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 Recession
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 → 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

R&D and GDP (1999 = 100)
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
- Hall, 2014; Reifschneider/Wascher/Wilcox, 2014: Decline in demand during GR source of reduction in capacity 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 productivity (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 $Y_t$:

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

- 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
  – Continuum 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

\[ Y_{mt} = \left( \int_0^{A_t} (Y_{mt}^j)^{\frac{1}{\varphi}} d\varphi \right)^{\varphi} \]

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

\[ Y_{mt}^j = \theta_t \left( U_t^j K_t^j \right)^\alpha (L_t^j)^{1-\alpha} \]

$\theta_t \equiv$ exogenous component of TFP.
Production Sector and Endogenous TFP (con’t)

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

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

- Final goods production function → \( \overline{Y}_t = Y_{mt} \)

- Given a symmetric equilibrium for intermediate goods:

\[ Y_t = Y_{mt} \]
\[ = X_t \cdot (U_tK_t)^{\alpha}(L_t)^{1-\alpha} \]
\[ = [A_t^{\vartheta-1}\theta_t] \cdot (U_tK_t)^{\alpha}(L_t)^{1-\alpha} \]

- 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:

$$\max_{L_{srt}^p} E_t \left\{ \Lambda_{t,t+1} J_{t+1} \varphi_t L_{srt}^p \right\} - w_{st} L_{srt}^p$$
R&D and Adoption (con’t)

- R&D decision problem: fonc

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

\[
\rightarrow E_t\{\Lambda_{t,t+1}J_{t+1}\chi_tZ_tL_{srt}^{\rho - 1}\} - w_{st} = 0
\]

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

- Evolution of aggregate stock of unadopted technologies:

\[
Z_{t+1} = \varphi_tL_{srt} + \phi Z_t
\]

\[
= \chi_tZ_tL_{srt}^\rho + \phi Z_t
\]
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
  - $\lambda_t = \lambda(Z_tL_{sat}) \equiv$ probability technology is adopted with $\lambda' > 0; \lambda'' < 0$
  - $\rightarrow \frac{1}{\lambda_t} = \text{mean diffusion lag}$

- 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:

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

\[
s.t. \; \lambda_t = \lambda(Z_t L_{sat})
\]

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

- \( V_t - J_t \) procyclical and \( w_{st} \) sticky \( \rightarrow L_{sat} \) 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)

\( L_{ht}^h \) and \( L_{st}^h \equiv \) unskilled and skilled labor supply

- Household decision problem

\[
\max_{C_t,B_t,L_{ht}^h,L_{st}^h} \mathbb{E}_t \sum_{\tau=0}^{\infty} \beta^\tau \left\{ \log(C_{t+\tau} - bC_{t+\tau-1}) + \varrho_t B_t - \nu_t \left[ \frac{(L_{ht}^h)^{1+\varphi} + (L_{st}^h)^{1+\varphi}}{1 + \varphi} \right] \right\}
\]

s.t.

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

with

\[
R_{kt} = \frac{D_t + Q_t}{Q_{t-1}}
\]
Households (con’t)

• foncs for capital and bonds

\[ 1 = E_t\{\Lambda_{t,t+1}R_{kt+1}\} \]
\[ 1 = E_t\{\Lambda_{t,t+1}R_{t+1}\} + \zeta_t \]

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

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

• Rise in \( \varrho_t \) 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:

\[ Y_t = [A_t^\theta - 1 \theta_t] \cdot (U_t K_t)^\alpha (L_t)^{1-\alpha} \]

\[ Z_{t+1}/Z_t = \chi_t L_{srt}^\rho + \phi \]

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

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 \( R_{kt+1} \)
    
    \[ \* \to R_{kt+1} \text{ has both direct and indirect effects} \]
Estimation Strategy

