What Inventory Behavior Tells Us About How Business Cycles Have Changed

Thomas Lubik Pierre-Daniel Sarte Felipe Schwartzman

Federal Reserve Bank of Richmond[1]

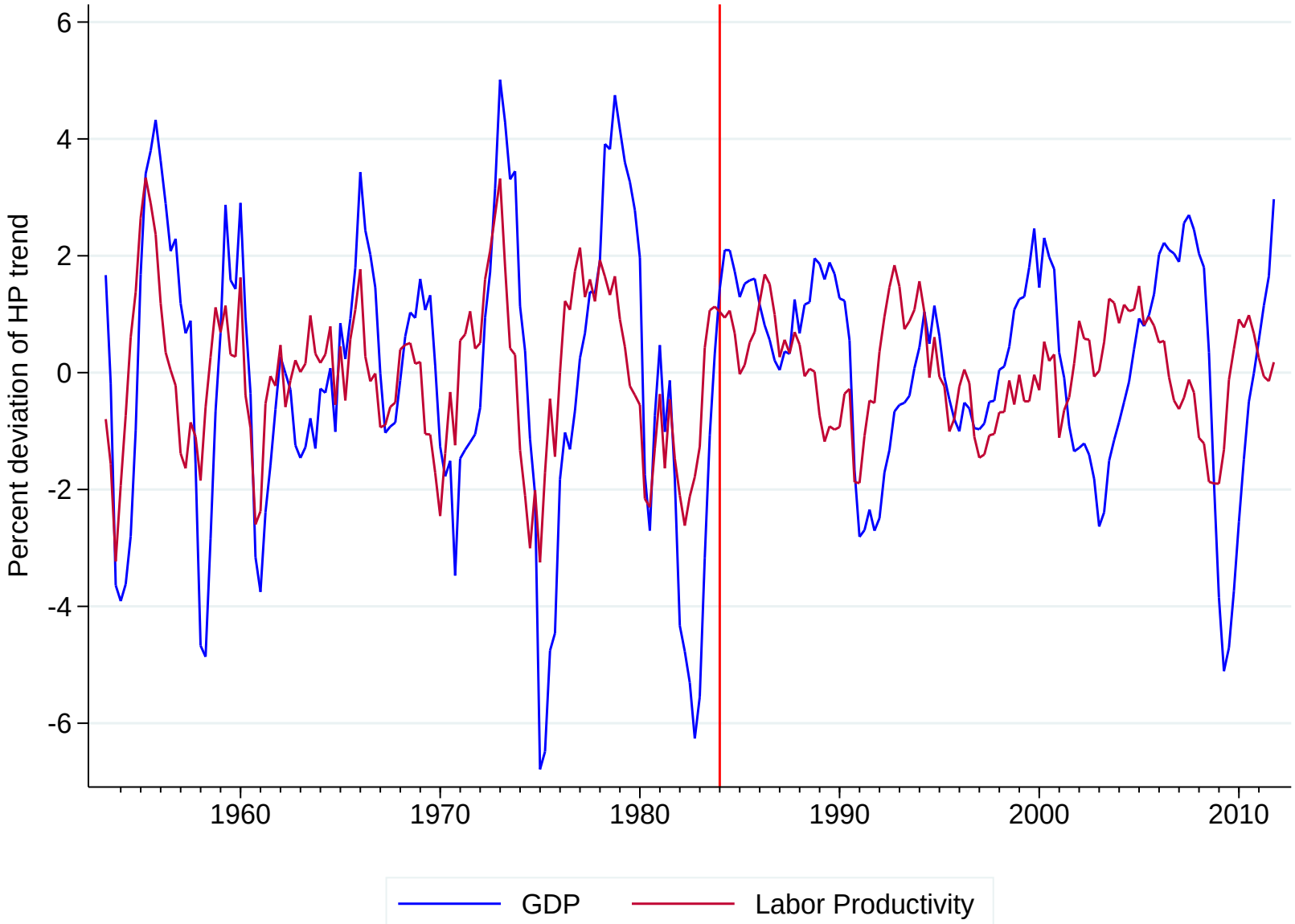
04/02/2014

[1]The views expressed in this paper are those of the authors and do not necessarily reflect the position of the Federal Reserve Bank of Richmond or the Federal Reserve System.

