajsek (2017).

- We propose an alternative resolution of the puzzle:
  - Importance of nonlinearities in price and wage-setting when the economy is exposed to large shocks.

What We Do

- Study inflation and output dynamics in *linearized* and *nonlinear* formulations of the NK model.
- **Key modification:** Add real rigidity to reconcile *macroevidence* of low Phillips curve slope and *microevidence* of frequent price re-setting.
  - Real rigidity: Kimball (1995) state-dependent demand elasticity.
- Study implications for:
  - Propagation of shocks
  - Nonlinear Phillips curves
  - Unconditional distribution of inflation (skewness)

Framework

- Benchmark model: Erceg-Henderson-Levin (2000) model.
  - Monopolistic competition and Calvo sticky prices and wages.
  - Fixed aggregate capital stock.
  - ZLB constraint on nominal interest rate.
- Estimated model: Christiano-Eichenbaum-Evans (2005)/Smets and Wouters (2007) model with endogenous capital.

Outline

- Benchmark model
- Parameterization
- Results
- Analysis in estimated model
- Conclusions

Model: Households

- Household j preferences:

$$E_0 \sum_{t=0}^{\infty} \beta^t \varsigma_t \left\{ \ln C_{j,t} - \omega \frac{N_{j,t}^{1+\chi}}{1+\chi} \right\}$$

  $\varsigma_t -$ discount factor shock.

- Household budget constraint:

$$P_t C_{j,t} + B_{j,t} = W_{j,t} N_{j,t} + R_t^K K_j + (1 + i_{t-1}) B_{j,t-1} + \Gamma_{j,t} + A_{j,t}$$

Model: Households

- Standard Euler equation

$$1 = \beta E_t \left(\delta_{t+1} \frac{1 + i_t}{1 + \pi_{t+1}} \frac{C_t}{C_{t+1}} \right)$$

  $\delta_{t+1} \equiv \frac{\varsigma_{t+1}}{\varsigma_t}$ where δ_t follows an AR(1) process.

- Calvo sticky wages (same conceptual setup as for sticky prices, discussed next).

