Endogenous Technology Adoption and R&D

as

Sources of Business Cycle Persistence

by

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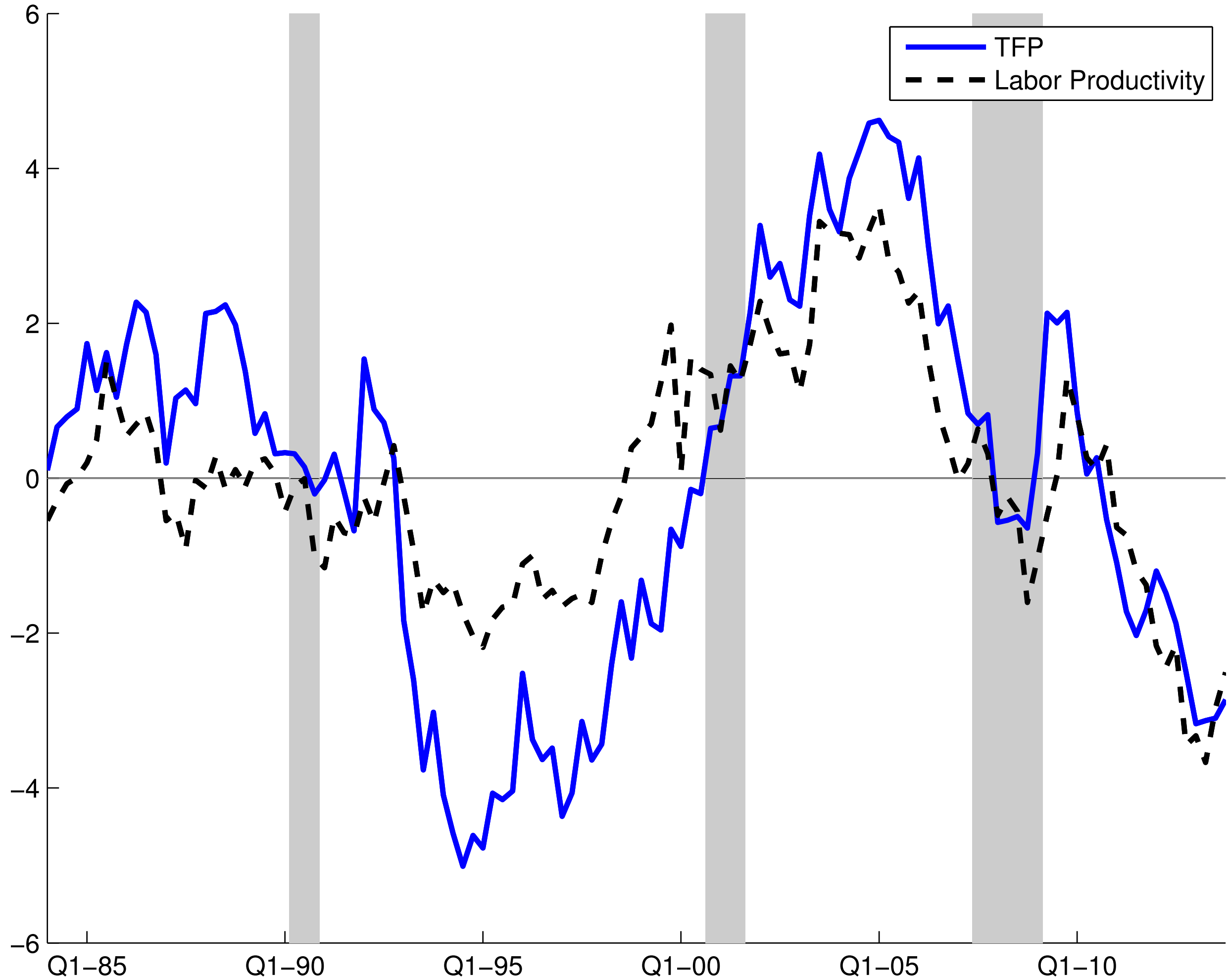
Motivation

- Slow recovery following a financial crisis
- Coincides with a slowdown of productivity growth (Fernald, 2014)
  - ∗ Also true for recent Euro area data (e.g. UK)
    - ∗ True following emerging market financial crises (Queralto)
- Candidate hypotheses: Bad luck versus endogenous response
- Bad luck view (at least for U.S): Fernald 2014
  - Observes that slowdown in TFP began in 2004, prior to Great Recesion

Figure 1: Detrended Capacity Adjusted TFP and Labor Productivity



Endogenous response to business cycle conditions

- Crisis induced large drop in investment in new technologies (both R&D and adoption)
  - Large R&D contraction during Great Recession
  - Large contraction also in 2001-2002 recession $\rightarrow$ TFP decline prior to GR

- Speed of technology diffusion is pro-cyclical.
  - Survey data: sample of 26 production technologies that diffused at various times over the period 1947-2003 in the US (5) and the UK (21).
  - Elasticity of speed of diffusion with respect to business cycle around 4.

