Technology Adoption and Labor Market Dynamics

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Motivation

- **two major shortcomings** in our understanding of cyclical labor market dynamics

- business cycle facts (U.S. data, 1953:I – 2009:IV):
  - unemployment is ***volatile***, 10$\times$ more than labor productivity
  - unemployment and labor productivity are only ***mildly*** (negatively) ***correlated***

Motivation

- in the workhorse Diamond-Mortensen-Pissarides model of equilibrium unemployment ...
  - ***std(Unemp)/std(LP)* = 0.93** ... in the data: **9.35**!

    see Andolfatto (1996), Shimer (2005), Costain-Reiter (2009)

  - ***corr(Unemp,LP)* = −0.96** ... in the data: **−0.41**!

    see Mortensen-Nagypal (2007), Hall-Milgrom (2008)

- ... when business cycles driven by technology shocks

Resolutions

- **Shimer Puzzle**: change relative bargaining power of workers & firms over the cycle, while preserving the nature of shocks
  - Gertler-Trigari (2007), Hall-Milgrom (2008)
- **Mortensen-Nagypal Puzzle**: hasn't been addressed in the search-and-matching literature
  - in the RBC literature, simply add shocks to 'labor supply'
- **our proposal**: consider a new business cycle shock that addresses both puzzles simultaneously

Business Cycle Shocks

- primary driving force in business cycle literature: technology shocks
- literal view on what these shocks are:
  - stochastic arrival of new technologies, sometimes more/less productive
  - costlessly implemented and have **immediate** impact on productivity

A Less Extreme View on Technology

- idea: technological innovations are not immediately adopted
  - upon arrival, new technology does not immediately reach full productive potential
  - takes workers & firms time to implement and "figure it out"
- **cyclical nature of our shock:**
  - **"*ease of adoption*" or time it takes for new technology to become fully productive**

A Simple Example: Office Workers and PCs

- current operating system = DOS (not user friendly)
  - takes a long time to become proficient, for PC technology to be adopted
- **shock**: Windows OS arrives (user friendly)
  - easier to become proficient, faster adoption

A Simple Example: Office Workers and PCs

- current operating system = DOS (not user friendly)
  - takes a long time to become proficient, for PC technology to be adopted
- **shock**: Windows OS arrives (user friendly)
  - easier to become proficient, faster adoption
- a negative shock is Vista ... no one can figure it out!

How Does It Work?

- consider a positive ***adoption rate*** shock:
  - expected future productivity $\uparrow$
  - PDV of firm profits while matched $\uparrow$
  - return to job creation / vacancy posting $\uparrow$
  - hiring $\uparrow$, unemployment $\downarrow$
  - gradual rise in productivity via technology adoption process
- **key**: generate response of economic activity with no direct impact on productivity

Supportive Evidence

- new interpretation of "***news shocks***" ...
  - Beaudry-Portier (2006): shocks to long-run TFP have **immediate** effects on economic activity (stock prices, employment), but **no** effect on productivity upon impact
  - these shocks explain up to 50% of business cycle fluctuations
    - see also Beaudry-Lucke (2009), Schmitt-Grohe-Uribe (2010)
- TFP exhibits smooth "diffusion" process ... no "jumps"
- conforms with evidence on procyclical technology adoption
  - ... Comin (2009), Comin-Gertler-Santacreu (2010)

Economic Environment: Basics

- technology adoption $\Rightarrow$ productivity improvement
  - modeled as productivity shift: $f_L \rightarrow f_H$
- output in a match depends on whether worker has "figured out" the (high productivity) technology
- type-L workers *upgrade* (become type-H) only while working ($\approx$ learning-by-doing)
  - probability of upgrade or ***adoption rate***: λ

Economic Environment: Basics

- worker's productivity is observable
  - firms post vacancies separately for L and H types

- key equilibrium variable: ***tightness ratio*** in each submarket $i = \{L, H\}$

$$\theta_i = \frac{v_i}{u_i}$$

  - *job finding probability*: $\mu(\theta_i)$
  - *job filling probability*: $q(\theta_i)$
  - matching function: $\mu(\theta_i) = \theta_i q(\theta_i)$

Technology Adoption: Market L

workers' value functions:

$$U_L = z + \beta E\left[\mu(\theta_L)W_L' + (1-\mu(\theta_L))U_L'\right]$$

$$W_L = \omega_L + \beta E\Big[\lambda\left[(1-\delta)W_H' + \delta U_H'\right] + (1-\lambda)\left[(1-\delta)W_L' + \delta U_L'\right]\Big]$$

firms' value function:

$$J_L = f_L - \omega_L + \beta(1-\delta)E\Big[\lambda J_H' + (1-\lambda)J_L'\Big]$$

