Resolving the Missing Deflation Puzzle

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- Core inflation, on the other hand, remained remarkably stable despite the large output contraction.
    - For instance, inflation measured by core CPI index, fell only by a modest 1 percent (see e.g. Christiano, Eichenbaum and Trabandt, 2015).

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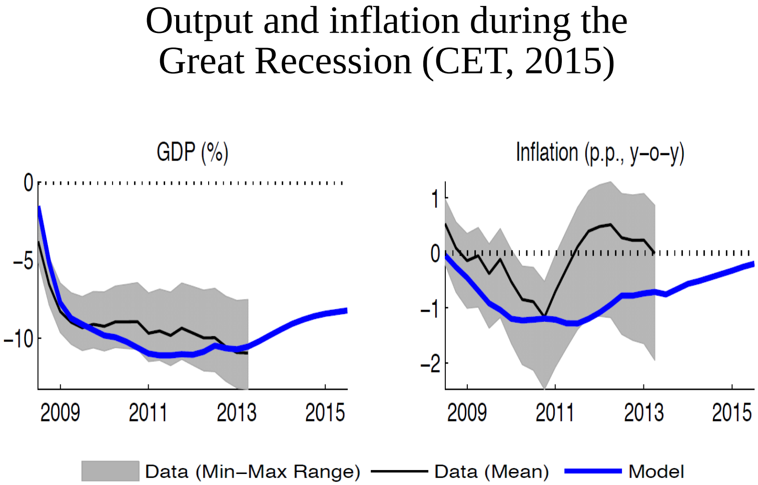
Large contraction in output but small drop in inflation



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- 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*".

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- Additionally, it has been debated why inflation did not display more volatility during the recession when Fed was at the ZLB.
  - Linearized workhorse NK models tend to be associated with unstable dynamics for extended ZLB episodes (Forward guidance puzzle).

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  - View our work as providing a complementary mechanism.

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    - Unconditional inflation distributions (skewness and kurtosis)

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- Robustness in estimated Christiano-Eichenbaum-Evans (2005)/Smets and Wouters (2007) model with endogenous capital.

Outline

- The simple benchmark model
- Parameterization
- Results
- Analysis in an estimated model with endogenous capital
- Tentative conclusions

- Variant of the benchmark Erceg-Henderson-Levin (2000) sticky price-wage model.

- Household j preferences:

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

  - ς_t discount factor shock.

- Household budget constraint:

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

- Standard aggregate consumption Euler equation

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

  - $\delta_{t+1} \equiv \frac{\varsigma_{t+1}}{\varsigma_t}$; affects potential real rate but not potential output (so effectively works as a demand shock).

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

Model

Final Good Firms

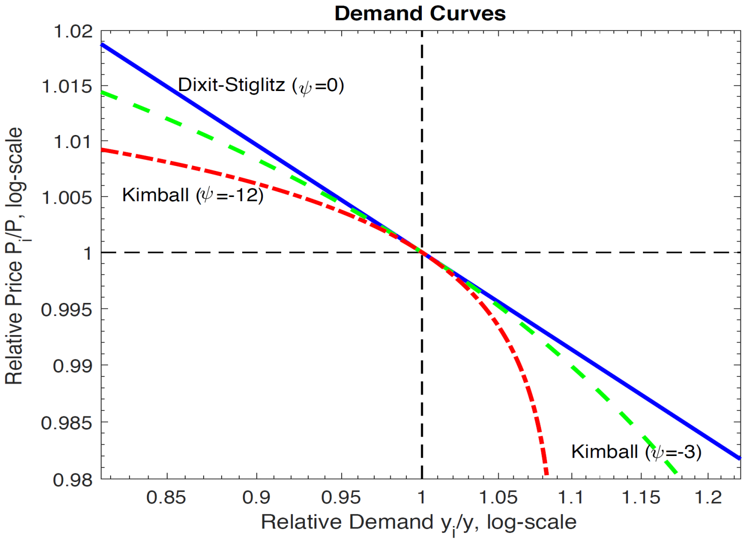
- Competitive firms aggregate intermediate goods $Y_t(f)$ into final good Y_t using technology $\int_0^1 G_Y\left(Y_t\left(f\right)/Y_t\right)df = 1$.
- Following Dotsey-King (2005) and Levin-Lopez-Salido-Yun (2007):