Figure 2: R&D

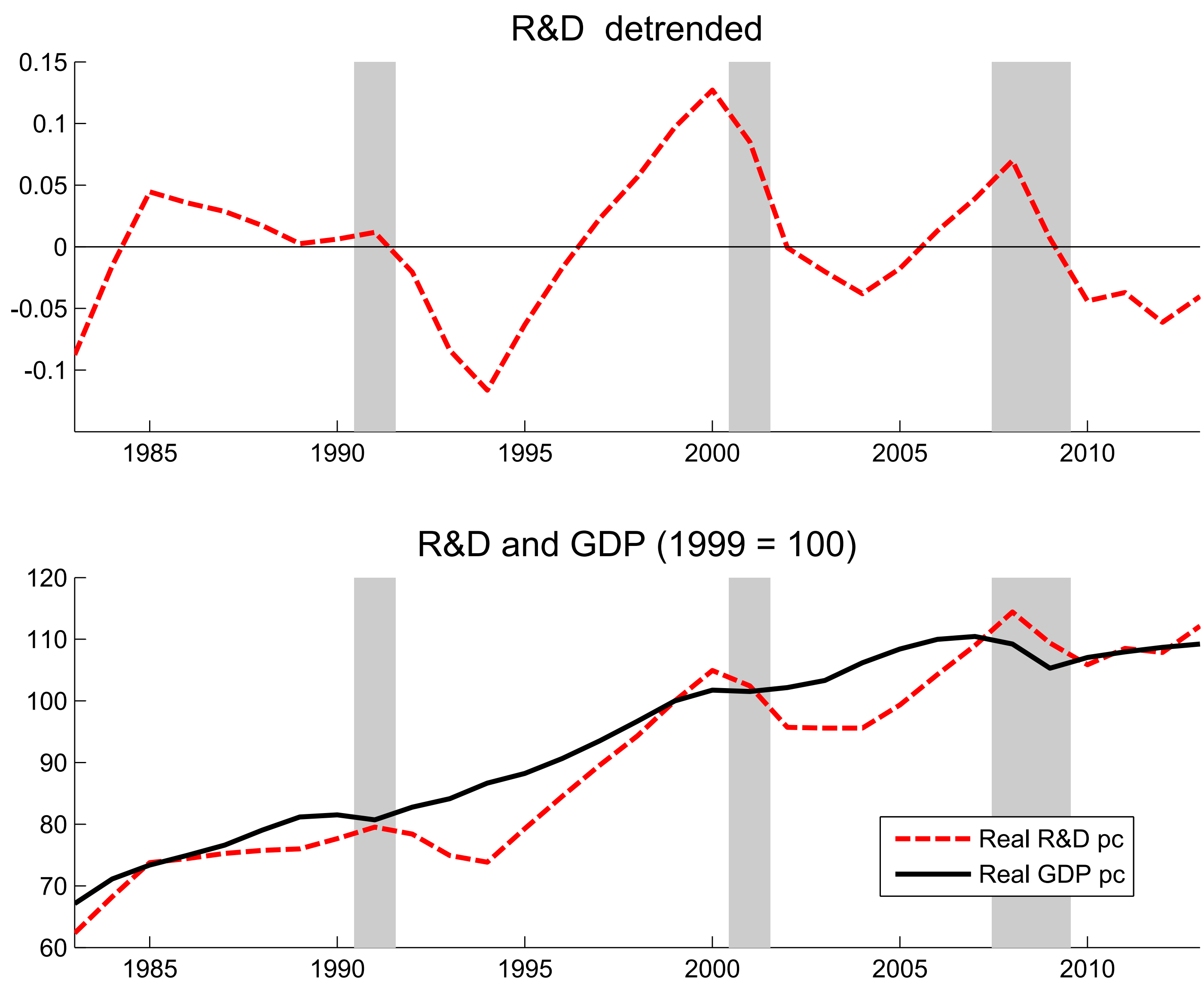

R&D detrended
0.15
0.1
0.05
0
-0.05
-0.1
1985
1990
1995
2000
2005
2010
R&D and GDP (1999 = 100)
120
110
100
90
80
70
60
Real R&D pc
Real GDP pc
1985
1990
1995
2000
2005
2010

Figure 3: Speed of Diffusion and Cycle

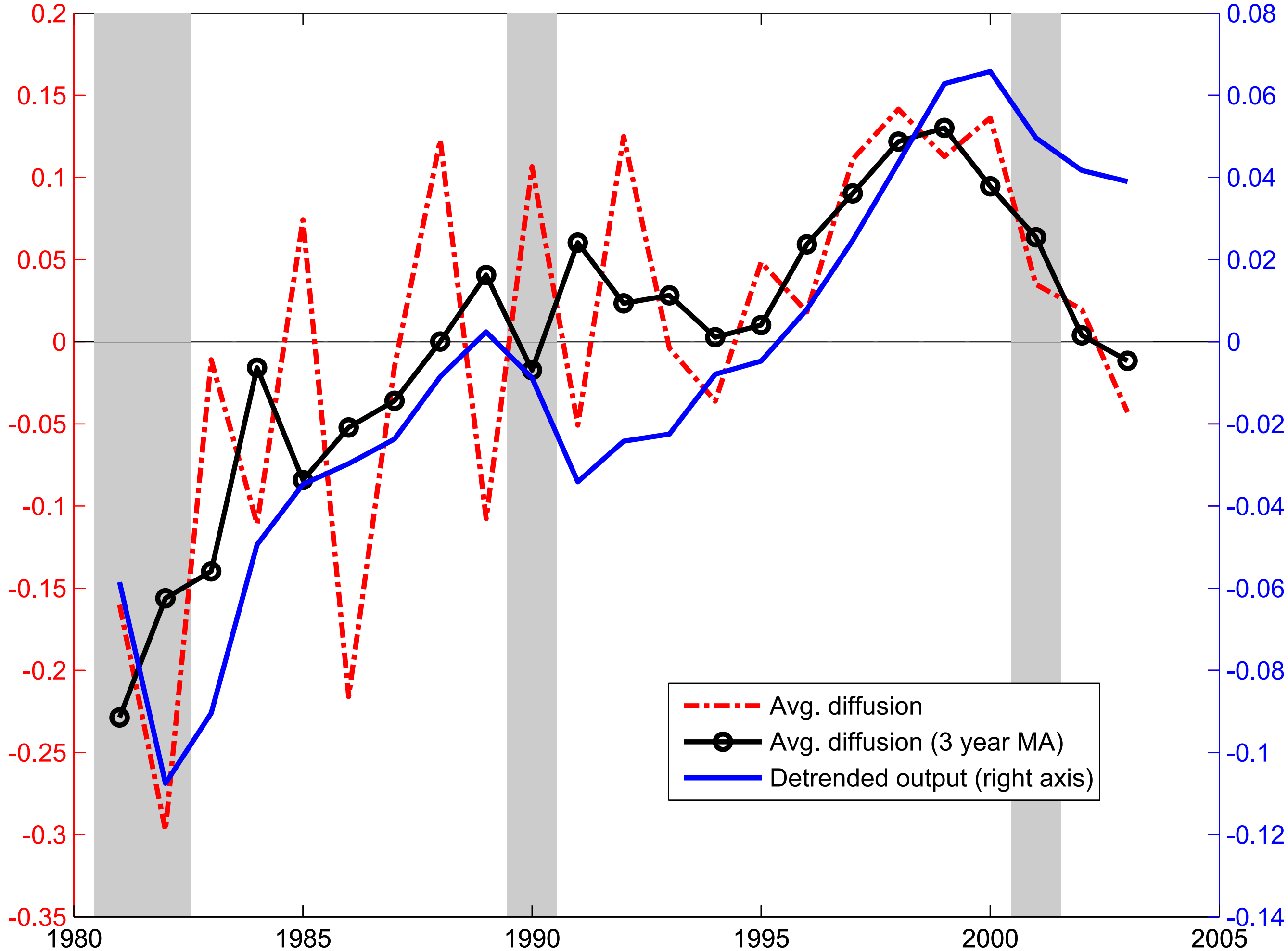
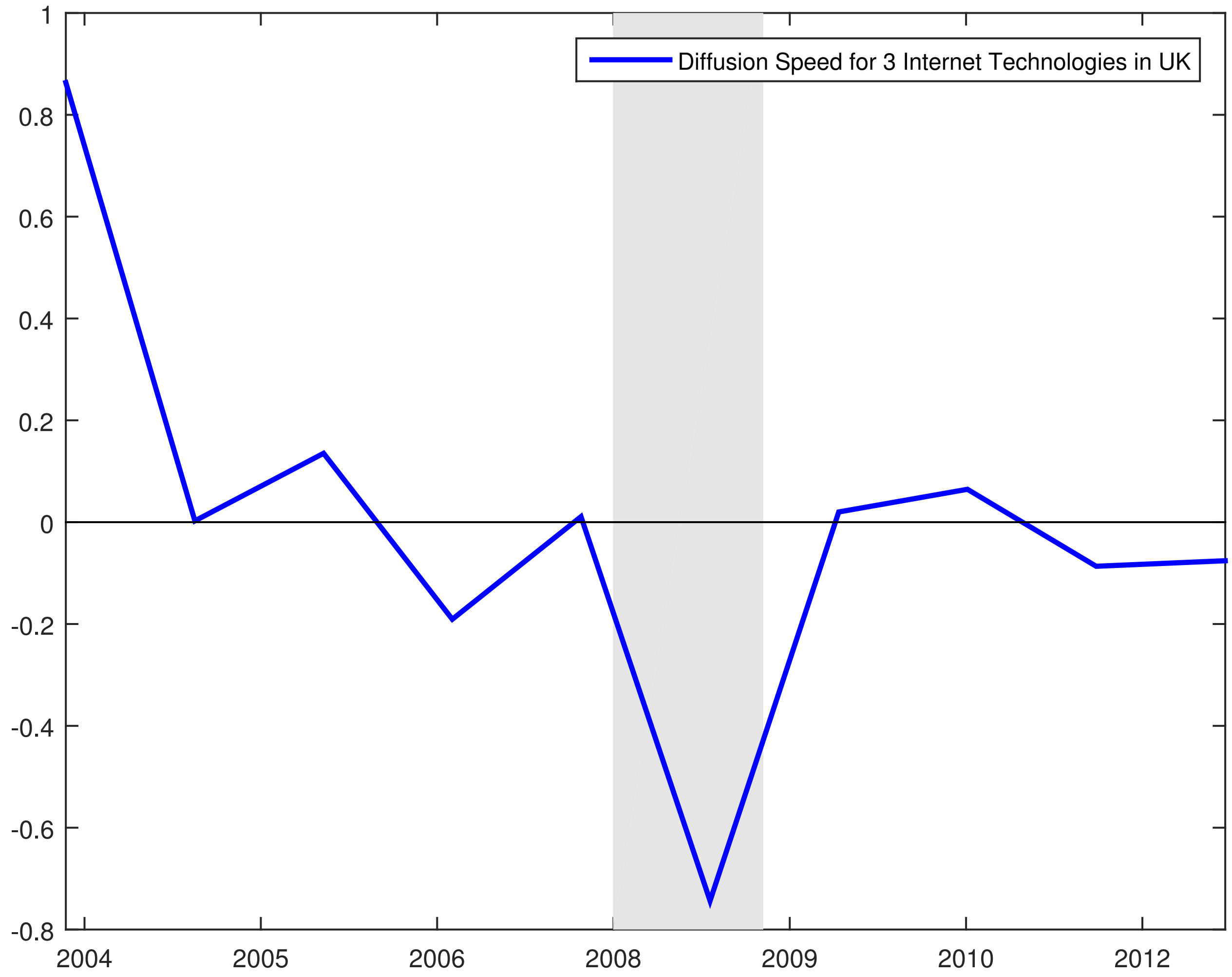