free entry: $\quad k = q(\theta_L)\beta E\left[J_L'\right]$

High Productivity Workers: Market H

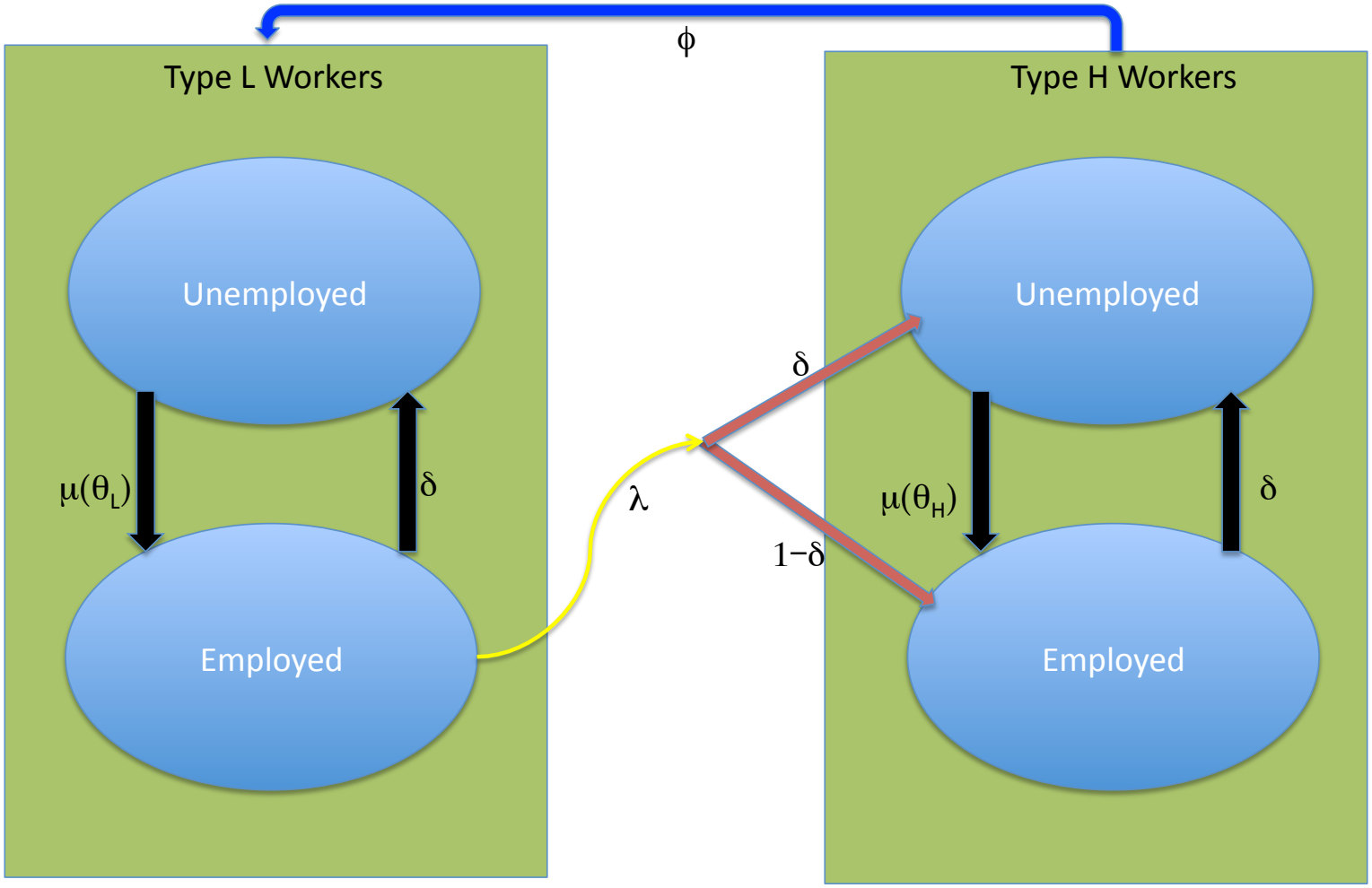
$$U_H = z + \beta E\Big[\mu(\theta_H)[(1-\phi)W'_H + \phi W'_L] + (1-\mu(\theta_H))\left[(1-\phi)U'_H + \phi U'_L\right]\Big]$$

$$W_H = \omega_H + \beta E\Big[(1-\phi)\left[(1-\delta)W'_H + \delta U'_H\right] + \phi\left[(1-\delta)W'_L + \delta U'_L\right]\Big]$$

$$J_H = f_H - \omega_H + \beta(1-\delta)E\Big[(1-\phi)J'_H + \phi J'_L\Big]$$

$$k = q(\theta_H)\beta E\Big[(1-\phi)J'_H + \phi J'_L\Big]$$

Summary


ϕ
Type L Workers
Unemployed
μ(θL)
δ
Employed
λ
δ
1−δ
Type H Workers
Unemployed
μ(θH)
δ
Employed

Other Details

- model collapses to standard DMP if:
  - $f_L = f_H$ or no adoption ($\lambda = 0$)
- Nash bargaining for wages
  - $\Rightarrow$ constant bargaining power over business cycle
- 'segmented' job markets
  - $\Rightarrow$ distribution of unemployed types not a state variable
- results robust to alternative specifications
  - e.g., random search, directed search with wage posting

Other Details

- constant / exogenous job destruction (δ) over business cycle
  - procyclical job creation explains 2/3 to 3/4 of unemployment volatility

    Shimer (2005), Hall (2005), Fujita-Ramey (2009), Elsby et al. (2009)

  - primary focus: modeling cyclical fluctuations in job creation

Analytical Results: Preview

- analytical results regarding deviations from steady state to illustrate:
  - weak amplification of technology shocks in DMP model
  - key difference with productivity upgrading
  - implications for technology shocks and adoption rate shocks