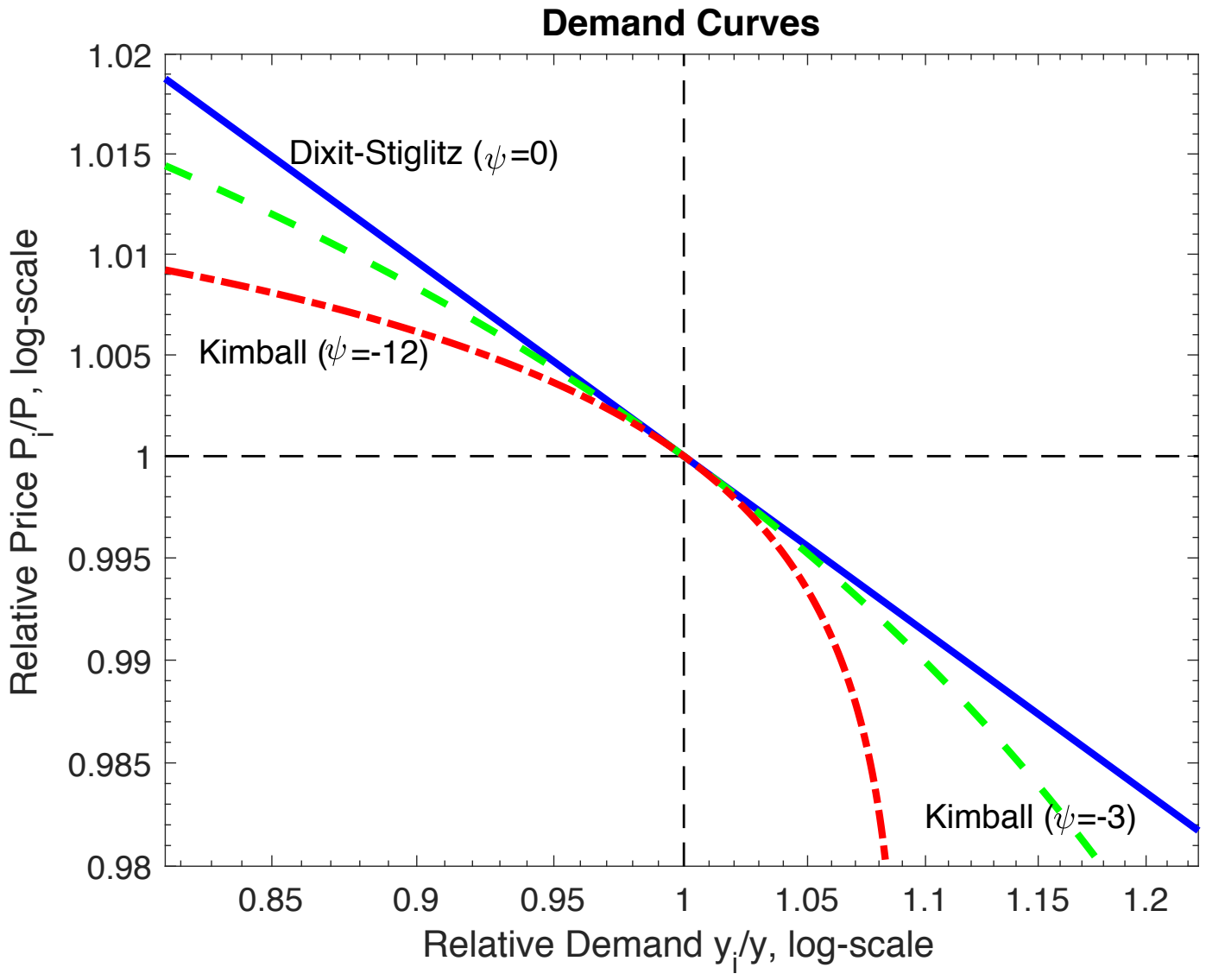
Model: Final Good Firms

- Competitive firms aggregate intermediate goods $Y_t(f)$ into final good Y_t using technology $\int_0^1 G_Y\left(Y_t\left(f\right)/Y_t\right)df = 1$.
- Following Dotsey-King (2005) and Levin-Lopez-Salido-Yun (2007):

$$G_Y\left(\frac{Y_t\left(f\right)}{Y_t}\right) = \frac{\omega_p}{1+\psi_p}\left[\left(1+\psi_p\right)\left(\frac{Y_t\left(f\right)}{Y_t}\right) - \psi_p\right]^{\frac{1}{\omega}} + 1 - \frac{\omega_p}{1+\psi_p}$$

- $\psi_p < 0$: Kimball (1995), $\psi_p = 0$: Dixit-Stiglitz.
- Kimball aggregator: demand elasticity for intermediate goods increasing function of relative price.
  - Dampens firms' price response to changes in marginal costs.

Levin, Lopez-Salido and Yun (2007)



Model: Intermediate Good Firms

- Continuum of monopolistically competitive firms f
  - Hire workers and rent capital; production technology $Y_t(f) = K(f)^{\alpha} N_t(f)^{1-\alpha}$
  - Calvo sticky prices: optimal price setting with probability $1 - \xi_p$, otherwise simple updating $\tilde{P}_t = (1 + \pi) P_{t-1}$.
- Fixed aggregate capital stock $K \equiv \int K(f)\, df$.

Model: Aggregate Resources

- Aggregate resource constraint:

$$C_t = Y_t \leq \frac{1}{p_t^* \left(w_t^*\right)^{1-\alpha}} K^{\alpha} {N_t}^{1-\alpha}$$

where p_t^* and w_t^* are Yun's (1996) aggregate price and wage dispersion terms.

Model: Monetary Policy

- Taylor rule:

$$1 + i_t = \max\left(1, (1+i)\left[\frac{1+\pi_t}{1+\pi}\right]^{\gamma_\pi}\left[\frac{Y_t}{Y_t^{pot}}\right]^{\gamma_x}\right)$$

  where Y_t^{pot} denotes flex price-wage output.

- Taylor rule in "linearized" model:

$$i_t - i = \max\left\{-i, \gamma_\pi\left(\pi_t - \pi\right) + \gamma_x x_t\right\}$$

Solving the Model

- Solve linearized and nonlinear model using Fair-Taylor (1983, ECMA):
  - Two-point boundary value problem.
  - Solution of nonlinear model imposes certainty equivalence (just as linearized model solution does by definition).
  - Use Dynare for computations: 'perfect foresight solution'/'deterministic simulation'.
  - Solution algorithm traces out implications of not linearizing equilibrium equations.
- Robustness: global solution with shock uncertainty, see Lindé and Trabandt (2018).

Parameterization

- Price setting:
  - $\xi_p = 0.67$ (3 quarter price contracts), $\phi_p = 1.1$ (10% markup).
  - $\psi_p = -12.2$ (Kimball) and $\beta = 0.9975$ (discounting) so that $\kappa_p \equiv \frac{(1-\xi_p)(1-\beta\xi_p)}{\xi_p} \frac{1}{1-\phi_p\psi_p} = 0.012$ in $\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + \kappa_p \widehat{mc}_t$ (Gertler-Gali 1999, Sbordone, 2002, ACEL 2011).
- Wage setting: $\xi_w = 0.75, \phi_w = 1.1$ and $\psi_w = -6$ (approx. estimate in estimated model).