Figure 4: Diffusion Speed for 3 Internet Technologies in the UK, 2004-2013



This Paper

- Develop and estimate monetary DSGE model with endogenous technology via R&D and adoption
- Use model to assess:
  - How much of the recent productivity growth decline was an endogenous response to the Great Recession.
  - Whether the mechanism can also account for the pre-GR productivity decline.
  - More generally, the extent to which endogenous productivity can help account for business cycle persistence

Related Literature

- Comin/Gertler, 2006: endogenous prod. as business cycle propagation mechanism
- Queralto, 2013; Guerron-Quintana/Jinnai, 2013; Garcia, 2013: application to financial crises
- Hall, 2014; Reifschneider/Wascher/Wilcox, 2014: Decline in demand during GR source of reduction in capacity growth
- Bianchi and Kung (2014): estimation of DSGE model with endogenous growth
  - Differences with BK:
    - 1. Explicit model of R&D and adoption with realistic adoption lags
    - 2. Use data on business R&D (excludes public R&D, includes software dev.)
    - 3. Impose ZLB on monetary policy (turns out to be important).

Main Findings

- Endogenous TFP important source of productivity slowdown following Great Recession
  - Mainly via drop in adoption intensity stemming from crisis.

- Mechanism also accounts for much of pre-GR slowdown in TFP
  - Though shocks to R&D technology an important driver

- Drop in physical investment in GR also contributes to decline in labor producitivty (as in Hall)

- Overall, strong effects of decline in aggregate demand during GR on aggregate supply

Model Features

- Non-standard features:
  - Endogenous productivity via R&D and technology adoption
  - Skilled labor is input for R&D and adoption processes
- Standard features
  - Habit formation in consumption
  - Flow investment adjustment costs
  - Variable Capital Utilization
  - "Calvo" price and wage rigidities
  - Taylor rule for monetary policy with ZLB constraint
- We do not model financial frictions explicitly
  - But include shock that transmits like financial shock

Production Sector and Endogenous TFP: Preliminaries

- Two types of firms: (i) final goods; (ii) intermediate goods
- Final goods firms
  - Continuum of measure unity, monopolistically competitive.
  - Firm i produces differentiated output Y_t^i
  - Final good composite Y_t:

$$Y_t = \left(\int_0^1 (Y_t^i)^{\frac{1}{\mu_t}} di \right)^{\mu_t}$$

  - Firm i uses Y_{mt}^i units of intermediate goods composite as input

$$Y_t^i = Y_{mt}^i$$

  - Sets nominal price P_t^i on a staggered basis.

Production Sector and Endogenous TFP (con't)

- Intermediate goods firms
  - Continuun of measure A_t, monopolistically competitive
  - $A_t =$ stock of "adopted" intermediate goods (i.e. technologies)
  - Firm j produces output Y_{mt}^j
  - Intermediate goods composite

$$Y_{mt} = \left(\int_0^{A_t} (Y_{mt}^j)^{\frac{1}{\vartheta}} dj \right)^{\vartheta}$$

  - Firm j uses capital services $U_t^j K_t^j$ and unskilled labor L_t^j as input

$$Y_{mt}^j = \theta_t \left(U_t^j K_t^j \right)^{\alpha} (L^j)^{1-\alpha}$$

$\theta_t \equiv$ exogenous component of TFP.

Production Sector and Endogenous TFP (con't)

$$Y_t = \left(\int_0^1 (Y_t^i)^{\frac{1}{\mu_t}} di \right)^{\mu_t} = \Omega_t \cdot \overline{Y}_t^i$$

$$\Omega_t \equiv \left(\int_0^1 (Y_t^i / \overline{Y}_t^i)^{\frac{1}{\mu_t}} di \right)^{\mu_t} = 1 \text{ to a 1st order}$$

- Final goods production function $\rightarrow \overline{Y}_t^i = Y_{mt}$
- $\rightarrow$ Given a symmetric equilibrium for intermediate goods:

$$\begin{aligned} Y_t &= Y_{mt} \\ &= X_t \cdot (U_t K_t)^{\alpha} (L_t)^{1-\alpha} \\ &= [A_t^{\vartheta - 1} \theta_t] \cdot (U_t K_t)^{\alpha} (L_t)^{1-\alpha} \end{aligned}$$

  - Endogenous TFP via A_t.

R&D and Adoption

$Z_t \equiv$ stock of "unadopted" technologies (intermediate goods)

$J_t \equiv$ value of unadopted technology

$L_{srt} \equiv$ stock of skilled labor working on R&D

$L_{srt}^p \equiv$ skilled labor employed in R&D by innovator p

- R&D technology: $\varphi_t \equiv \#$ of new technologies at $t+1$ unit of L_{srt}^p can create:

$$\varphi_t = \chi_t Z_t L_{srt}^{\rho-1}$$

- Innovator $p's$ R&D decision problem:

$$\max_{L_{srt}^p} E_t\{\Lambda_{t,t+1} J_{t+1} \varphi_t L_{srt}^p\} - w_{st} L_{srt}^p$$

R&D and Adoption (con't)

- R&D decision problem: fonc

$$E_t\{\Lambda_{t,t+1} J_{t+1} \varphi_t\} - w_{st} = 0$$

$$\rightarrow E_t\{\Lambda_{t,t+1} J_{t+1} \chi_t Z_t L_{srt}^{\rho-1}\} - w_{st} = 0$$

  - J_{t+1} procylical and w_{st} sticky $\rightarrow L_{srt}$ procyclical

- Evolution of aggregate stock of unadopted technologies:

$$\begin{aligned} Z_{t+1} &= \varphi_t L_{srt} + \phi Z_t \\ &= \chi_t Z_t L_{srt}^{\rho} + \phi Z_t \end{aligned}$$

R&D and Adoption (con't)

- Adoption: conversion of Z_t to A_t.
  - Adopter buys new technology from innovator for price J_t
  - Hires skilled labor L_{sat} to adopt
  - $\lambda_t = \lambda(Z_t L_{sat}) \equiv$ probability technology is adopted with $\lambda' > 0$; $\lambda'' < 0$
  - $\rightarrow \frac{1}{\lambda_t} =$ mean diffusion lag

- Value of adopted good

$$V_t = \Pi_{mt} + \phi E_t\{\Lambda_{t,t+1} V_{t+1}\}$$

$\Pi_{mt} \equiv$ profits from adopted intermediate good.