Standard DMP Analysis

- total match surplus in steady state:

$$TS = f - z - \frac{\tau}{1-\tau} k\theta + \beta(1-\delta)TS$$

- free entry condition in vacancy creation:

$$k = q(\theta)\beta J = q(\theta)\beta(1-\tau)TS$$

Standard DMP Analysis

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- problem: feedback effect via option value to worker of remaining unemployed

Inspecting the Mechanism

- total surplus in DMP model:

$$TS = f - z - \frac{\tau}{1-\tau} k\theta + \beta(1-\delta)TS$$

- total surplus with potential for upgrade:

$$TS_L = f_L - z - \frac{\tau}{1-\tau} k\theta_L + \beta(1-\delta)TS_L$$
$$+ \beta\lambda\Big[\,(1-\delta)\Big(J_H - J_L + W_H - W_L\Big) \;+ \delta\Big(U_H - U_L\Big)\Big]$$

Inspecting the Mechanism

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$$+ \beta\lambda\Big[\underbrace{(1-\delta)\Big(TS_H - TS_L\Big)}_{\text{matched value of adoption}} + \underbrace{\Big(U_H - U_L\Big)}_{\text{worker's value of adoption}}\Big]$$

Inspecting the Mechanism

$$TS_L = f_L - z - \frac{\tau}{1-\tau} k\theta_L + \beta(1-\delta) TS_L$$

$$+ \underbrace{\beta\lambda\Big[(1-\delta)\Big(TS_H - TS_L\Big) + \Big(U_H - U_L\Big)\Big]}_{\text{total value of adoption} \equiv \Delta}$$

Proposition 1: In any steady state equilibrium $U_L < U_H$

$$\Rightarrow \quad (TS_H - TS_L) > 0 \;\text{ and }\; \Delta > 0$$

Amplification of Technology Shocks

$$TS_L = f_L - z - \frac{\tau}{1-\tau} k\theta_L + \beta(1-\delta) TS_L$$

$$+ \underbrace{\beta\lambda\Big[(1-\delta)\Big(TS_H - TS_L\Big) + \Big(U_H - U_L\Big)\Big]}_{\Delta}$$

Proposition 2: In response to $\hat{f}_L > 0$, $\hat{\Delta} > 0$

- procyclical response of Δ offsets the feedback effect

  amplifies effect of TFP shocks on job creation

- ... but quantitatively not very important

Adoption Rate Shocks

$$TS_L = f_L - z - \frac{\tau}{1-\tau} k\theta_L + \beta(1-\delta)TS_L$$

$$+ \underbrace{\beta\lambda\Big[(1-\delta)\Big(TS_H - TS_L\Big) + \Big(U_H - U_L\Big)\Big]}_{\Delta}$$

Proposition 3: In response to $\hat{\lambda} > 0$, $\hat{\Delta} > 0$

- adoption rate shocks generate job creation
- ... quantitatively important!

Adoption Rate Shocks

$$TS_L = f_L - z - \frac{\tau}{1-\tau} k\theta_L + \beta(1-\delta) TS_L$$

$$+ \underbrace{\beta\lambda\Big[(1-\delta)\Big(TS_H - TS_L\Big) + \Big(U_H - U_L\Big)\Big]}_{\Delta}$$

Proposition 3: In response to $\hat{\lambda} > 0$, $\hat{\Delta} > 0$

- positive adoption rate shock $\Rightarrow$ rise in expected future match output/profit
- $\Rightarrow$ rise in job creation today

Surplus in High Productivity Matches

$$TS_H = f_H - z - \frac{\tau}{1-\tau} k\theta_H + \beta(1-\delta) TS_H$$

$$\underbrace{-\beta\phi(1-\delta)\Big(TS_H - TS_L\Big)}_{\Theta}$$

Proposition 4: In response to $\hat{\lambda} > 0$, $\widehat{\Big(TS_H - TS_L\Big)} < 0$

- $\Rightarrow \hat{\Theta} > 0$

Calibration

parameter	*target*
$f_H = 1$	normalization
$\beta = 0.996$	*discount rate, monthly freq*; ann int rate $= 5\%$
$\delta = 0.026$	*exo separation rate*; $u_{ss} = 5.8\%$
$\alpha = 0.4$	$\xi v_i^{\alpha} u_i^{1-\alpha}$; Petrongolo-Pissarides (2001), Brugemann (2008), Pissarides (2
$\tau = 1 - \alpha$	*worker's bargaining power*; Hosios (1990) condition
ξ, k	*job finding rate* $\mu(\bar{\theta}_{ss}) = 0.45$, normalize $\bar{\theta}_{ss} = 1$; Shimer (2005)
$z = 0.45$	*flow utility when unemployed*; Hall-Milgrom (2008)

Calibration

- new parameters:
  - $f_H/f_L = 2$ ... Ljungqvist and Sargent (1998, 2004) to match returns to labor market experience
  - $\lambda = 0.01$ ... Ljungqvist and Sargent; Mansfield (1988,1989) to match diffusion rate in industrial robotics technology
  - $\phi = \lambda$ ... implies approx. 50%-50% split in L and H workers in steady state