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

- $\omega_p \equiv \frac{\phi_p\left(1+\psi_p\right)}{1+\phi_p\psi_p}$, $\psi_p = 0$: Dixit-Stiglitz. $\psi_p < 0$: Kimball (1995).
- 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)

Kimball vs. Dixit-Stiglitz Demand Schedules (Steady State)



- Continuum of monopolistically competitive firms f
  - Hire worker bundle and rent capital, prod. technology $Y_t(f) = K(f)^{\alpha} N_t(f)^{1-\alpha}$
  - Calvo sticky prices: price re-optimization with probability $1 - \xi_p$.
  - Non-optimizers set price $\tilde{P}_t = (1 + \pi) P_{t-1}$ where π is steady state net inflation.
- Fixed aggregate capital stock $K \equiv \int K(f)\, df$

Model

Aggregate Resource Constraint

- All output Y_t consumed:

$$Y_t = C_t$$

- Aggregate resource constraint:

$$Y_t \leq \frac{1}{p_t^* \left(w_t^*\right)^{1-\alpha}} \underbrace{K^{\alpha} N_t{}^{1-\alpha}}_{\equiv Y_t^{sum}}$$

- $Y_t^{sum} = \int_0^1 Y_t(f) df$ and p_t^* and w_t^* is Yun's (1996) aggregate price and wage dispersion terms.

- Monetary policy 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, i and π denote steady state nominal interest rate and inflation.

- 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 and Taylor (1983, ECMA) method:
  - 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: comparing stochastic model solutions with global methods, see Lindé and Trabandt (2018).

- Price mark-up $\phi_p = 1.1$, 3 quarter price contracts ($\xi_p = 0.667$) based on microevidence (Nakamura and Steinsson, 2008, and Klenow and Malin, 2010).
- Set $\psi_p = -12.2$ so $\kappa_p \equiv \frac{(1-\xi_p)(1-\beta\xi_p)}{\xi_p}\frac{1}{1-\phi_p\psi_p}$ in

$$\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + \kappa_p \widehat{mc}_t,$$

  equals 0.012 (Gertler-Gali 1999, Sbordone, 2002, ACEL 2011) when $\beta = 0.9975$.

- Wage parameters: $\xi_w = 0.75, \phi_w = 1.1$ and $\psi_w = -6$ (close to estimate in workhorse model given ξ_w and ϕ_w).

Parameterization

Other Parameters

- Linear labor disutil. ($\chi = 0$), labor share ≈ 0.7 ($\alpha = 0.3$).
- Steady state inflation 2 percent, nominal interest rate 3 percent ($\beta = 0.995$, $\pi = 1.005 => i = 1.0075$).
- Taylor rule coefficients ($\gamma_\pi = 1.5$, $\gamma_x = 0.125$).
- δ_t follows AR(1) process with $\rho_\delta = 0.95$, σ_δ set so that probability of being at the ZLB equals 10 percent in both linearized and nonlinear model

Results

Comparing the Properties of Linearized and Nonlinear Solutions

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  2. Stochastic simulations: simulate long sequences of data and plot "Phillips curves"