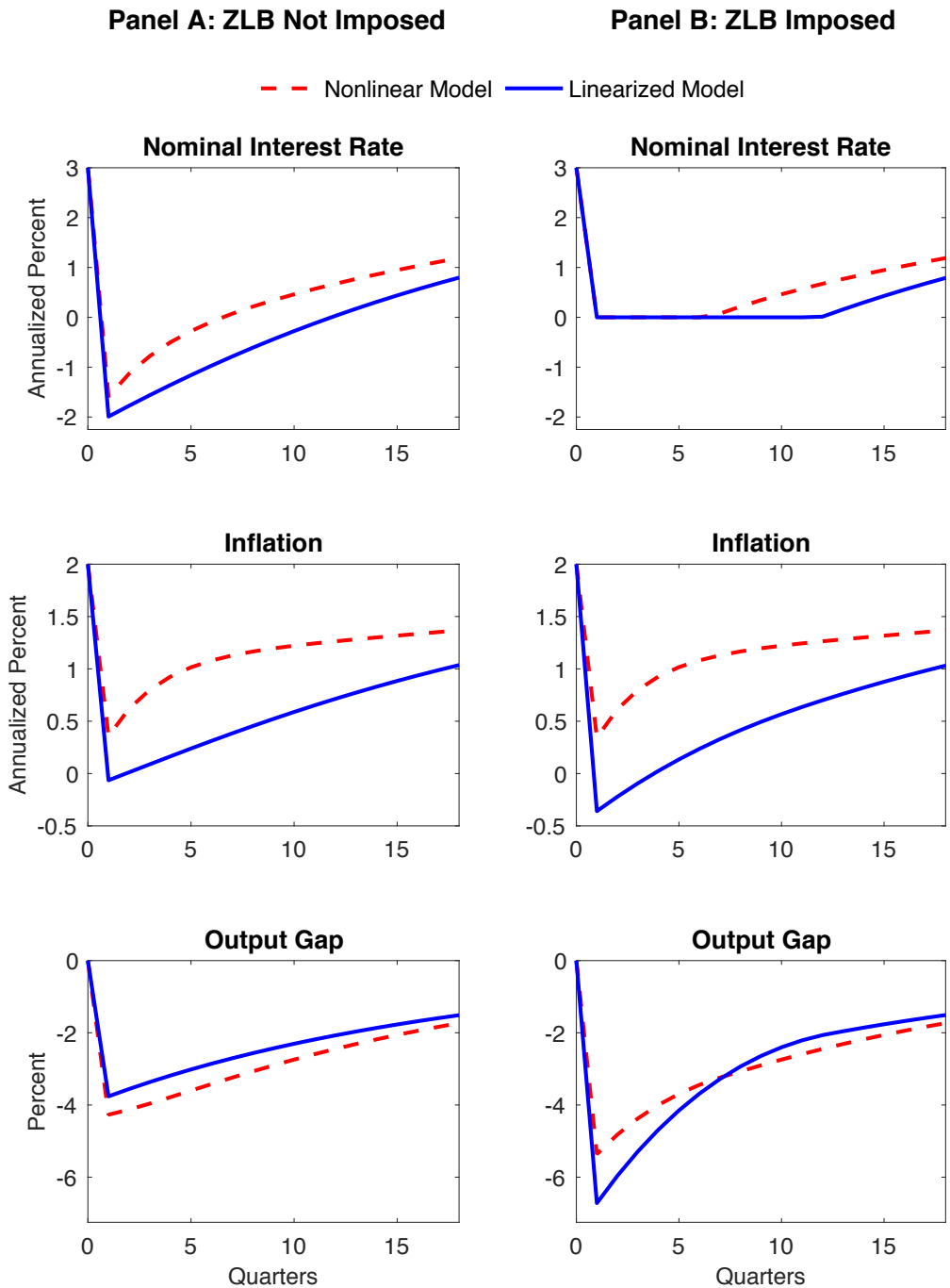
Parameterization

- Labor share $= 0.7$ ($\alpha = 0.3$), linear labor disutil. ($\chi = 0$)
- Steady state inflation 2 percent, nominal interest rate 3 percent.
- Taylor rule: $\gamma_\pi = 1.5$, $\gamma_x = 0.125$.
- δ_t follows AR(1) with $\rho = 0.95$

Results: Effects of a Discount Factor Shock

- Follow ZLB literature: assume negative demand shock hits the economy.
  - Discount factor shock δ_t rises by 1 percent before gradually receding.