Results

	Data	DMP	*f* shocks
std(LP)	0.02	0.02	0.02
standard deviation relative to std(LP)			
unemployment	9.34	0.93	1.11
job finding rate	6.05	0.98	1.19
tightness ratio	18.2	2.32	2.81
correlations			
corr(unemp,vacancies)	-0.89	-0.90	-0.92
corr(unemp,LP)	-0.41	-0.96	-0.97
corr(job finding,LP)	0.44	1.00	1.00
corr(tightness,LP)	0.39	1.00	1.00

Quarterly average of monthly data

Deviations from hp trend

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Quarterly average of monthly data

Deviations from hp trend

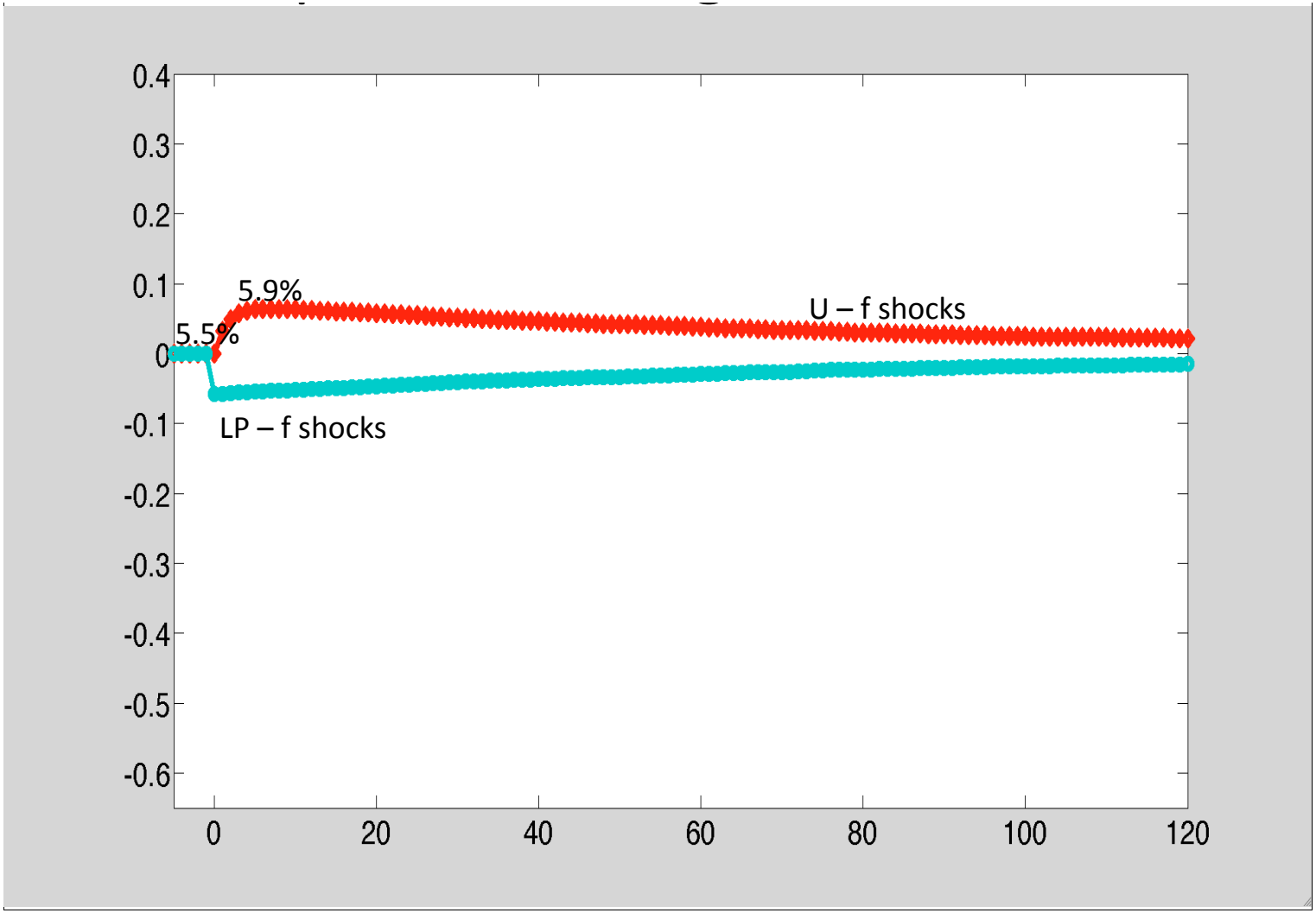
Results

	Data	DMP	f shocks	λ shocks
std(LP)	0.02	0.02	0.02	0.02
standard deviation relative to std(LP)				
unemployment	9.34	0.93	1.11	5.10
job finding rate	6.05	0.98	1.19	5.56
tightness ratio	18.2	2.32	2.81	9.23
correlations				
corr(unemp,vacancies)	-0.89	-0.90	-0.92	-0.88
corr(unemp,LP)	-0.41	-0.96	-0.97	-0.40
corr(job finding,LP)	0.44	1.00	1.00	0.39
corr(tightness,LP)	0.39	1.00	1.00	0.39