The Changing Nature of the Business Cycle

- The cyclical behavior of labor productivity has changed between the pre- and post-Great Moderation period.
- This presents a challenge for real business cycle models driven by temporary productivity shocks.
  - McGrattan and Prescott (2012) call this the "Labor Productivity Puzzle".
- It also affects our understanding and interpretation of the Great Moderation

The Changing Nature of the Business Cycle: Labor Productivity



The Changing Nature of the Business Cycle: Labor Productivity

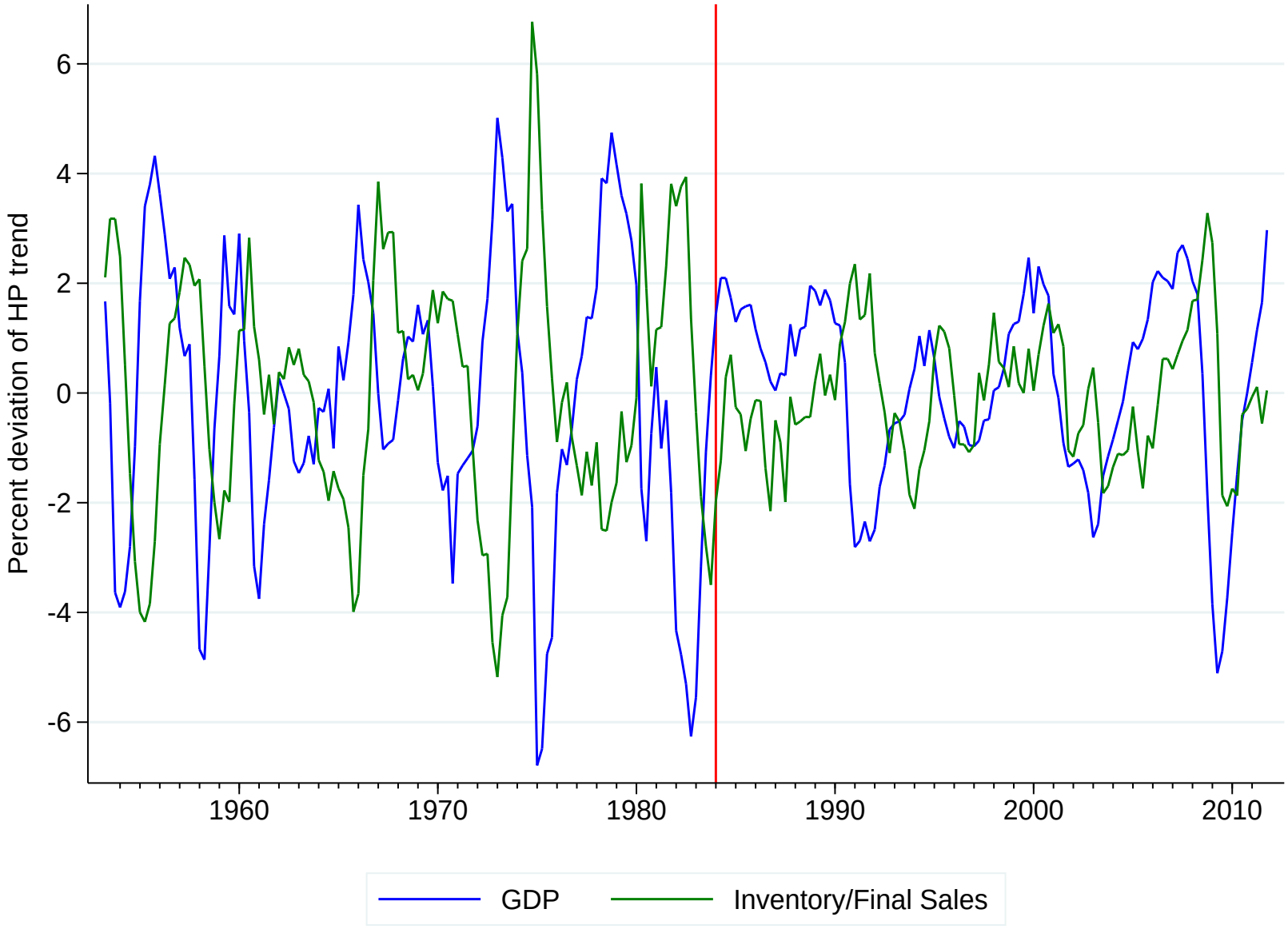
Table 1. Changes in Business Cycle Properties in the Post-War Era (HP-Filtered Series)