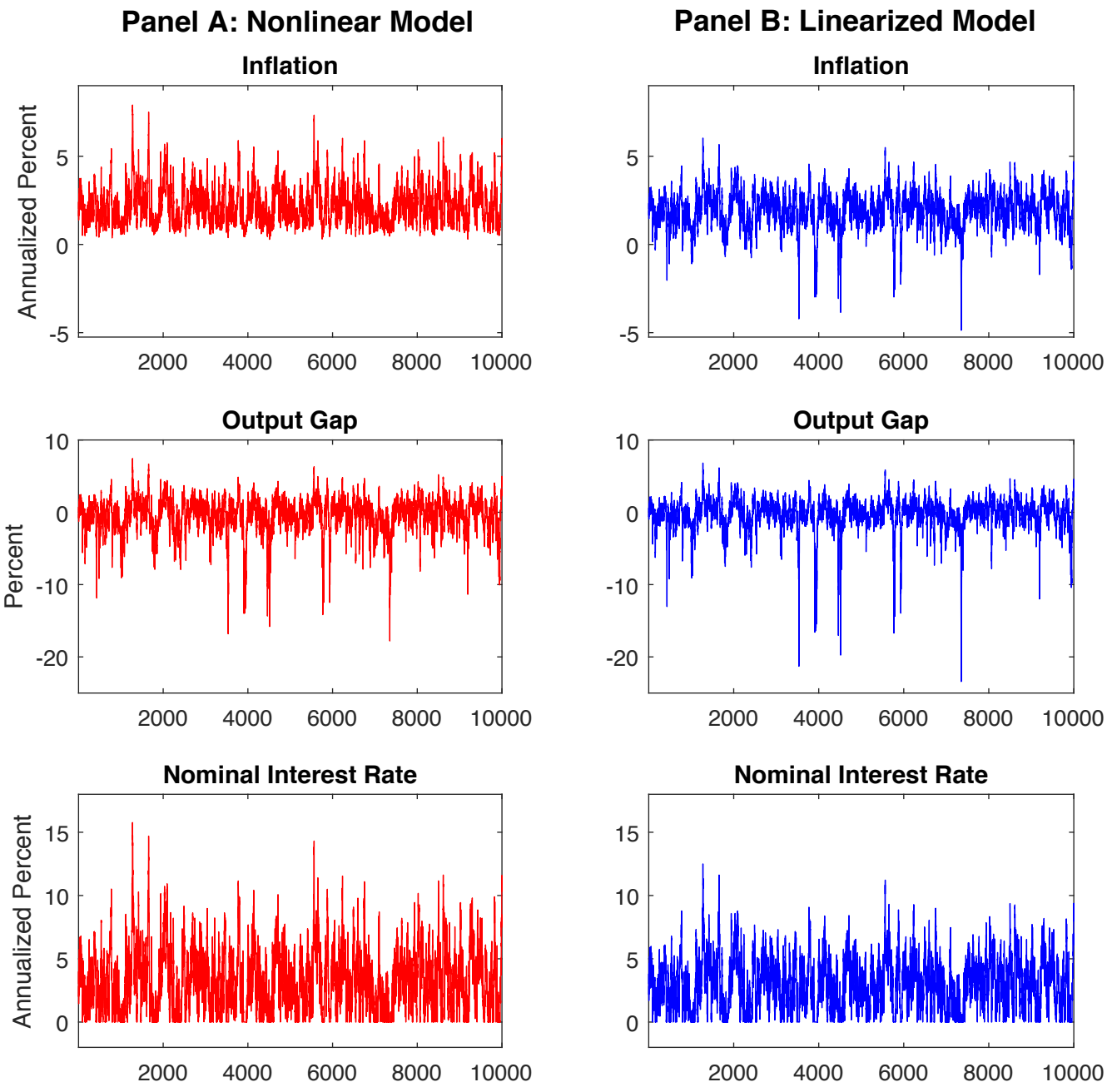
Figure 2: Impulse Responses to a 1% Discount Factor Shock