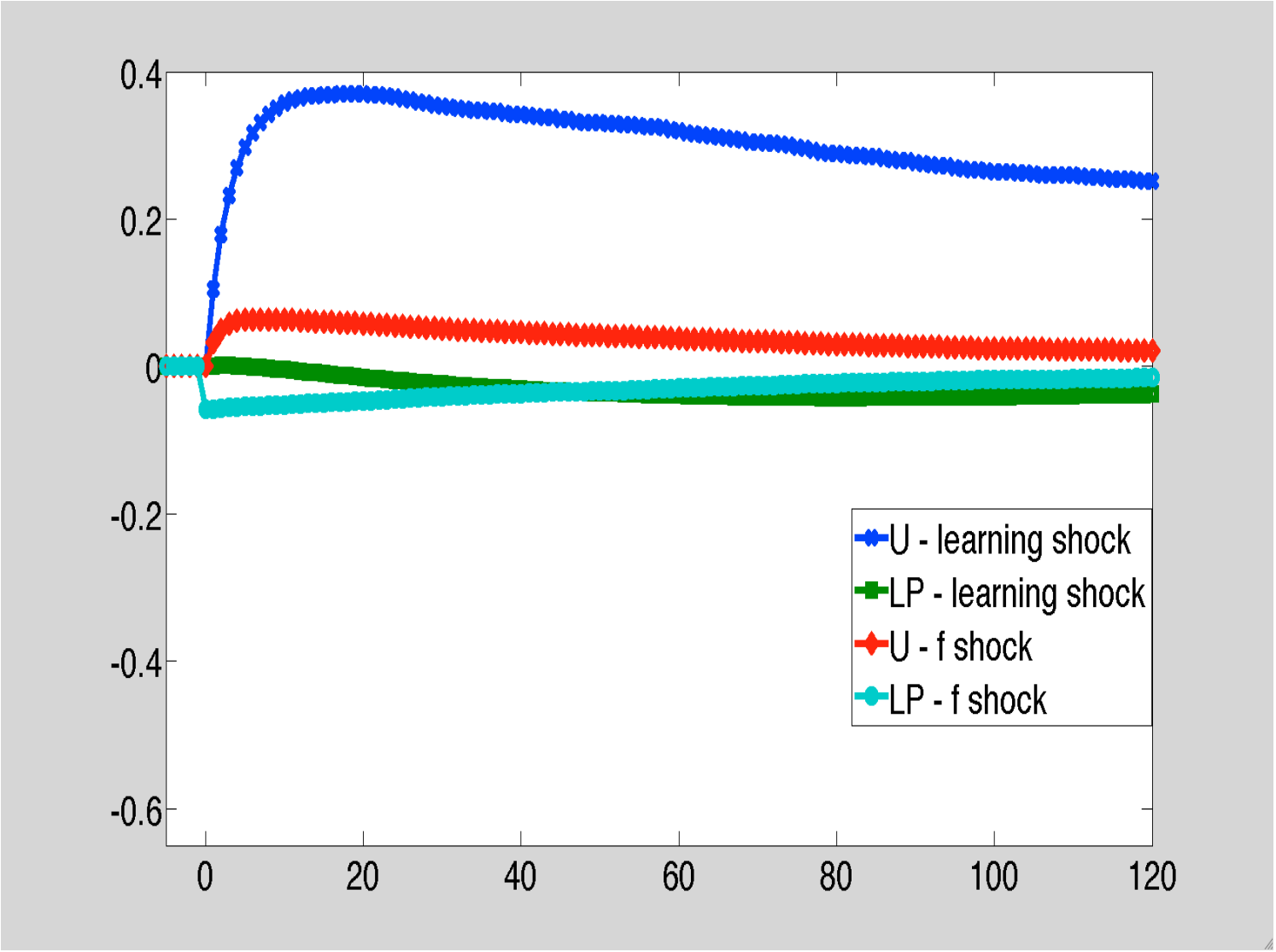
Quarterly average of monthly data

Deviations from hp trend

IRFs: Negative Technology Shock



IRFs: Negative Adoption Rate Shock

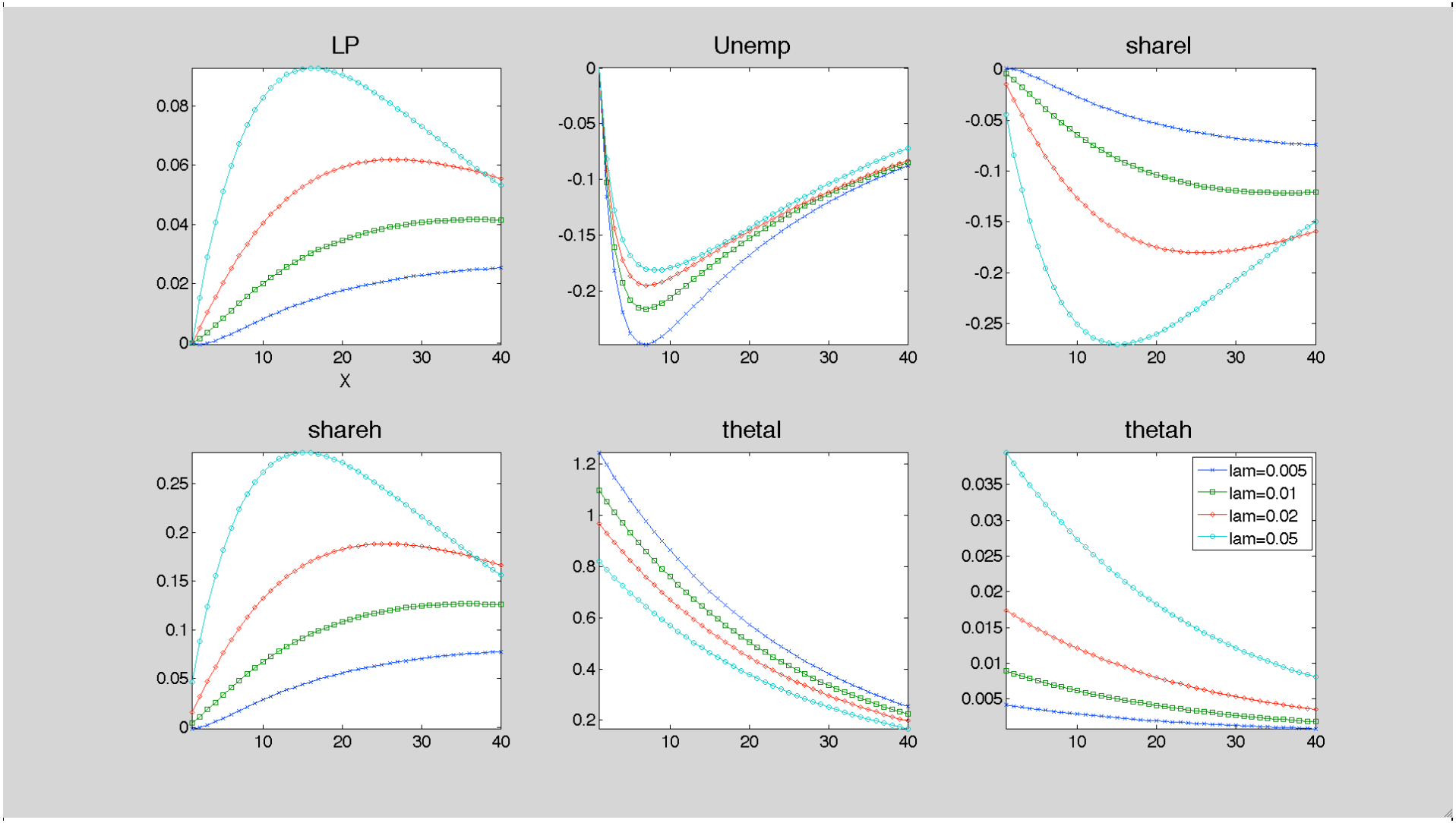


Intuition

- return to job creation, TS_L, determined largely by future output/profit, Δ
  - shock to λ has quantitatively 'strong' effect on Δ, and therefore on job creation, θ_L, and unemployment

- labor productivity determined by workforce composition
  - λ small; technology adoption follows 'diffusion' process
  - shock to λ has delayed, persistent effect on productivity that is quantitatively 'small'
  - moreover, shock affects $\theta_L \Rightarrow$ opposing *composition* effect due to job creation