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Recessionary Scenario

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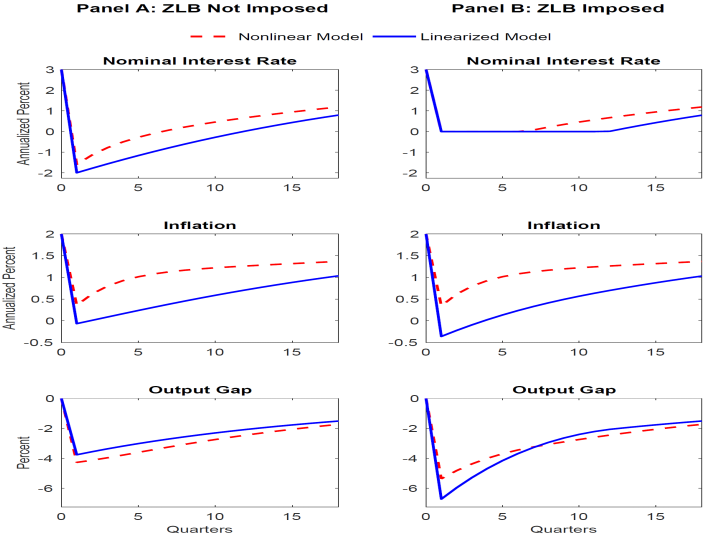
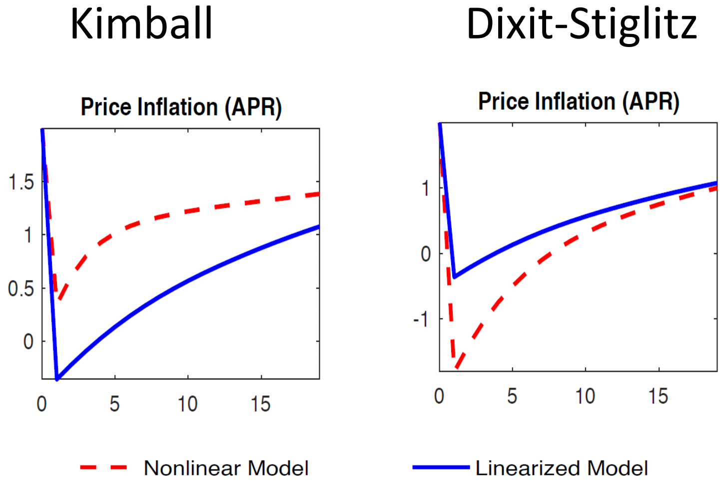
Results

Effects of Positive Savings Shock



Results

Kimball Aggregator Crucial for Muted Inflation Response



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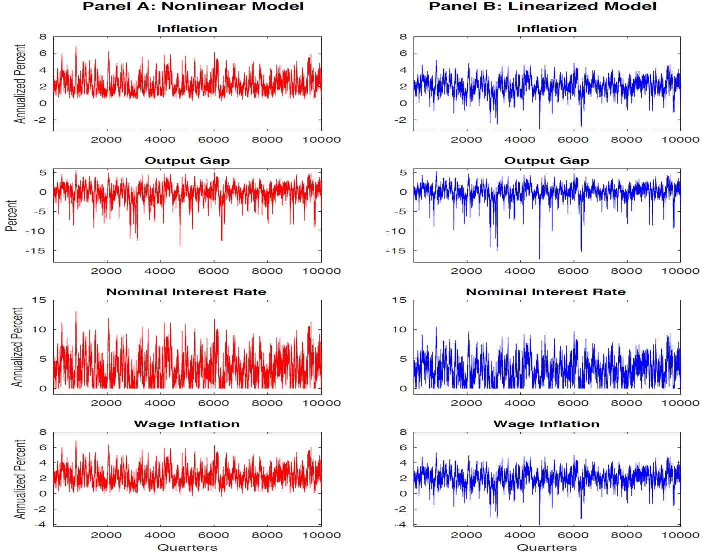
  - But always same $\varepsilon_{\delta,t}$, so only difference in $\{\delta_t\}$ for $t = 1, ..., T$ is scaling

$$\delta_t - \delta = \rho_\delta \left(\delta_{t-1} - \delta \right) + \sigma_\delta \varepsilon_{\delta,t}$$

Results

Stochastic Simulations of Linearized and Nonlinear Model when ZLB Binds



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    - Put annualized price and wage inflation on the y-axis and negative output gap (x_t) on the x-axis
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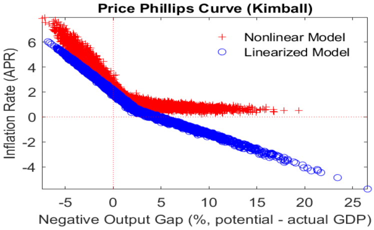
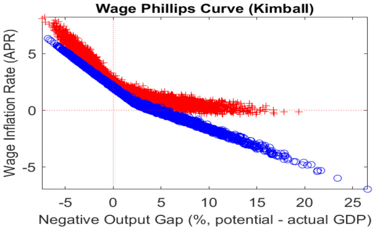
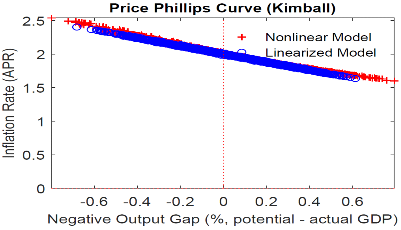
Price and Wage Phillips Curves based on Simulated Model Data