R&D and Adoption (con't)

- Adopter's decision problem:

$$J_t = \max_{L_{sat}} E_t\{-w_{st}L_{sat} + \phi\Lambda_{t,t+1}[\lambda_t V_{t+1} + (1-\lambda_t)J_{t+1}\}$$

$$s.t.\ \lambda_t = \lambda(Z_t L_{sat})$$

$$\to Z_t\lambda' \cdot \phi E_t\{\Lambda_{t,t+1}[V_{t+1} - J_{t+1}]\} = w_{st}$$

- $\to V_t - J_t$ procylical and w_{st} sticky $\to L_{sat}$ procyclical

- Evolution of adopted technologies

$$A_{t+1} = \lambda_t\phi[Z_t - A_t] + \phi A_t$$

Households

$B_t \equiv$ riskless bond (zero net supply)

$\varrho_t \equiv$ "liquidity demand" shock (Fisher 2014)

L_t^h and $L_{st}^h \equiv$ unskilled and skilled labor supply

- Household decision problem

$$\max_{C_t, B_t, L_t^h, L_{st}^h} E_t \sum_{\tau=0}^{\infty} \beta^{\tau} \{\log(C_{t+\tau} - bC_{t+\tau-1}) + \varrho_t B_t - \upsilon_t [\frac{(L_t^h)^{1+\varphi} + (L_{st}^h)^{1+\varphi}}{1+\varphi}]\}$$

s.t.

$$C_t = w_t^h L_t + w_{st}^h S_t + \Pi_t + R_{kt} Q_{t-1} K_t - Q_t K_{t+1} + R_t B_t - B_{t+1}$$

with

$$R_{kt} = \frac{D_t + Q_t}{Q_{t-1}}$$

Households (con't)

- foncs for capital and bonds

$$
\begin{aligned}
1 &= E_t\{\Lambda_{t,t+1} R_{kt+1}\} \\
1 &= E_t\{\Lambda_{t,t+1} R_{t+1}\} + \zeta_t
\end{aligned}
$$

$$\Lambda_{t,t+1} \equiv \beta u'(C_{t+1})/u'(C_t); \quad \zeta_t = \varrho_t/u'(C_t)$$

$$\rightarrow E_t\{\Lambda_{t,t+1}(R_{kt+1} - R_{t+1})\} = \zeta_t$$

- Rise in ϱ_t reduces both consumption and investment demand
  - Also reduces R&D and adoption since $\Lambda_{t,t+1} \approx 1/R_{kt+1}$ declines
  - Transmits through economy like monetary shock (shift in R_{t+1})
  - Increases spread $R_{kt+1} - R_{t+1}$ like financial shock

Rest of Model

- Final goods firms set prices on staggered basis: Calvo with indexing
- Households set nominal wages on staggered basis: Calvo with indexing
- Capital producers: "Q" equation for investment with flow adj. costs
- Monetary Policy: Taylor rule with partial smoothing and ZLB constraint

Model Summary

- Conventional DSGE model with endogenous TFP via R&D and adoption
- Key modifications:

$$\begin{aligned} Y_t &= [A_t^{\vartheta-1}\theta_t] \cdot (U_t K_t)^{\alpha} (L_t)^{1-\alpha} \\ Z_{t+1}/Z_t &= \chi_t L_{srt}^{\rho} + \phi \\ A_{t+1} &= \lambda_t \phi [Z_t - A_t] + \phi A_t \end{aligned}$$

with

$$\lambda_t = \lambda(Z_t L_{sat})$$

- Skilled labor devoted to R&D L_{srt} and to adoption L_{sat}:
  - Endogenous and procyclical
  - Depends inversely cost of capital R_{kt+1}
    - $\rightarrow R_{kt+1}$ has both direct and indirect effects

Estimation Strategy

- Seven standard quarterly series plus R&D
  - Standard series: $Y_t, C_t, I_t, W_t/P_t, N_t, r_t^n, \pi_t$
  - R&D: spending by private firms on R&D, including software development
    - Annual series $\longrightarrow$ mixed frequency estimation
- One shock for each series. Mostly standard except:
  - Liquidity premium replaces discount factor as main demand shock
  - Shock to productivity of R&D investment
- Sample period: 1984Q1-2013Q4
  - Structural parameters estimated over non-ZLB period 1984Q1-2008Q4
  - Historical decompositions over entire sample (imposing ZLB constraint)

Estimation Strategy (con't)

- Estimate conventional DSGE parameters
- Use mix of estimation and calibration for new parameter associated with R&D sector
  - Estimate $\rho \equiv$ elasticity of new technologies w.r.t. R&D
  - Identify labor supply elasticity and wage setting frequency of skilled labor by assuming it is the same as for unskilled labor
  - Calibrate other parameters to hit various targets.
- Use Bayesian methods (see, e.g., An and Schorfeide, 2006)
  - Combine model likelihood function with priors for parameters to be estimated to obtain posterior distribution
  - Let the data speaks as much as possible.

Table 1: Calibrated Parameters

Parameter	Description	Value
α	Capital share	1/3
δ	Capital depreciation	0.02
β	Discount factor	0.995
$\frac{G}{Y}$	SS government consumption/output	0.2
γ_y	SS output growth	1.87%
μ	SS final goods mark up	1.1
μ_w	SS wage mark up	1
ϑ	Intermediate goods mark up	1.35
$1-\phi$	Obsolescence rate	0.08/4
$\bar{\lambda}$	SS adoption lag	0.15/4
ρ_λ	Adoption elasticity	0.95

Table 2: Structural Parameters Prior and Posterior Distributions

Parameter	Description	Prior			Posterior		
		Distr	Mean	St. Dev.	Mode	Mean	St. Dev.
ρ	Taylor rule smoothing	Beta	0.7	0.15	0.693	0.805	0.044
ϕ_π	Taylor rule inflation	Gamma	1.5	0.25	0.921	1.571	0.459
ϕ_y	Taylor rule labor	Gamma	0.3	0.1	0.646	0.470	0.169
φ	Inverse Frisch elast	Gamma	2	0.75	2.609	3.381	0.976
f''	Investment adj cost	Gamma	4	1	0.916	1.286	0.249
$\frac{\delta'(U)}{\delta}$	Capital util elast	Gamma	4	1	3.946	3.868	0.939
ξ_p	Calvo prices	Beta	0.5	0.1	0.943	0.927	0.017
ξ_w	Calvo wages	Beta	0.75	0.1	0.946	0.870	0.087
ι_p	Price indexation	Beta	0.5	0.15	0.157	0.276	0.112
ι_w	Wage indexation	Beta	0.5	0.15	0.242	0.338	0.130
b	Consumption habit	Beta	0.7	0.1	0.340	0.389	0.044
ρ_z	R&D elasticity	Beta	0.6	0.2	0.342	0.390	0.147

