Resolving the Missing Deflation Puzzle

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A key feature of the recent Great Recession in the United States and other advanced economies was an abrupt and persistent fall in output by roughly 10 percent relative to its pre-crisis trend.
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For instance, inflation measured by core CPI index, fell only by a modest 1 percent (see e.g. Christiano, Eichenbaum and Trabandt, 2015).
Motivation
Large contraction in output but small drop in inflation

Output and inflation during the Great Recession (CET, 2015)
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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).
To explain the missing deflation puzzle, recent work emphasize the role of financial frictions:

- Christiano, Eichenbaum and Trabandt (2015) argue that firms' cost to borrow funds for working capital played a critical role.
- Del Negro, Giannoni and Schorfheide (2015) argue that a financial accelerator together with a flattening of the Phillips curve can account for the small drop in inflation during the Great Recession.
- Gilchrist, Schoenle, Sim and Zakrajsek (2016) argue that customer markets create an incentive for financially constrained firms to raise prices in response to adverse financial or demand shocks.

We propose an alternative resolution of the puzzle which rests on important pricing and wage nonlinearities when the economy is exposed to large adverse shocks.

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- Document the properties of suggested modification for:
  - Propagation of recessionary shocks in linearized and nonlinear model
  - Phillips curves in linearized and nonlinear model
  - Unconditional inflation distributions (skewness and kurtosis)

- Monopolistic competition and Calvo sticky prices and wages.

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- Fixed aggregate capital stock
Analysis Framework

  - Monopolistic competition and Calvo sticky prices and wages.
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  - ZLB constraint on nominal interest rate.

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Outline

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

Household $j$ preferences:

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

- $\zeta_t$ discount factor shock.

Household budget constraint:

$$P_t C_{j,t} + B_{j,t} = W_{j,t} N_{j,t} + R^K_t K_j + (1 + i_{t-1}) B_{j,t-1} + \Gamma_{j,t} + A_{j,t}$$
Model
Households continued

- Standard aggregate consumption Euler equation

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

- \( \delta_{t+1} \equiv \frac{\zeta_{t+1}}{\xi_t} \); 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 \( \int_0^1 G_Y(Y_t(f)/Y_t) \, df = 1 \).

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

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

- \( \omega_p \equiv \frac{\phi_p(1+\psi_p)}{1+\phi_p\psi_p} \), \( \psi_p = 0 \): 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.
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 $\pi$ 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:
  \[ Y_t \leq \frac{1}{p_t^* (w_t^*)^{1-\alpha}} K^\alpha N_t^{1-\alpha} \equiv Y_t^{sum} \]

- $Y_t^{sum} = \int_0^1 Y_t(f) df$ 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 \( \pi \) denote steady state nominal interest rate and inflation.

Taylor rule in “linearized” model:

\[ i_t - i = \max \left\{ -i, \gamma_{\pi} (\pi_t - \pi) + \gamma_x x_t \right\} \]
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 ($\bar{\xi}_p = 0.667$) based on microevidence (Nakamura and Steinsson, 2008, and Klenow and Malin, 2010).

Set $\psi_p = -12.2$ so $\kappa_p \equiv \frac{(1-\xi_p)(1-\beta\xi_p)}{\xi_p} \frac{1}{1-ph_p\psi_p}$ in

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

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 $\xi_w$ and $\phi_w$).
Parameterization

Other Parameters

- Linear labor disutil. ($\chi = 0$), labor share $\approx 0.7$ ($\alpha = 0.3$).

- Steady state inflation 2 percent, nominal interest rate 3 percent ($\beta = 0.995$, $\pi = 1.005 \Rightarrow i = 1.0075$).

- Taylor rule coefficients ($\gamma_\pi = 1.5$, $\gamma_x = 0.125$).

- $\delta_t$ follows AR(1) process with $\rho_\delta = 0.95$, $\sigma_\delta$ set so that probability of being at the ZLB equals 10 percent in both linearized and nonlinear model.
Compare outcomes in linearized and nonlinear model solutions.
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Results
Comparing the Properties of Linearized and Nonlinear Solutions

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Two parts:

1. Recessionary scenario: rise in $\delta_t$ triggers deep recession with binding ZLB.
2. Stochastic simulations: simulate long sequences of data and plot “Phillips curves”
Follow ZLB literature: assume negative demand shock (increase in $\delta_t$) hits the economy.
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- $\delta_t$ rises from 1 to 1.01 on impact before gradually receding.
Results

Effects of Positive Savings Shock

Panel A: ZLB Not Imposed

- Nominal Interest Rate
- Inflation
- Output Gap

Panel B: ZLB Imposed

- Nominal Interest Rate
- Inflation
- Output Gap
Results
Kimball Aggregator Crucial for Muted Inflation Response