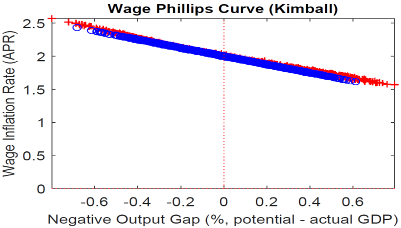
Benchmark Shock Size





Small Shock Size





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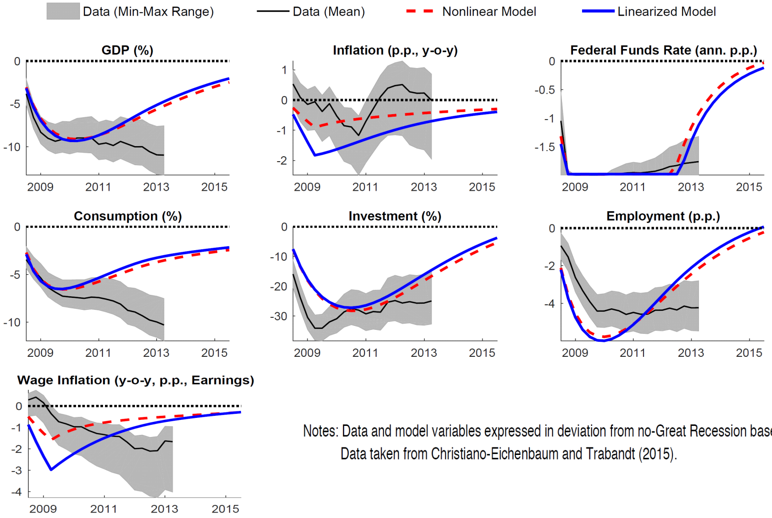
  - Calibrate stickiness parameters ($\xi_p = .667$ and $\xi_w = .75$) and markups (ϕ_p=ϕ_w=1.1), estimate Kimball parameters ψ_p (post. mean -12.5) and ψ_w (post. mean -8.3).

Analysis in Estimated Model with Endog. Capital

- First, repeat same analysis as in the stylized EHL model. Study differences between linearized and nonlinear model to a large recessionary shock (large increase in risk-premium).
- Second, we study the implied Phillips curves using estimated laws of motion for the exogenous variables.
  - Both around the steady state, and in an 8-quarter liquidity trap.
- Third and finally, we study the ability of the linearized and nonlinear model to fit unconditional inflation distributions (skewness and kurtosis) using estimated laws of motion for the exogenous variables.

Analysis in Estimated Model with Endog. Capital

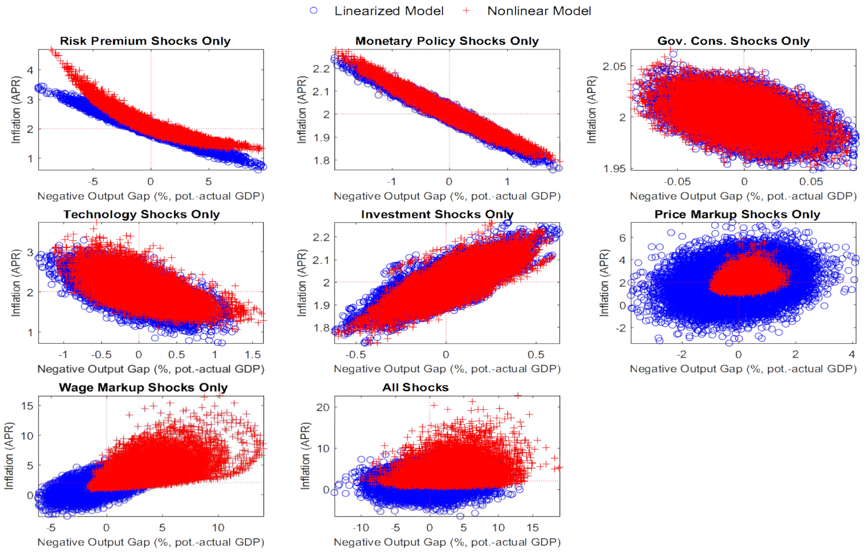
Great Recession: Data vs. Estimated Model