	'53-'84	'84-'08	'08-'12
	a. Standard Deviations		
Output	2.61	1.43	2.57
Hours Relative to Output	0.77	1.12	1.04
	b. Cross Correlations		
Output per Hour and Output	0.65	0.06	0.06
Output per Hour and Hours	0.13	-0.47	-0.33

The Changing Nature of the Business Cycle: Inventories

- At the same time, the cyclical behavior of inventories also changed.
- This presents a challenge for many inventory models:
  - Wen (2005) provides a taxonomy of various puzzles.
- It also affects how we interpret the Great Moderation period.

The Changing Nature of the Business Cycle: Inventories



The Changing Nature of the Business Cycle: Inventories

Table 2. Changes in Business Cycle Properties in the Post-War Era (HP-Filtered Series) Inventory Facts

	'53-'84	'84-'08	'08-'12
	a. Standard Deviations		
Inventories to Output	0.75	1.13	1.22
	b. Cross Correlations		
Inventories and Output	0.37	0.74	0.76
Inventory-Sales Ratio and Output	-0.57	-0.03	0.18

Our Approach

- Interpret changes in hours, output and inventories data in a unified framework.

- Modeling Framework:
  - Multi-stage, multi-sector Real Business Cycle Model.
  - Nests storage technology and time to build.
  - Stages of production have implications for inventories

- Methodology:
  - Look for "wedges" in a prototype frictionless economy that allow it to account for data. (Chari et al. 2007)
  - Sufficient detail in technology needed for "wedges" to correspond to frictions. (Christiano and Davis 2006)
  - External validation.

Wedges

- Efficiency Wedges:
  - Technological progress, changes in taxes and regulations that distort the composition of intermediate inputs or the allocation of resources across sectors and firms.
- Labor Wedge (MPL - MRS of C and L):
  - Distorts consumption/leisure choice.
  - Stands in for labor market frictions.
  - Sticky prices/wages, labor taxes etc.
- Investment Wedge (MPK - MRS of C_t and C_{t+1}):
  - Distorts inter-temporal choice.
  - Stands in for most credit frictions.
- Chari et al. (2007): Given simple one sector model, productivity and Labor Wedges are important, investment wedge not so much.

Key Findings

- Inventories help us distinguish between *total* investment wedge and return to *fixed* investment.
- Fluctuations in TFP ("efficiency wedges") explain most of business cycles pre 84, less so afterwards.
- Contribution of investment wedge increases after 84.
- Behavior of investment wedge mirrors that of alternative indicators of credit conditions.

Some Recent Literature: Labor Productivity

- McGrattan and Prescott (2012): Mismeasurement of productivity.
- Cole and Ohanian (2001,2011): Increased labor market distortions.
- Gali and van Rens (2008), Berger (2012): Reduced labor market distortions.
- Francis and Ramey (2002): Labor saving shocks.

Some Recent Literature: Inventories

- Bils and Kahn (2000): Inventories can tell us about business cycles.
- Khan and Thomas (2007): TFP shocks in GE models induce countercyclical inventory/sales-ratio.
- Iacoviello, Schiantarelli and Schuh (2012): General equilibrium model with input and output inventories.