Kimball

Dixit-Stiglitz

Price Inflation (APR)

Nonlinear Model

Linearized Model

Lindé and Trabandt (Riksbank and FUB)  Resolving the Missing Deflation Puzzle  May 16, 2018  23 / 32
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- Use different standard deviations for linearized ($\sigma_{\delta} = 0.00125$) and nonlinear ($\sigma_{\delta} = 0.0015$) solution, to have $\text{prob}(\text{ZLB}) = .10$ in both models.
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- Use different standard deviations for linearized ($\sigma_\delta = 0.00125$) and nonlinear ($\sigma_\delta = 0.0015$) solution, to have $\text{prob}(\text{ZLB}) = .10$ in both models.
- But always same $\epsilon_{\delta,t}$, so only difference in $\{\delta_t\}$ for $t = 1, ..., T$ is scaling

$$\delta_t - \delta = \rho_\delta (\delta_{t-1} - \delta) + \sigma_\delta \epsilon_{\delta,t}$$
Results
Stochastic Simulations of Linearized and Nonlinear Model when ZLB Binds
Use simulated data to plot Phillips curves for nonlinear and linearized model.
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- Put annualized price and wage inflation on the y-axis and negative output gap ($x_t$) on the x-axis.
Results
Plot Phillips Curves on Simulated Data

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  - Put annualized price and wage inflation on the y-axis and negative output gap ($x_t$) on the x-axis
  - Draw on Okun’s law of negative relationship between unemployment and the output gap
Results
Price and Wage Phillips Curves based on Simulated Model Data

Benchmark Shock Size

Small Shock Size
• Assess robustness in CEE/SW workhorse model with endogenous capital.
Analysis in Estimated Model with Endog. Capital

Key Model Features

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- Key model features:
  - Nominal price stickiness
  - Nominal wage stickiness
  - Habit persistence and investment adjustment costs
  - Variable capital utilization
Estimate linearized variant of model on same seven time data series that Smets and Wouters (2007) used
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• Estimate 27 parameters
  • Calibrate stickiness parameters ($\xi_p = .667$ and $\xi_w = .75$) and markups ($\phi_p = \phi_w = 1.1$), estimate Kimball parameters $\psi_p$ (post. mean -12.5) and $\psi_w$ (post. mean -8.3).
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

GDP (%)

Inflation (p.p., y-o-y)

Federal Funds Rate (ann. p.p.)

Consumption (%)

Investment (%)

Employment (p.p.)

Wage Inflation (y-o-y, p.p., Earnings)

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

- Data (1965Q1-2007Q4)
- Linearized Medium-Sized Model
- Nonlinear Medium-Sized Model

Core PCE Inflation

Wage Inflation (Hourly Earnings)
Tentative conclusions

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

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

\[
\psi_p = \frac{(1 - \phi_p) \epsilon_p}{\phi_p}, \quad \omega_p = \frac{\phi_p - (\phi_p - 1) \epsilon_p}{1 - (\phi_p - 1) \epsilon_p}
\]

- Special case: \( \epsilon_p = 0 \rightarrow \text{Dixit-Stiglitz} \)
Kimball Demand Schedules

- The first order conditions can be written as

\[
\frac{Y_t(f)}{Y_t} = \frac{1}{1+\psi_p} \left( \left( \frac{P_t(f)}{P_t} \right)^{\frac{\phi_p}{1-\phi_p}} (1+\psi_p) + \psi_p \right),
\]  

(1)

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

\[
\vartheta_t = 1 + \psi_p - \psi_p \int \frac{P_t(f)}{P_t} df,
\]

where \(\vartheta_t^p\) 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

\[
\frac{Y_t(f)}{Y_t} = \left[ \frac{P_t(f)}{P_t} \right]^{\frac{\phi_p}{\phi_p-1}} \quad , \quad P_t = \left[ \int P_t(f)^{\frac{1}{1-\phi_p}} df \right]^{1-\phi_p}
\]
Sensitivity Analysis in EHL Model

Results not Contingent on Asymmetric Real Rigidities in Wage Setting

Benchmark - Kimball in wage-setting

Alternative with flexible wages

Price Inflation (APR)

2. Yearly Inflation ($\ln(\frac{P_t}{P_{t-4}})$)

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 $\xi_p = 0.75$ & $\psi_p = -5.5$

2. Yearly Inflation ($\ln(P_t/P_{t-4})$)

Graph showing the comparison between the nonlinear model and the linearized model for the yearly inflation.