IRFs: Positive Adoption Rate Shock

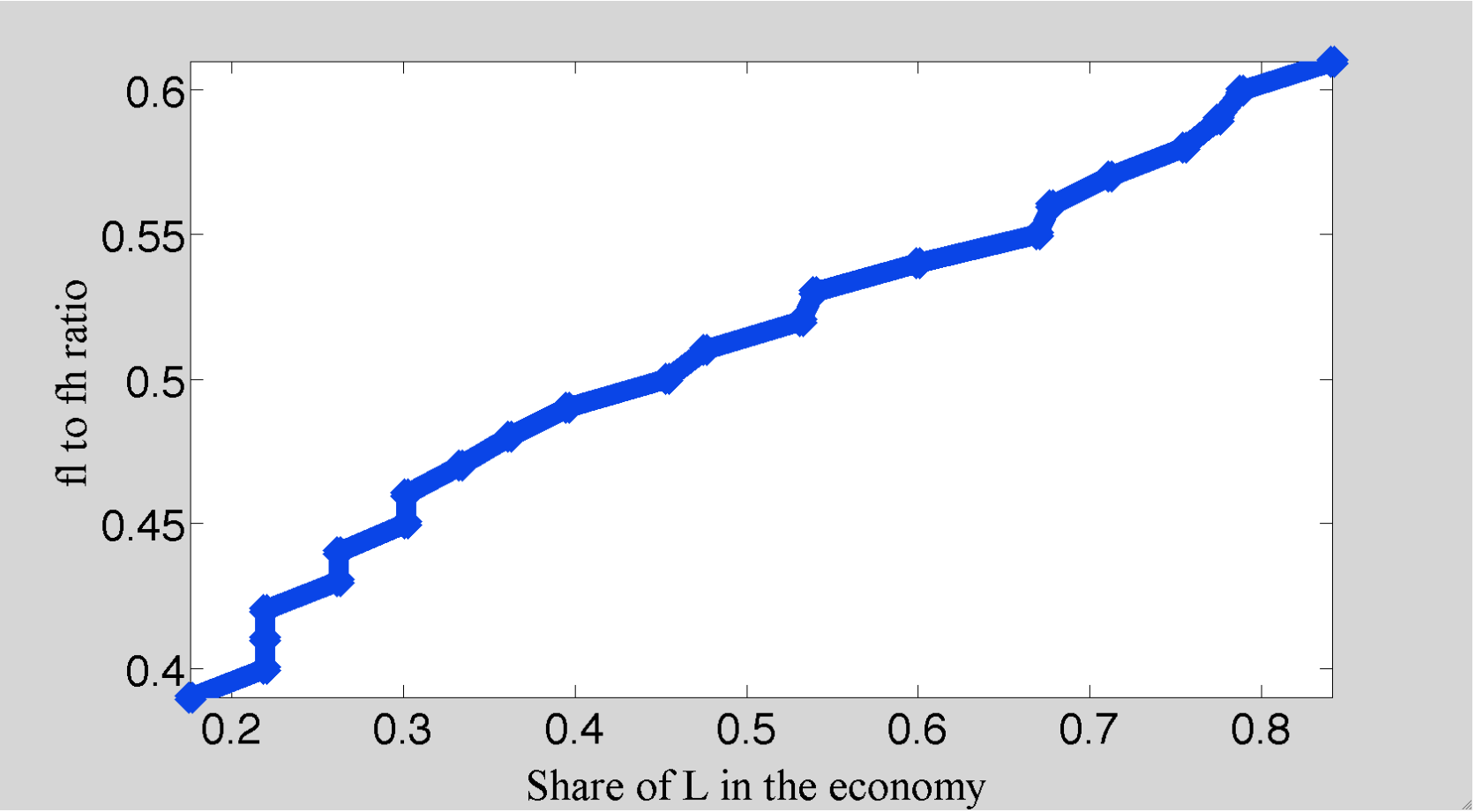


Robustness

- quantitative results from adoption rate shocks depends on two features:
  - f_H/f_L : "pay-off" to successful upgrade in productivity
  - λ vs ϕ : steady state share of workers with upgrade potential
- simple experiment: vary f_H/f_L and ϕ to retain volatility of unemployment

Relation between Share L and fl/fh:

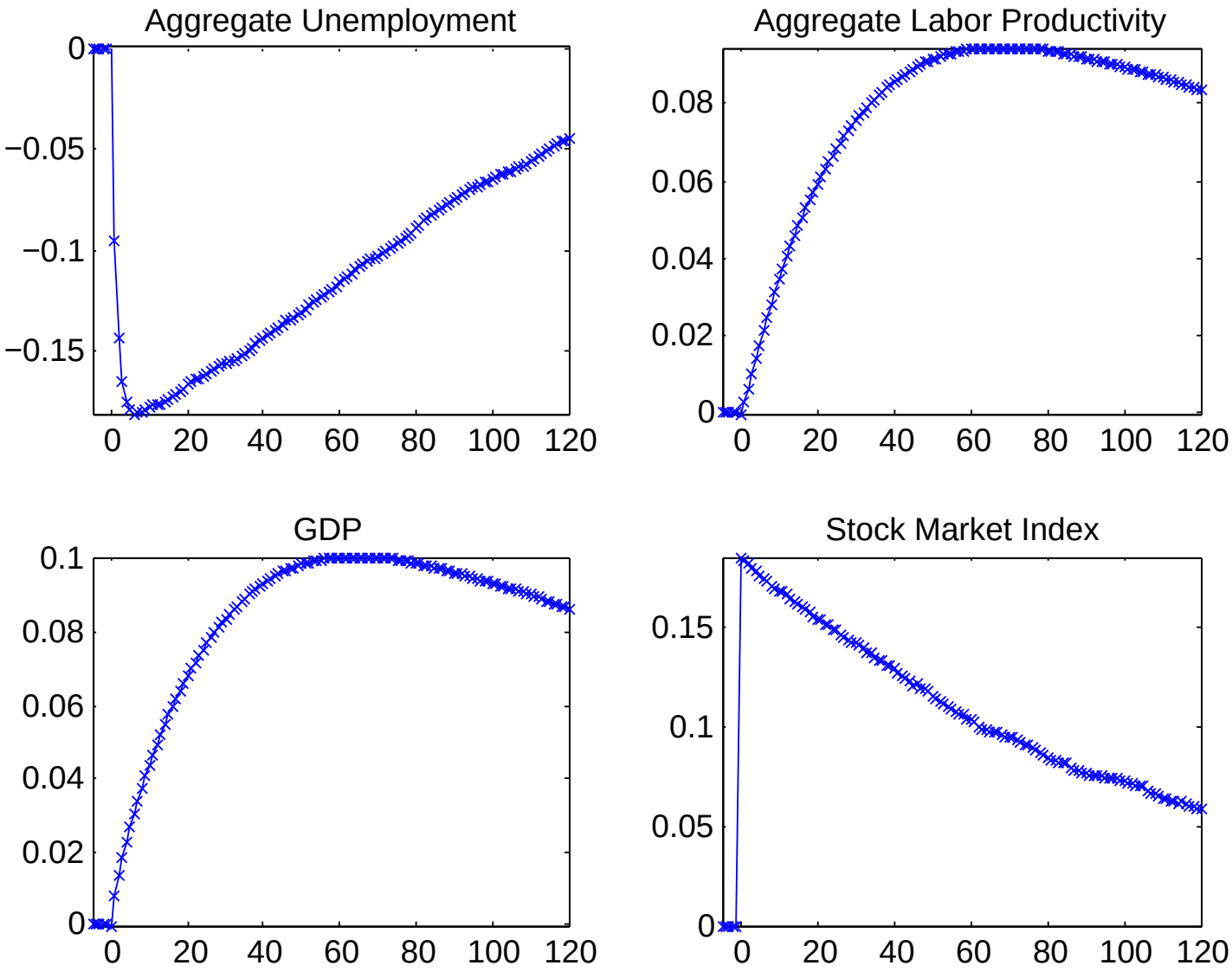
Match similar magnification, beveridge, and cor(u,lp)



“News” Shocks

- recent emphasis in literature on shocks to future productivity
- Beaudry-Portier (2006) identify shocks to long-run TFP in simple structural VAR
  - **immediate** effect on stock market value (expected profit) and unemployment
  - **essentially no** effect on current productivity ... TFP lags as in adoption/diffusion process
- our adoption rate shocks generate same dynamic response ...