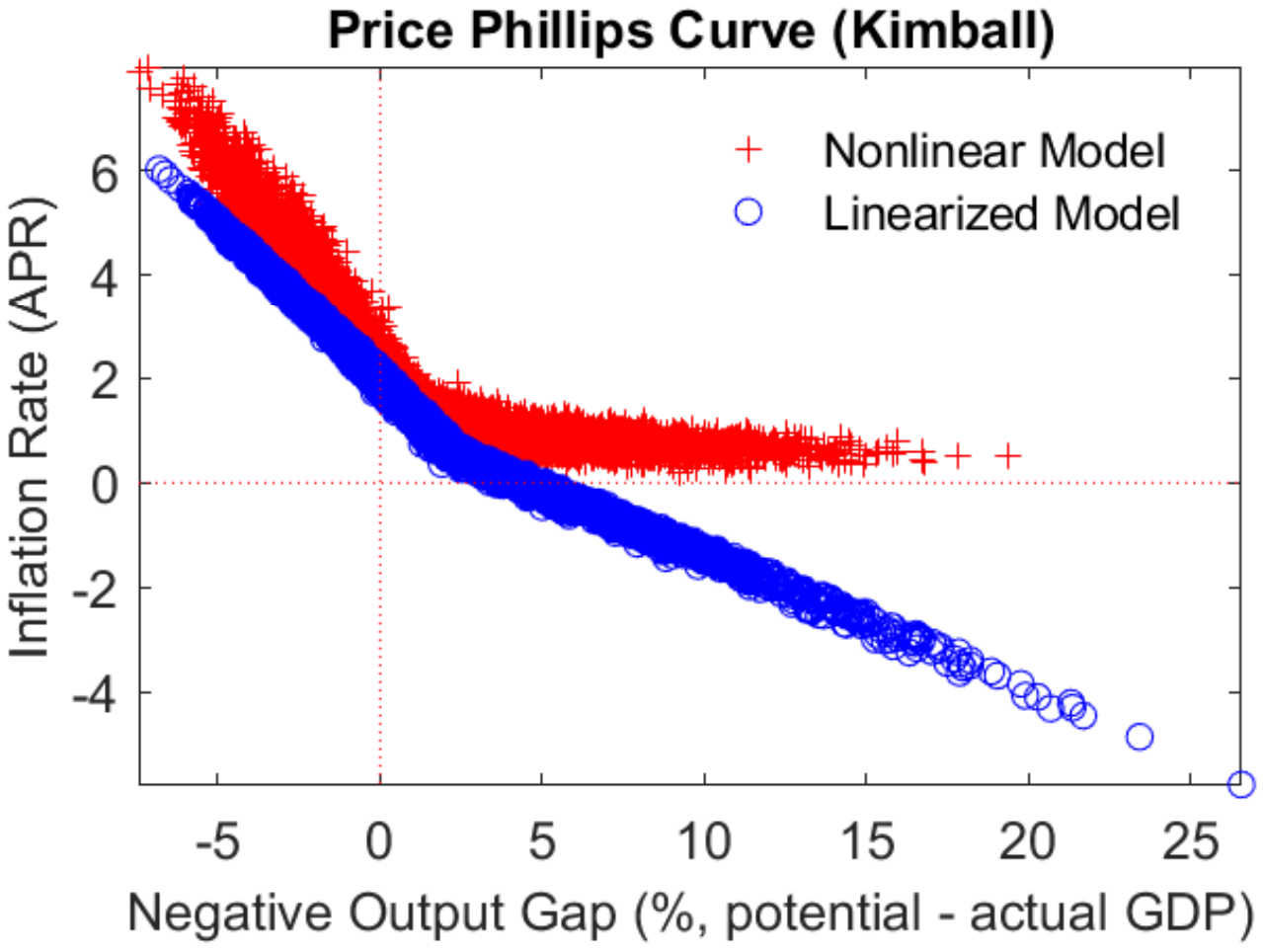
Results: Stochastic Simulations

- Next, do stochastic simulations of linearized and nonlinear model using discount factor shocks.
- Subject both models to long sequence of discount factor shocks:
  - $\delta_t - \delta = 0.95\,(\delta_{t-1} - \delta) + \sigma\varepsilon_t$ with $\varepsilon_t \sim N(0,1)$
  - Set σ such that prob(ZLB) $= 0.10$ in both models.

Figure 3: Stochastic Simulation of Nonlinear and Linearized Model



Results: Phillips Curves



Analysis in Estimated Model

- Assess robustness in CEE/SW workhorse model with endogenous capital.
- Key model features:
  - Nominal price stickiness
  - Nominal wage stickiness
  - Habit persistence and investment adjustment costs
  - Variable capital utilization

Analysis in Estimated Model

- Estimate linearized model on standard macro data (SW 2007)
  - Output, consumption, investment, hours worked per capita, inflation, wage inflation and federal funds rate.
  - Pre-crisis sample: 1965Q1-2007Q4.
  - Same seven shocks as in SW (2007).