- Seven standard quarterly series plus R&D
  - Standard series: $Y_t, C_t, I_t, W_t/P_t, N_t, r^n_t, \pi_t$
  - R&D: spending by private firms on R&D, including software development
    * Annual series $\rightarrow$ 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 Schorfheide, 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>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
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<tr>
<td>$\alpha$</td>
<td>Capital share</td>
<td>$\frac{1}{3}$</td>
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<td>$\delta$</td>
<td>Capital depreciation</td>
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<td>$\beta$</td>
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<td>$\frac{G}{Y}$</td>
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<td>$\gamma_y$</td>
<td>SS output growth</td>
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<td>$\mu$</td>
<td>SS final goods mark up</td>
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<td>$\mu_w$</td>
<td>SS wage mark up</td>
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<td>$\vartheta$</td>
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<td>$1 - \phi$</td>
<td>Obsolescence rate</td>
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<td>$\bar{\lambda}$</td>
<td>SS adoption lag</td>
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<td>Adoption elasticity</td>
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<td>$\xi_{w}$</td>
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<td>$\rho_{z}$</td>
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<td>$\rho_\theta$</td>
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<tr>
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<td>Monetary</td>
<td>Beta 0.50 0.20</td>
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<td>Mark up</td>
<td>Beta 0.50 0.20</td>
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<td>$\rho_g$</td>
<td>Govt Exp</td>
<td>Beta 0.50 0.20</td>
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<td>$\rho_{\mu_w}$</td>
<td>Wage mark up</td>
<td>Beta 0.50 0.20</td>
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<td>$\rho_\chi$</td>
<td>R&amp;D</td>
<td>Beta 0.50 0.20</td>
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<td>TFP</td>
<td>Inv. Gamma 0.10 2.00</td>
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<td>$\sigma_{pk}$</td>
<td>Investment</td>
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<td>R&amp;D</td>
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Table 4: Variance Decomposition (%)

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<tr>
<th>Variables</th>
<th>Liquidity Demand</th>
<th>Money Exp</th>
<th>Govt Exp</th>
<th>Price of Capital</th>
<th>TFP</th>
<th>R&amp;D</th>
<th>Mark up</th>
<th>Wage mark up</th>
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<tr>
<td>Output Growth</td>
<td>28.7</td>
<td>24.1</td>
<td>7.2</td>
<td>5.7</td>
<td>32.8</td>
<td>0.3</td>
<td>0.7</td>
<td>0.6</td>
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<td>Consumption Growth</td>
<td>19.2</td>
<td>14.7</td>
<td>37.3</td>
<td>2.2</td>
<td>26.0</td>
<td>0.0</td>
<td>0.3</td>
<td>0.3</td>
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<td>Investment Growth</td>
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<td>17.1</td>
<td>2.6</td>
<td>39.4</td>
<td>16.1</td>
<td>1.1</td>
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<td>3.3</td>
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<td>1.7</td>
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<td>9.7</td>
<td>0.1</td>
<td>7.9</td>
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<td>Hours</td>
<td>40.2</td>
<td>30.3</td>
<td>6.1</td>
<td>6.8</td>
<td>15.9</td>
<td>0.1</td>
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<td>R&amp;D Growth</td>
<td>7.4</td>
<td>8.4</td>
<td>3.3</td>
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<td>21.4</td>
<td>51.9</td>
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<td>Endogenous TFP</td>
<td>17.1</td>
<td>11.7</td>
<td>2.7</td>
<td>5.1</td>
<td>40.2</td>
<td>16.3</td>
<td>4.8</td>
<td>2.3</td>
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<td>Int. Goods Varieties</td>
<td>0.4</td>
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<td>0.3</td>
<td>0.9</td>
<td>1.9</td>
<td>94.3</td>
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<td>Speed of Diffusion</td>
<td>28.7</td>
<td>13.7</td>
<td>3.5</td>
<td>2.7</td>
<td>37.1</td>
<td>11.3</td>
<td>2.1</td>
<td>1.0</td>
</tr>
</tbody>
</table>

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

- **Liq Demand**
- **Output**
- **Money**
- **TFP**
- **Consumption**
- **Invest**
- **Endog TFP**
- **Inflation**
- **Nominal R**

Graphs showing the impulse response of various economic variables to a 1 standard deviation 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

\[ TFP = \frac{Y_t}{(U_tK_t)^\alpha(L_t)^{1-\alpha}} = A_t^{\phi-1}\theta_t \]

\[ LP = \frac{Y_t}{L_t} = A_t^{\phi-1}\theta_t \left(\frac{U_tK_t}{L_t}\right)^\alpha \]

- Endogenous prod. \( A_t^{\phi-1} \) 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/recession 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)