Table 3: Demand and Supply Shocks Prior and Posterior Distributions

Parameter	Description	Prior			Posterior		
		Distr	Mean	St. Dev.	Mode	Mean	St. Dev.
ρ_θ	TFP	Beta	0.50	0.20	0.90	0.91	0.03
ρ_{pk}	Investment	Beta	0.50	0.20	0.88	0.87	0.03
ρ_ϱ	Liq Demand	Beta	0.50	0.20	0.90	0.91	0.03
ρ_{mp}	Monetary	Beta	0.50	0.20	0.90	0.57	0.20
ρ_μ	Mark up	Beta	0.50	0.20	0.37	0.38	0.13
ρ_g	Govt Exp	Beta	0.50	0.20	0.99	0.99	0.01
ρ_{μ_w}	Wage mark up	Beta	0.50	0.20	0.16	0.26	0.14
ρ_χ	R&D	Beta	0.50	0.20	0.84	0.84	0.06
σ_θ	TFP	Inv. Gamma	0.10	2.00	0.53	0.51	0.04
σ_{pk}	Investment	Inv. Gamma	0.10	2.00	0.58	0.74	0.09
σ_ϱ	Liq Demand	Inv. Gamma	0.10	2.00	0.25	0.23	0.04
σ_{mp}	Monetary	Inv. Gamma	0.10	2.00	0.13	0.10	0.01
σ_μ	Mark up	Inv. Gamma	0.10	2.00	0.11	0.10	0.01
σ_g	Govt Exp	Inv. Gamma	0.10	2.00	2.73	2.87	0.24
σ_{μ_w}	Wage mark up	Inv. Gamma	0.10	2.00	0.30	0.30	0.04
σ_χ	R&D	Inv. Gamma	0.10	2.00	1.90	2.13	0.56

Table 4: Variance Decomposition (%)

Variables	Liquidity Demand	Money	Govt Exp	Price of Capital	TFP	R&D	Mark up	Wage mark up
Output Growth	28.7	24.1	7.2	5.7	32.8	0.3	0.7	0.6
Consumption Growth	19.2	14.7	37.3	2.2	26.0	0.0	0.3	0.3
Investment Growth	17.8	17.1	2.6	39.4	16.1	1.1	2.6	3.3
Inflation	0.0	0.0	0.2	0.0	2.5	0.0	87.3	9.8
Nominal R	66.0	5.3	1.7	4.9	9.7	0.1	7.9	4.3
Hours	40.2	30.3	6.1	6.8	15.9	0.1	0.6	0.0
R&D Growth	7.4	8.4	3.3	4.0	21.4	51.9	3.0	0.5
Endogenous TFP	17.1	11.7	2.7	5.1	40.2	16.3	4.8	2.3
Int. Goods Varieties	0.4	0.7	0.3	0.9	1.9	94.3	1.2	0.3
Speed of Diffusion	28.7	13.7	3.5	2.7	37.1	11.3	2.1	1.0

Variance decomposition with ZLB (10,000 simulations, HP filtered series, $\lambda = 1600$).