“News” Shocks


Aggregate Unemployment
0
−0.05
−0.1
−0.15
0 20 40 60 80 100 120
Aggregate Labor Productivity
0.08
0.06
0.04
0.02
0
0 20 40 60 80 100 120
GDP
0.1
0.08
0.06
0.04
0.02
0
0 20 40 60 80 100 120
Stock Market Index
0.15
0.1
0.05
0
0 20 40 60 80 100 120

Model Extensions

- modeling job creation & job destruction over business cycle jump
- modeling lead-lag structure of productivity and unemployment jump

Summing up

- **simple, tractable** model of labor market search and productivity upgrading
  - ability to deliver analytical results regarding cyclical dynamics
- first step in studying importance of cyclicality of technological adoption
  - important quantitative channel for amplification **and** correlation over the cycle

Job Destruction

- in our model: unemployment driven completely by fluctuations in job finding rate
- in the data: fluctuations in job destruction play role as well
  - accounts for 1/4 to 1/3 of unemployment volatility
- in DMP model, shocks to separation rate (δ) increase volatility of unemployment
  - but reverses sign of Beveridge curve!
- our model suggests new way to vary separation rate while maintaining Beveridge curve

Job Destruction

$$W_L = \omega_L + \beta E\Big[\lambda\left[(1-\delta_L)W'_H + \delta_L U'_H\right] + (1-\lambda)\left[(1-\delta_L)W'_L + \delta_L U'_L\right]\Big]$$

$$W_H = \omega_H + \beta E\Big[(1-\phi)\left[(1-\delta)W'_H + \delta U'_H\right] + \phi\left[(1-\delta)W'_L + \delta U'_L\right]\Big]$$

- idea: in recession, layoffs concentrated among low wage workers jump

Job Destruction: δ_L Shocks

	Data	λ shocks	λ & δ shocks
std(LP)	0.02	0.02	0.02
standard deviation relative to std(LP)			
unemployment	9.34	5.10	8.35
job finding rate	6.05	5.56	7.1
tightness ratio	18.2	9.23	12.51
correlations			
corr(unemp,vacancies)	-0.89	-0.88	-0.80
corr(unemp,LP)	-0.41	-0.40	-0.30
corr(tightness, LP)	0.39	0.39	0.37
corr(destruction,LP)	-0.52	0	-0.43
share of jfr	0.75	1	0.76

Quarterly average of monthly data

Deviations from hp trend

Lead-Lag Structure

- in the data: labor productivity leads unemployment by 2 quarters over the cycle:
  - $\rho(LP_{t-2}, U_t) = -0.60 \quad \rho(LP_{t-1}, U_t) = -0.53$
    $\rho(LP_t, U_t) = -0.41$
- by construction, λ shocks generate wrong conditional lead-lag correlation structure
  - same is true of empirically identified "news shocks"
- implies unconditional correlation structure likely due to other business cycle shocks

Lead-Lag Structure

- consider simple modification of the model using the same shock
- purpose: show mechanism preserves main results
- modification borrows RBC idea of time-to-build / adjustment lags

Lead-Lag Structure

- agents receive "news" about technological innovations in advance
  - e.g., announcement about Windows 3.0 OS release
- effort devoted to learning OS affects adoption probability with a lag ... "time-to-adopt"
  - work harder with Windows 2.0 now; get familiar with technology so that it is easier to figure out 3.0 when it arrives
- additional effort today impacts output/productivity today

$$TS_L = \left(\frac{l_t}{l_{ss}}\right)^{\psi} f_L - (l_t - l_{ss}) + \ldots; \quad \lambda_t = \left(\frac{l_{t-6}}{l_{ss}}\right)^{\rho} \varepsilon_{\lambda,t-6}$$

Lead-Lag Structure

- estimate: $\frac{f_H}{f_L}, \psi, \rho$, persistence of $\varepsilon_\lambda, \lambda^{ss}$
- match five moments:

$$\frac{std(JFR)}{std(LP)} = 6$$

$$corr(LP_{t-1}, JFR_t) = 0.54$$

$$corr(LP_t, JFR_t) = 0.44$$

$$corr(LP_{t+1}, JFR_t) = 0.34$$

$$corr(U, V) = -0.89$$

Lead-Lag Structure

	Data	Model
$\frac{std(U)}{std(LP)}$	9.5	5.4
$Corr(LP_{t-2}, Unemp_t)$	-0.60	-0.61
$Corr(LP_{t-1}, Unemp_t)$	-0.53	-0.52
$Corr(LP_t, Unemp_t)$	-0.41	-0.42

jump