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

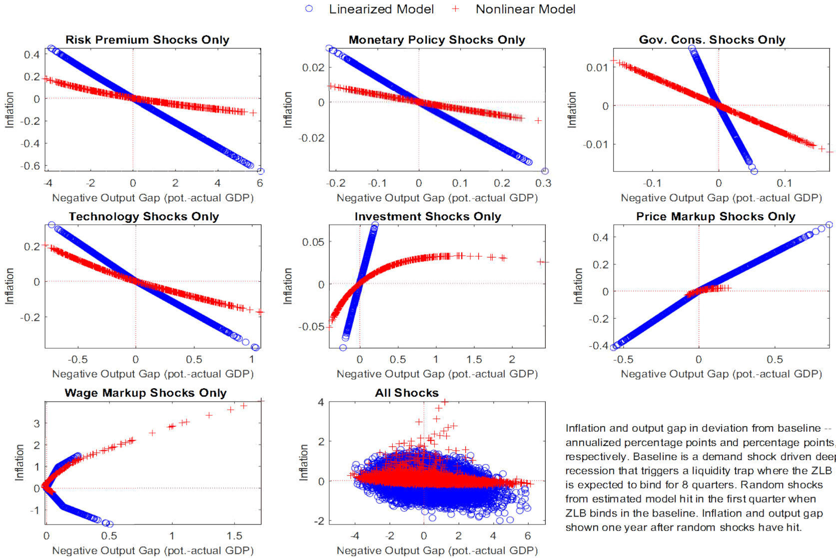
Analysis in Estimated Model with Endog. Capital

Phillips Curves in Linear and Nonlinear Solutions Around Steady State



Analysis in Estimated Model with Endog. Capital

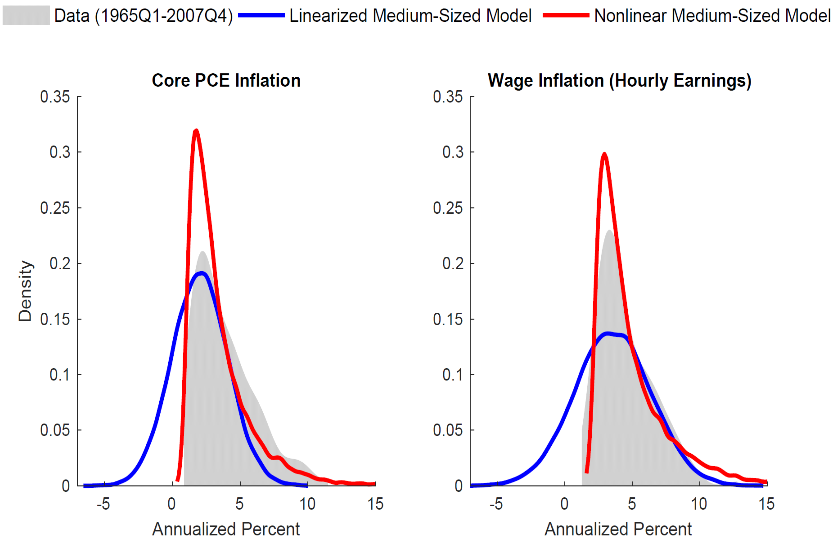
Phillips Curves Conditional on an 8-quarter Liquidity Trap



Inflation and output gap in deviation from baseline -- annualized percentage points and percentage points, respectively. Baseline is a demand shock driven deep recession that triggers a liquidity trap where the ZLB is expected to bind for 8 quarters. Random shocks from estimated model hit in the first quarter when ZLB binds in the baseline. Inflation and output gap shown one year after random shocks have hit.