Our Model: The Production Function

- Sales in Sector j, time t are:

$$Y_{j,t} = \left(B_j \sum_{s=0}^{S} \omega_j(s)^{\frac{1}{\rho}} Z_{j,t-s|t}^{\frac{\rho-1}{\rho}} \right)^{\frac{\rho}{\rho-1}}, \ \rho > 0$$

- where

$$Z_{j,t-s|t} = K_{j,t-s|t}^{\alpha_j} \left(\prod_{i=1}^{N} M_{ij,t-s|t}^{\gamma_{ij}} \right) (A_{j,t-s} L_{j,t-s|t})^{1-\alpha_j-\Sigma_{i=1}^{N}\gamma_{ij}}.$$

  - Kydland and Prescott (1982): $\gamma_{ij} = 0$, $\rho \to 0$, $\omega(v) = 1$
  - Long and Plosser (1983) $\alpha_j = 0$, V=1, $\omega(0) = 0$
  - Linear Storage: $\rho \to \infty$, $\omega(v)^{\frac{1}{\rho}} \to (1-\delta)^v$
  - Large ρ: Approaches linear storage, but with target inventory/sales ratio.

From Stages of Production to Inventories

- Inventory Investment is $\Delta N_t = V_t - \mathcal{FS}_t$, where

$$V_t = \sum_{j=1}^{N} \sum_{s=0}^{S} Z_{j,t|t+s} - \sum_{i=1}^{N} \sum_{j=1}^{N} M_{ij,t}$$

$$\mathcal{FS}_t = \sum_{j=1}^{N} Y_{j,t} - \sum_{i=1}^{N} \sum_{j=1}^{N} M_{ij,t}$$

- Cost of goods sold:

$$\sum_{j=1}^{N} Y_{j,t} \approx \sum_{j=1}^{N} \sum_{s=0}^{S} Z_{j,t-s|t}$$

- Hence,

$$\Delta N_t \approx \sum_{j=1}^{N} \sum_{s=0}^{S} Z_{j,t|t+s} - \sum_{j=1}^{N} \sum_{s=0}^{S} Z_{j,t-s|t}$$

Intertemporal Utility Function and Resource Constraints

$$\max E_t \sum_{t=0}^{\infty} \left(\beta^t \prod_{v=0}^{t-1} \zeta_v \right) \left[\kappa \sum_{j=1}^{N} \eta_j \ln C_{j,t} + (1-\kappa) \ln(1 - \Upsilon_t L_t) \right],$$

$$C_{j,t} + \sum_{i=1}^{N} I_{ji,t} + \sum_{i=1}^{N} M_{ji,t} = Y_{j,t}$$

$$K_{j,t+1} = \Xi_j \prod_{i=1}^{N} I_{ij,t}^{\theta_{ij}} + (1-\delta) K_{j,t},$$

$$\sum_{s=0}^{S} K_{j,t|t+s} = K_{j,t}, \quad \sum_{j=1}^{N} \sum_{s=0}^{S} L_{j,t|t+s} = L_t,$$

Shock Processes

- $A_{j,t}$ is sector-specific Hicks-Neutral Productivity Shocks.

$$A_{j,t} = u_t A_t a_{j,t},$$

where:

$$\frac{A_t}{A_{t-1}} = g_t$$

is a stationary process

  - A_t is a stochastic trend
  - $a_{j,t}$ is a sector-specific temporary shock
  - u_t is an aggregate temporary shock.

- Labor disutility shock Υ_t.

- Discount rate shock ζ_t.

Efficienty Wedges: A Closer Look

- In a multi-sector model, efficiency wedges are defined separately for each sector. In log-linearized form, they are,

$$\tau_{j,t}^{A} = \widehat{Z}_{j,t} - \alpha_j \widehat{K}_{j,t} - \xi_j \widehat{L}_{j,t} - \sum_i \gamma_{ij} \widehat{M}_{ij,t}.$$

- In our environment these wedges are a function of time-varying productivity parameters,

$$\tau_{j,t}^{A} = \xi_j \left(\widehat{u}_t + \widehat{A}_t + \widehat{a}_{j,t} \right),$$

The Labor Wedge: A Closer Look

- The labor wedge in the prototypical one-sector growth model can be expressed as:

$$\widetilde{\tau}_t^L = \underbrace{\left(\widehat{Z}_t - \widehat{L}_t\right)}_{\text{Labor Productivity}} - \left(\widehat{C}_t + \frac{L}{1-L}\widehat{L}_t\right),$$

- In our framework it is

$$\tau_t^L = \sum_{j=1}^{N} \underbrace{\eta_j \left(\widehat{Z}_{j,t} - \widehat{L}_{j,t}\right)}_{\text{Sectoral Labor Productivity}} - \left(\widehat{C}_t + \frac{L}{1-L}\widehat{L}_t\right) + \sum_{j=1}^{N} \eta_j \widehat{\phi}_{j,t},$$

where $\widehat{\phi}_{j,t}$ is the cost of transforming current output $Z_{j,t}$ into current sales $Y_{j,t}$.