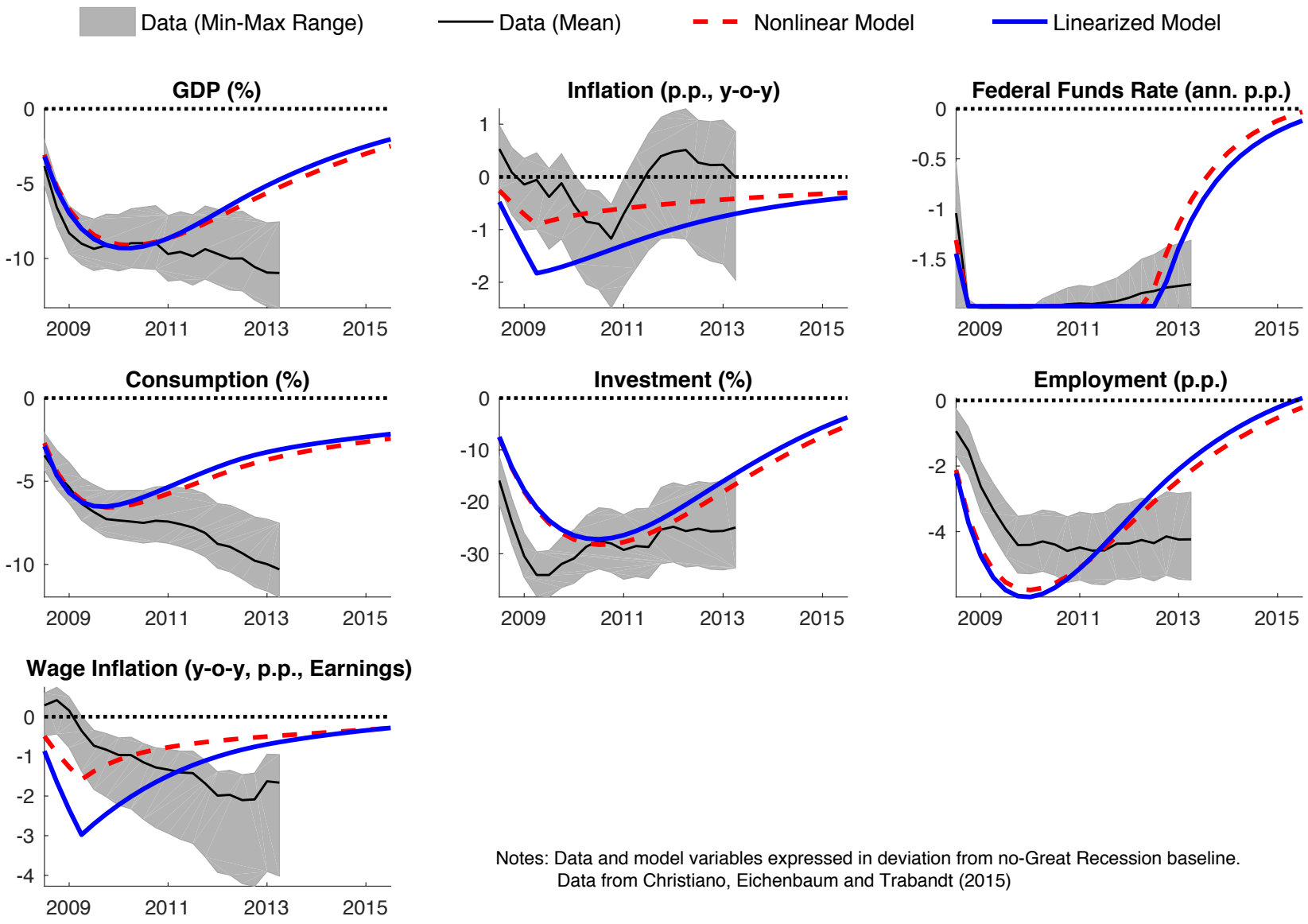
- Estimate 27 parameters
  - Calibrate price and wage stickiness parameters ($\xi_p = .667$ and $\xi_w = .75$) and markups (ϕ_p=ϕ_w=1.1).
  - Estimate Kimball parameters ψ_p (post. mean -12.5) and ψ_w (post. mean -8.3).

Analysis in Estimated Model: Great Recession

- Next, we aim to examine the model's ability to shed light on the 'missing deflation puzzle'.