Analysis in Estimated Model with Endog. Capital

Implications for Unconditional Price and Wage Inflation Distributions



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- Moreover, the nonlinear model offers an explanation why inflation rose so little during the recovery.

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- Our analysis proposes a resolution of the missing deflation puzzle, i.e. the fact that inflation fell very little during the Great Recession against the backdrop of the large and persistent fall in GDP.
  - Complementary to other mechanisms, attractive in our eyes due to its simplicity and that it resolves the tension between micro and macro pricesetting evidence.
- Our resolution of the puzzle stresses the importance of nonlinearities in price and wage-setting (Kimball, 1995) for large shocks.
  - Kimball aggregator important, going nonlinear with standard Dixit-Stiglitz aggregator does not avoid deflation.
- Moreover, the nonlinear model offers an explanation why inflation rose so little during the recovery.
- Finally, It can also reproduce the skewness and kurtosis in post-war U.S. price and wage inflation (and other macro variables, work in progress).

Kimball Aggregator

- Final output good Y_t produced using continuum of differentiated intermediate goods $Y_t(f)$.
- Following Kimball (1995), technology for transforming intermediate goods into final output good is:

$$\int_0^1 G\left(\frac{Y_t(f)}{Y_t}\right) df = 1.$$

- $G(\cdot)$ strictly concave and increasing function.

Kimball Aggregator

- Following Dotsey and King (2005) and Levin, Lopez-Salido and Yun (2007), we assume:

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

$$\psi_p = \frac{(1-\phi_p)\epsilon_p}{\phi_p}, \omega_p = \frac{\phi_p - \left(\phi_p - 1\right)\epsilon_p}{1 - \left(\phi_p - 1\right)\epsilon_p}$$

- Special case: $\epsilon_p = 0 \rightarrow$ Dixit-Stiglitz

Kimball Demand Schedules

- The first order conditions can be written as

$$\frac{Y_t(f)}{Y_t} = \frac{1}{1+\psi_p}\left(\left(\frac{P_t(f)}{P_t}\frac{1}{\vartheta_t^p}\right)^{\frac{\phi_p}{1-\phi_p}(1+\psi_p)}+\psi_p\right), \quad (1)$$

$$P_t\vartheta_t^p = \left(\int P_t(f)^{\frac{1+\psi_p\phi_p}{1-\phi_p}}df\right)^{\frac{1-\phi_p}{1+\psi p\phi_p}},$$

$$\vartheta_t^p = 1+\psi_p-\psi_p\int\frac{P_t(f)}{P_t}df,$$

where ϑ_t^p denotes the Lagrange multiplier on the aggregator constraint.

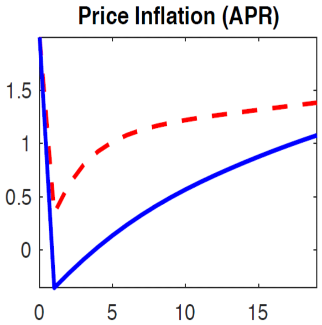
- Note that for $\psi_p = 0$, this problem leads to the usual Dixit and Stiglitz (1977) expressions

$$\frac{Y_t(f)}{Y_t} = \left[\frac{P_t(f)}{P_t}\right]^{-\frac{\phi_p}{\phi_p-1}}, \; P_t = \left[\int P_t(f)^{\frac{1}{1-\phi_p}}df\right]^{1-\phi_p}$$

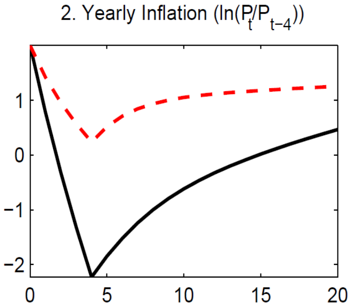
Sensitivity Analysis in EHL Model

Results not Contingent on Asymmetric Real Rigidities in Wage Setting

Benchmark - Kimball in wage-setting



Alternative with flexible wages



Nonlinear Model

Linearized Model

Sensitivity Analysis in EHL Model

Large Differences Remain With Notably Lower Asymmetries in Price Setting

Benchmark - Kimball with psi_p=-12.2

Alternative with xi_p=.75 & psi_p=-5.5