The Investment Wedge: A Closer Look

- In one-sector model with no lags in production:

$$\widetilde{\tau}_t^X = E_t \underbrace{\left[\left(1-\widetilde{\beta}\right)\left(\widehat{Z}_{t+1}-\widehat{K}_{t+1}\right)\right]}_{\text{Marginal Return to Investment}} - E_t\left(\Delta \widehat{C}_{t+1}\right),$$

- With multiple sectors and stages:

$$\begin{aligned}\tau_t^X &= E_t\left[\left(1-\widetilde{\beta}\right)\sum_{j=1}^{N}\eta_j\left(\widehat{Z}_{j,t+1}-\widehat{K}_{j,t+1}+\widehat{\phi}_{j,t+1}\right)\right] \\ &\quad + E_t\left[\left(\sum_{i=1}^{N}\theta_{ji}\eta_i-\eta_j\right)\left(\widetilde{\beta}\widehat{\lambda}_{j,t+1}-\widehat{\lambda}_{j,t}\right)\right] - E_t\left(\Delta \widehat{C}_{t+1}\right),\end{aligned}$$

where $\widehat{\lambda}_{j,t+1}$ is the price of good j at time $t+1$.

Investment Wedge (cont.)

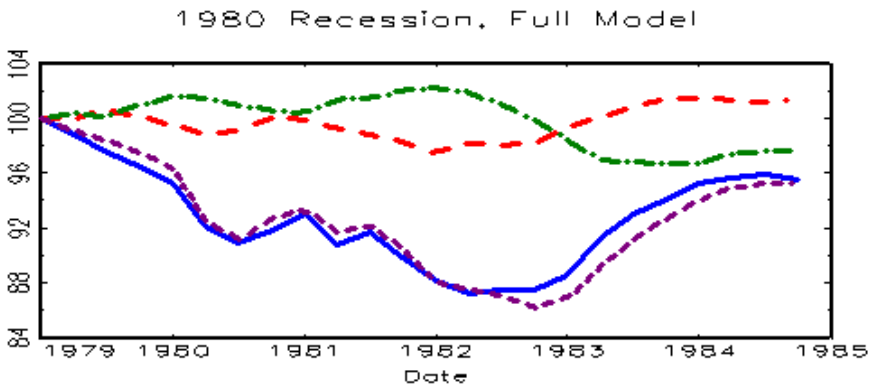
- Multiple stages of production link investment wedge to inventory investment:

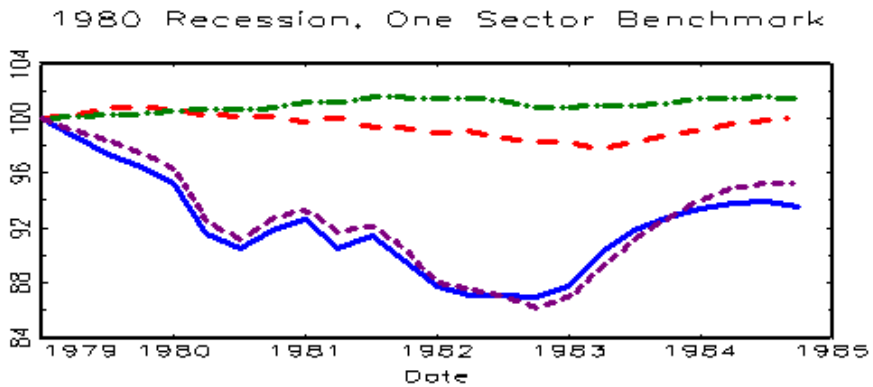
$$E_t\left(\sum_{s=0}^{S}\psi_j(s)\left[\sum_{u=0}^{s-1}\tau^X_{t+u}\right]\right) = -\widehat{\phi}_{j,t} - \frac{1}{\rho}\left(\frac{\Delta N_{j,t}}{Y_{j,t}}\right)$$
$$+E_t\left(\psi_j(s)\sum_{s=0}^{S}\left[\frac{1}{\rho}\Delta\widehat{Y}_{j,t+s} + \Delta\widehat{\lambda}_{j,t+s}\right]\right)$$