Figure 5: Output Growth Decomposition

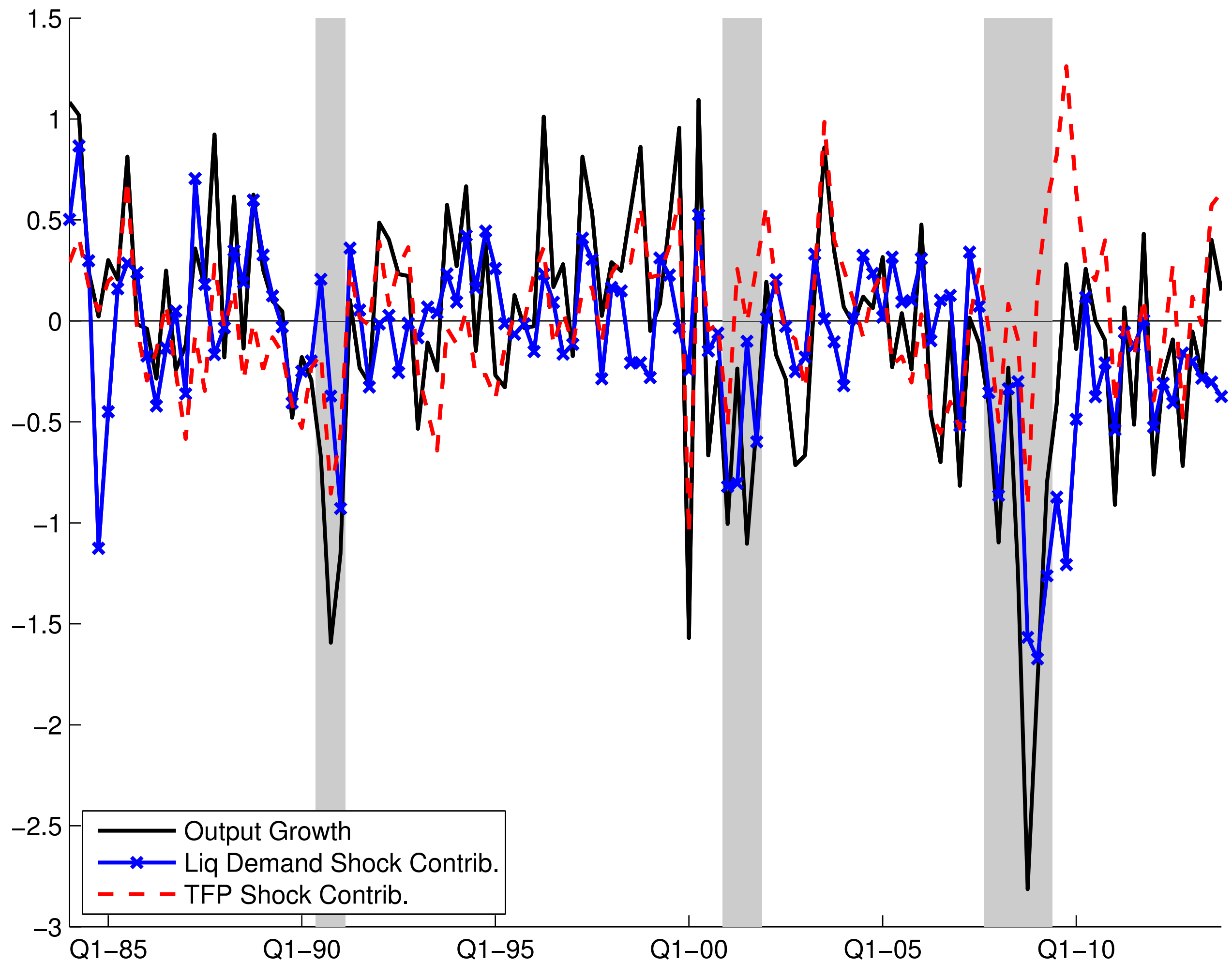


Figure 6: Impulse Response to 1 std. dev. Shock