- Subject nonlinear and linearized model to risk premium shock:
  - Risk premium shock as in Smets-Wouters (2007). Bondholding FOC: $\lambda_t = \beta E_t \lambda_{t+1} \frac{\epsilon_{RP,t} R_t}{\Pi_{t+1}}$.
  - $\epsilon_{RP,t}$ elevated for 16 quarters before gradually receding. Increase $\epsilon_{RP,t}$ such that both models deliver a fall in output as in the data.
  - Compare resulting paths of model and data for inflation.

Analysis in Estimated Model: Great Recession

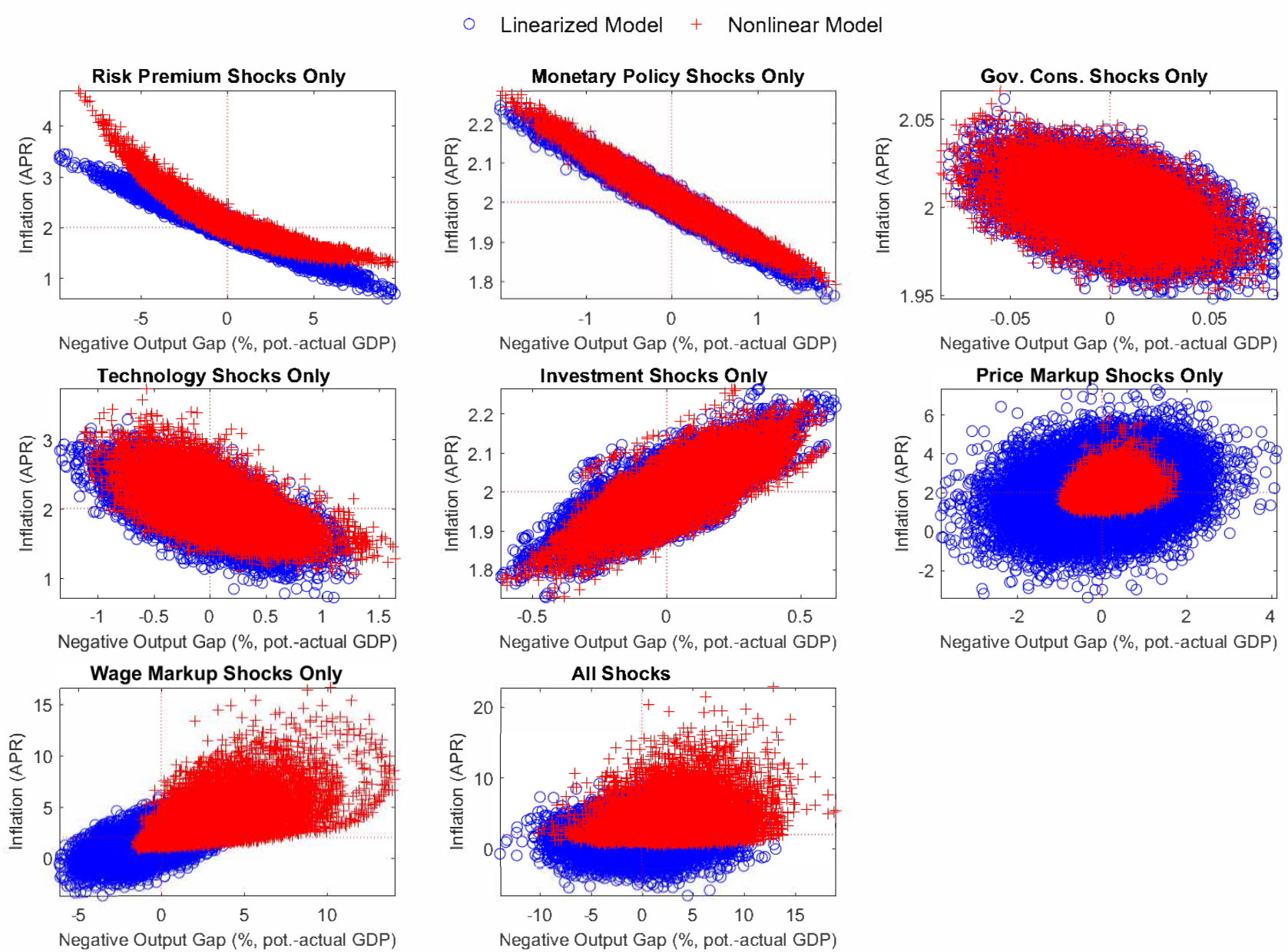


Notes: Data and model variables expressed in deviation from no-Great Recession baseline.
Data from Christiano, Eichenbaum and Trabandt (2015)