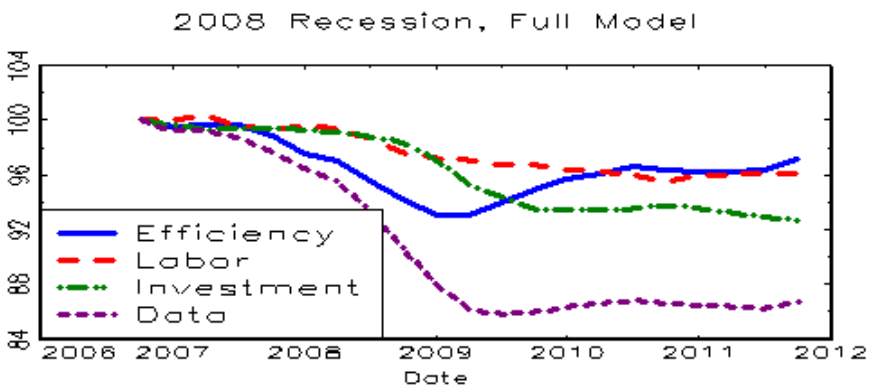
Calibration / Estimation

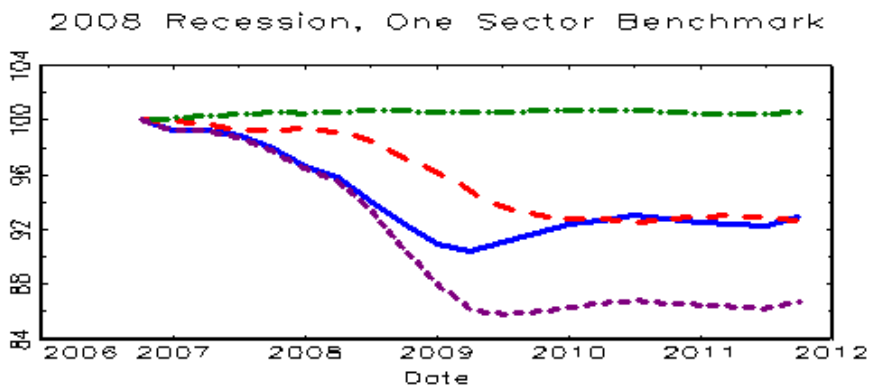
- Two sectors: Durables and Non-Durables, weights from I-O matrix.
- Stages of production to match average inventory/sales for each sector.
  - $\omega_j(s) = \phi_j^s$
  - Truncation at 3 lags
- AR(1) shocks to wedges, correlated with one another.
- Bayesian estimation:
  - Data: Output, Consumption, Hours and Inventories,
  - Elasticity of substitution between stages $\rho = 18.9$ (maximum posterior).