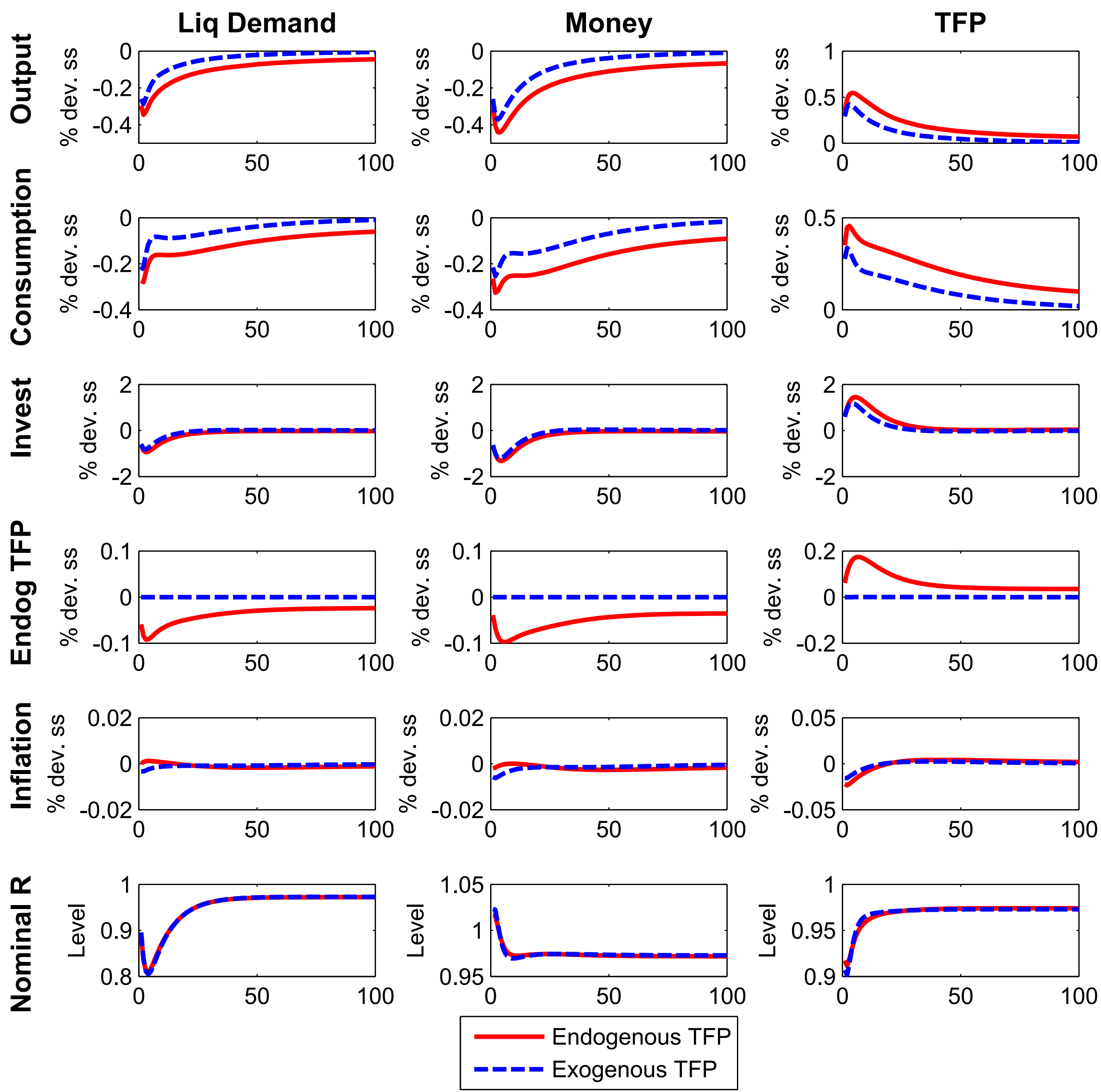


Figure 7: Liquidity Demand Shock and the ZLB

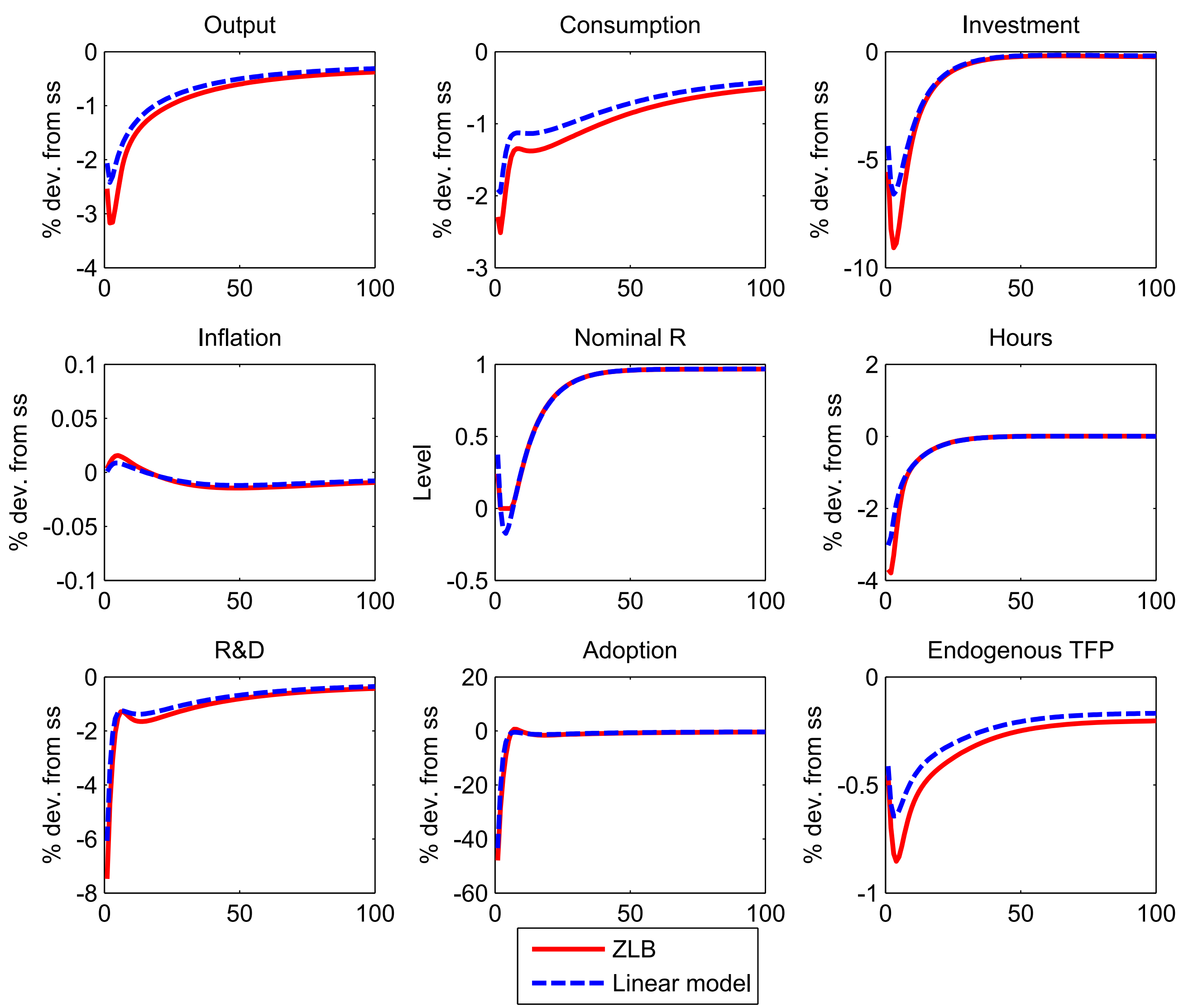
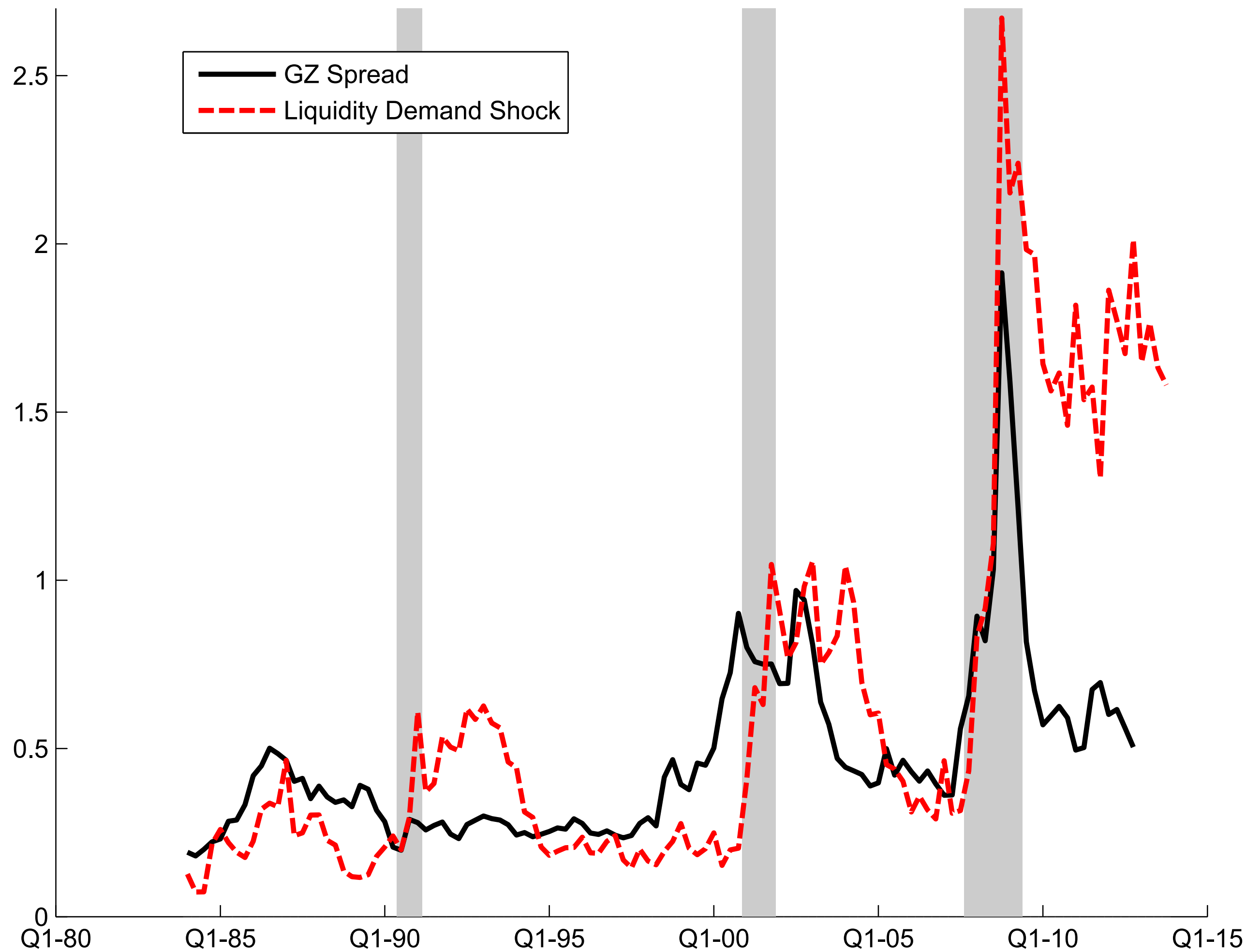