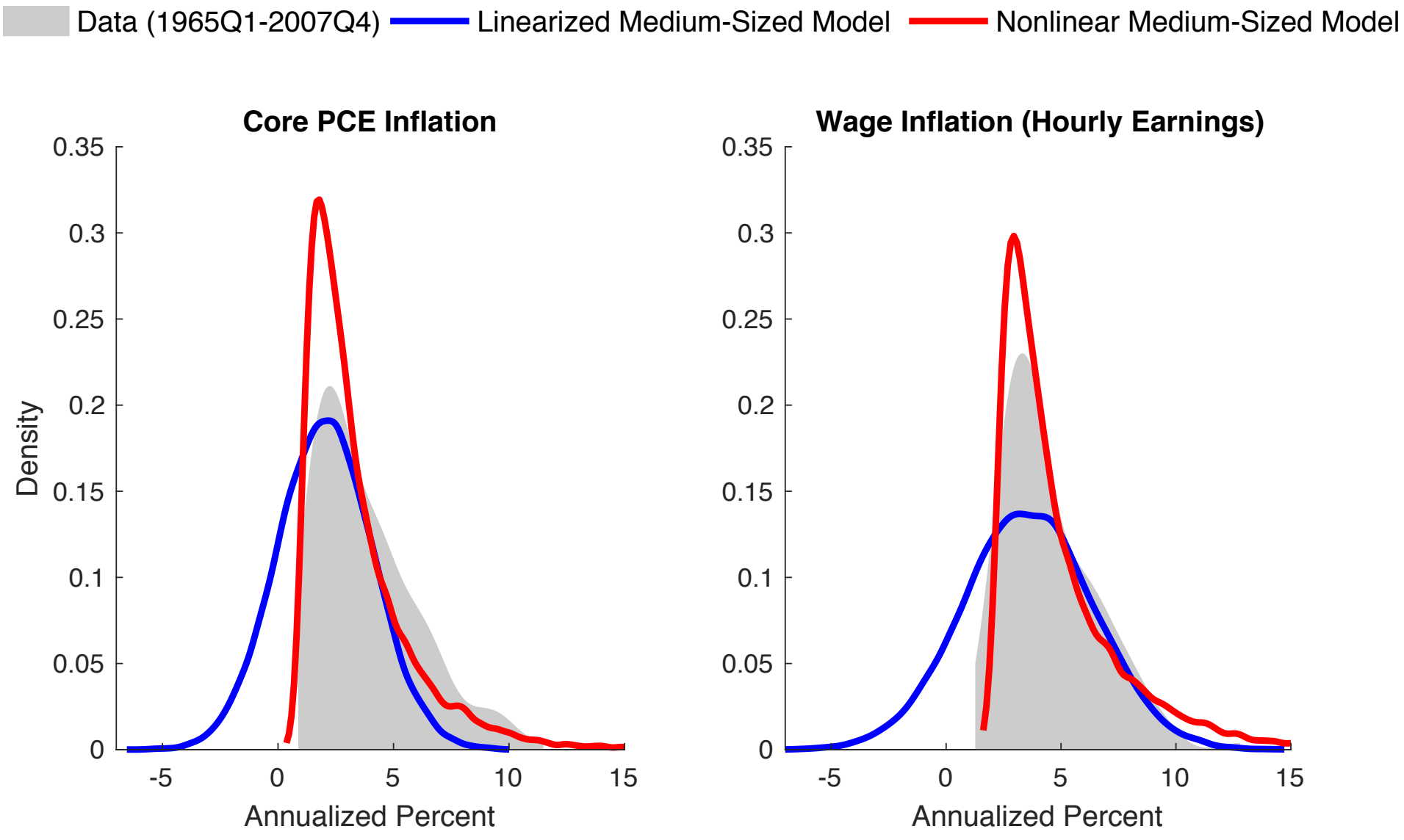
Analysis in Estimated Model: Great Recession

- Next, study the implications of the nonlinear and linearized model for the Phillips curve.
- Simulate the model for each of the seven exogenous processes using the estimated model parameters.

Analysis in Estimated Model: Phillips Curves



Analysis in Estimated Model: Inflation Densities



Conclusions

- Our analysis focuses on nonlinearities in price and wage- setting using Kimball (1995) aggregation.
- Our *nonlinear* NK model with Kimball aggregation resolves the 'missing deflation puzzle' while the *linearized* version fails to do so.
- Our nonlinear model generates nonlinear Phillips curves and reproduces the skewness of price and wage inflation observed in post-war U.S. data.
- All told, our results caution against the common practice of using linearized models when the economy is exposed to large shocks.