Decomposition of Output in 1980 and 2008 Recessions

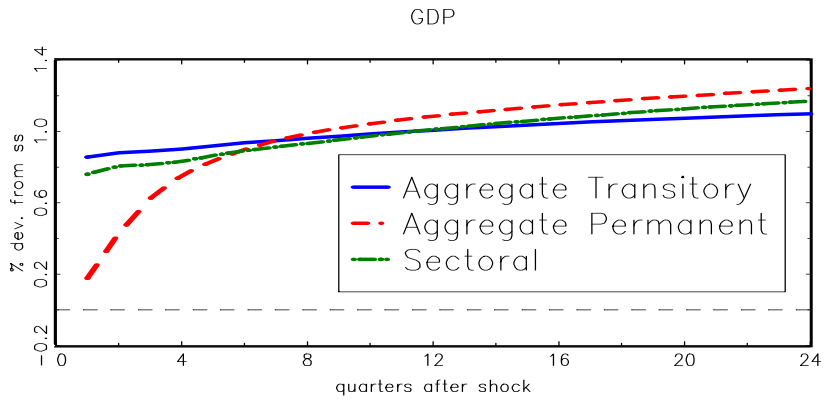


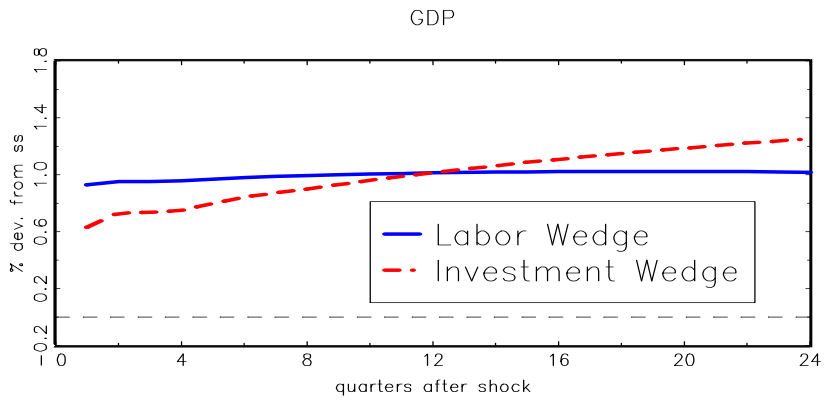


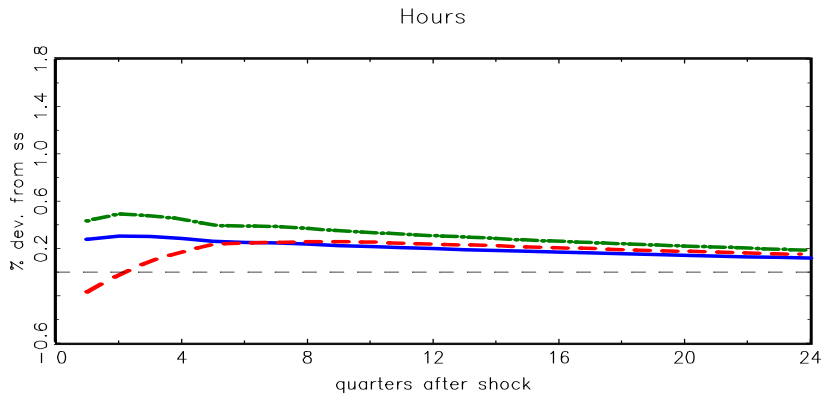


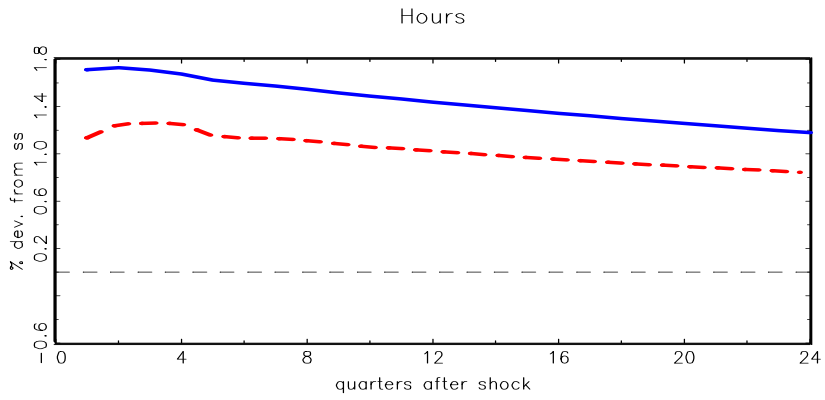