Figure 8: GZ Spread and Model Spread - correlation: 0.69



Endogenous Productivity, and TFP vs Labor Productivity

$$TFP = \frac{Y_t}{(U_t K_t)^{\alpha}(L_t)^{1-\alpha}} = A_t^{\vartheta-1}\theta_t$$

$$LP = \frac{Y_t}{L_t} = A_t^{\vartheta-1}\theta_t(\frac{U_t K_t}{L_t})^{\alpha}$$

- Endogenous prod. $A_t^{\vartheta-1}$ has similar impact on TFP and LP
- We focus on LP for two reasons:
  - Capital in model includes both housing and consumer durables $\rightarrow$ some discrepency between model measure of TFP and conventional measures.
  - LP captures effect of decline in capital - another channel via which demand contraction from GR reduced capacity output.

Figure 9: Endogenous TFP, TFP and Labor Productivity

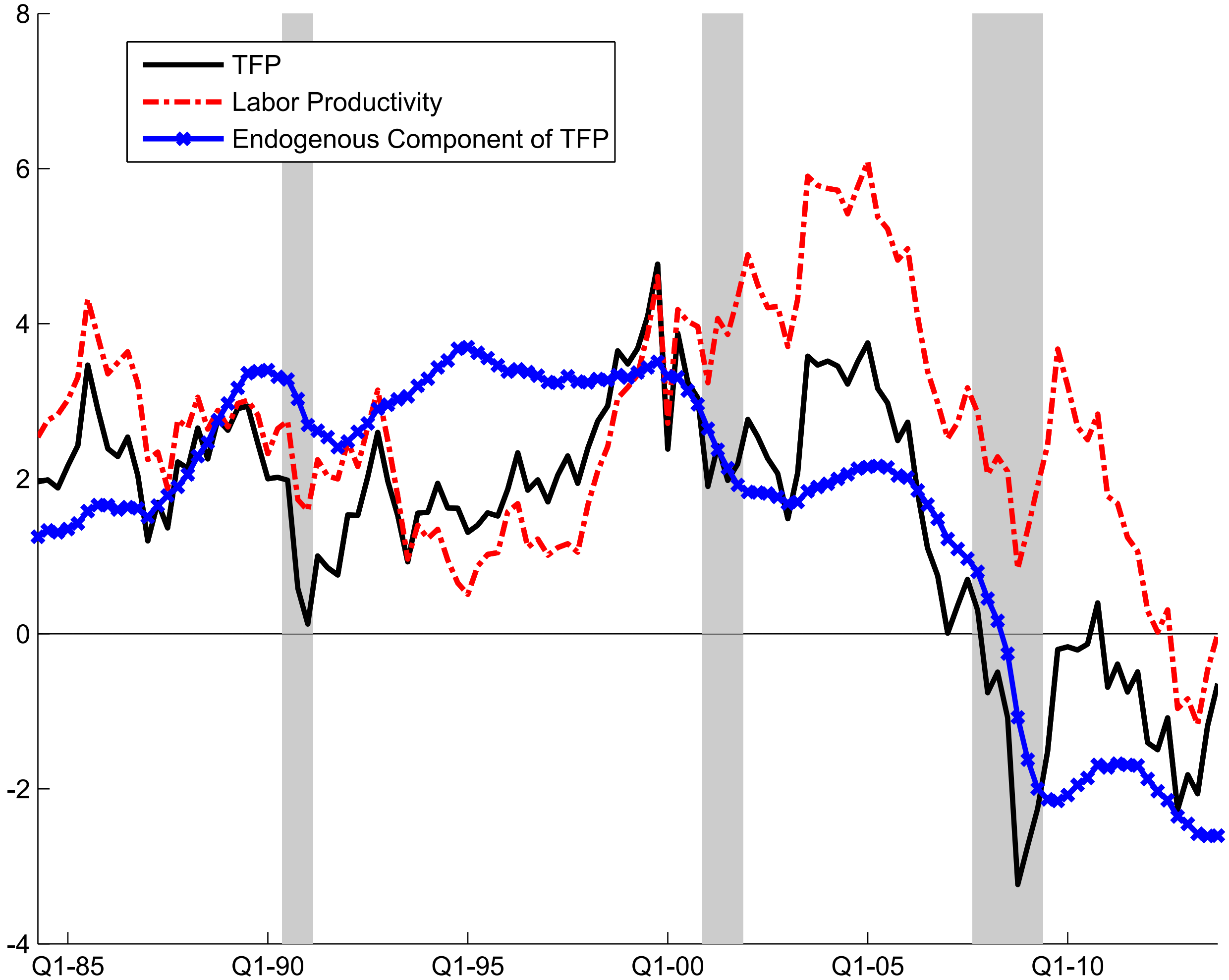


Figure 10: Endogenous TFP Decomposition

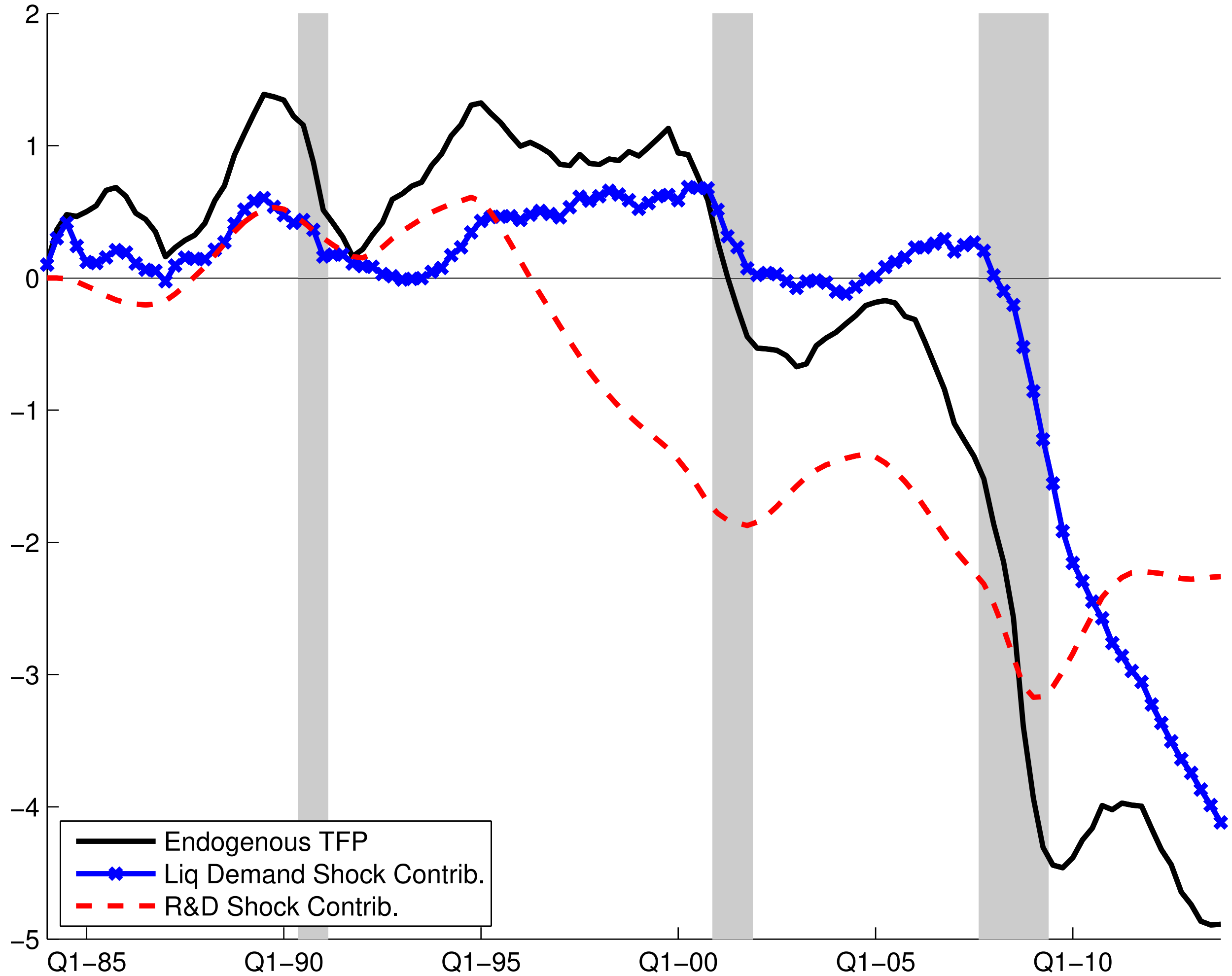
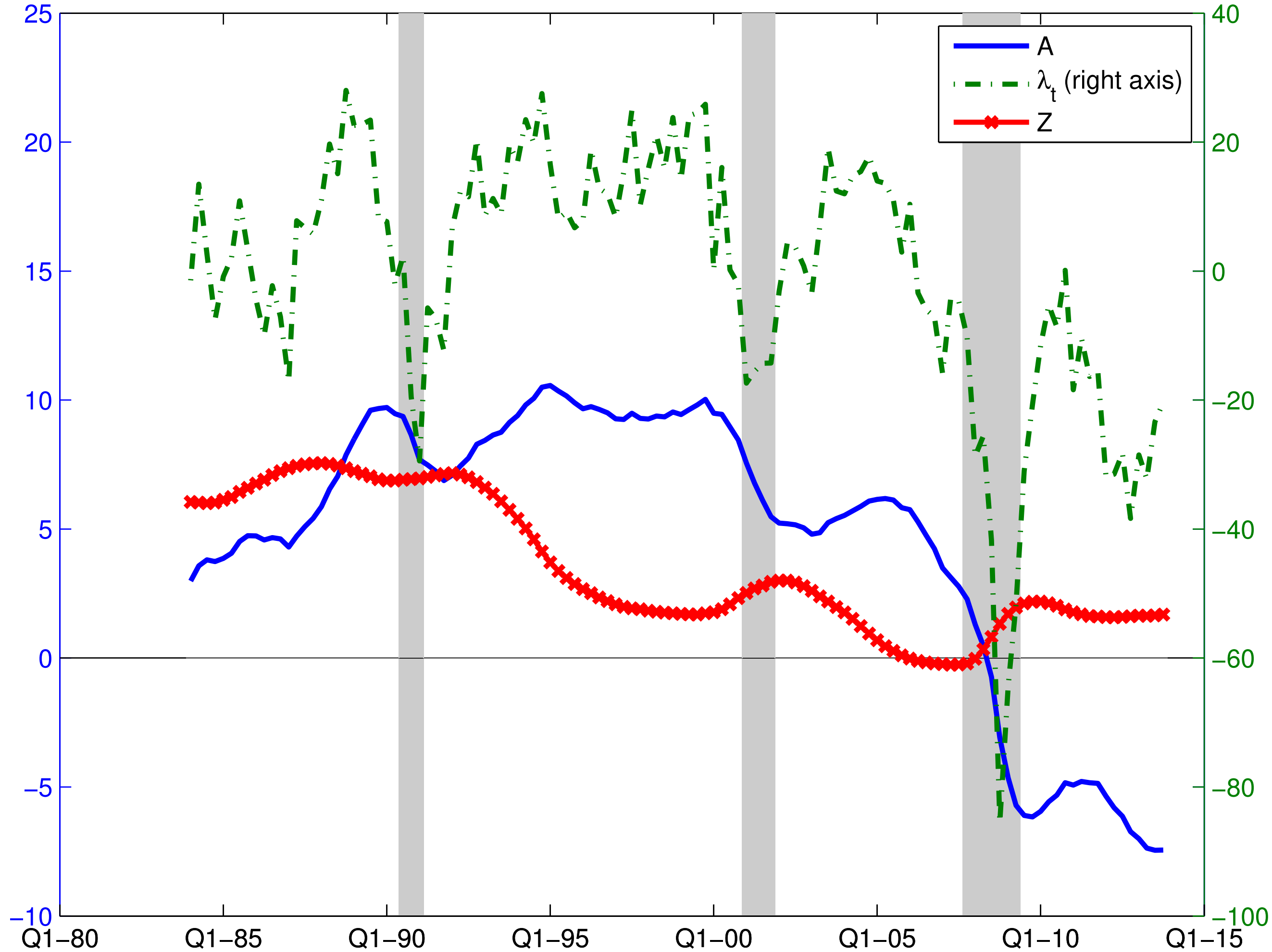


Figure 11: Sources of Endogenous Technology



Concluding Remarks

- Estimate DSGE model with endogenous productivity via R&D and adoption
  - Use model to identify source of productivity decline following Great Recession
- Key result: Much of the productivity decline an endogenous response to recession
  - Drop in adoption due to financial crisis/recesssion main channel
  - Overall, insufficient demand during GR contributed to productivity slowdown
- Mechanism also helps account for smoothness in inflation during GR
- Overall, results suggest that recent low productivity growth may reflect (medium term) cyclical factors as opposed to secular ones.

Figure 12: R&D Salaries and Other Expenses (logs, 2008 = 0)