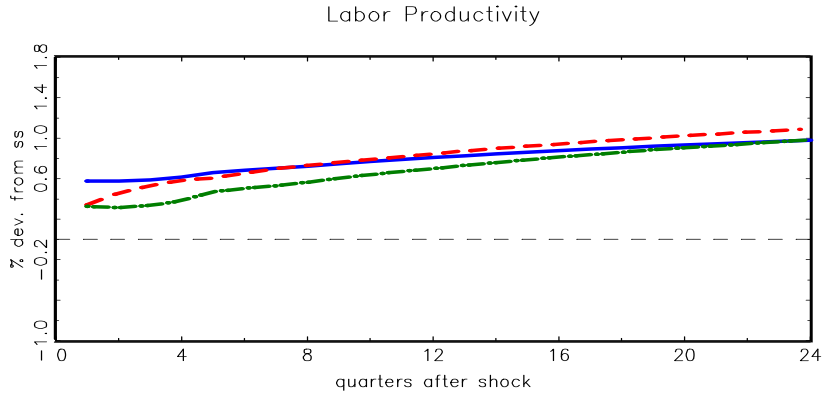
Impulse Response Functions

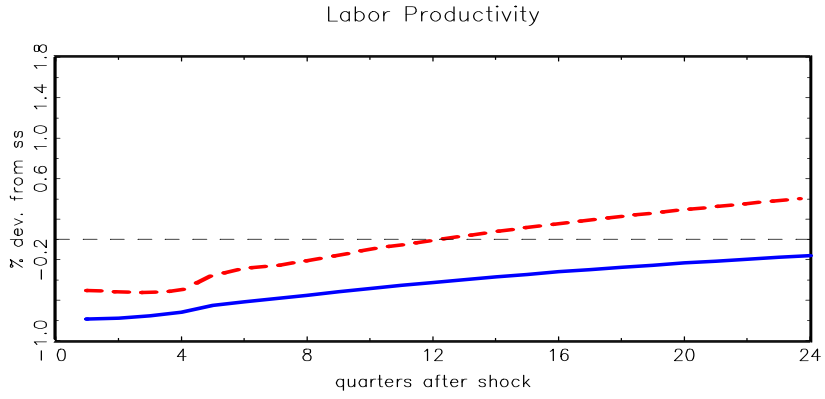




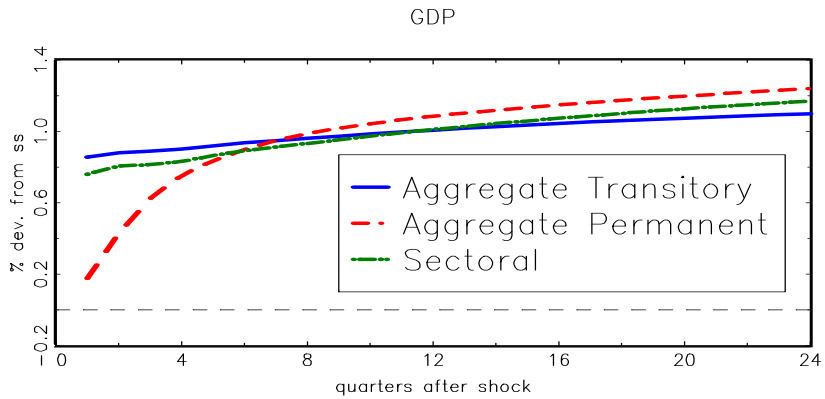


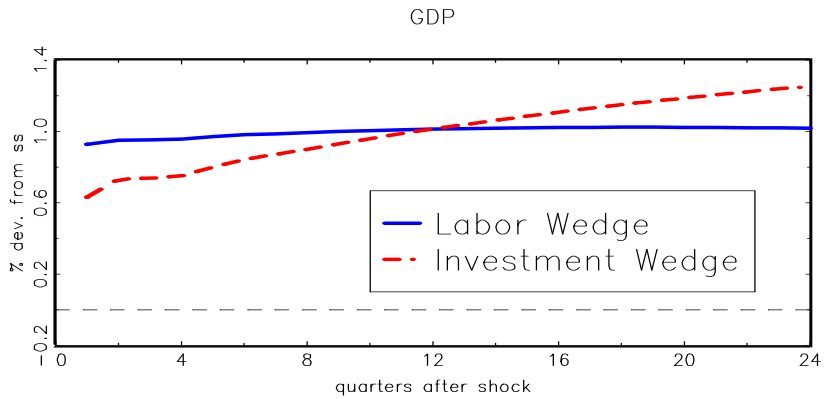


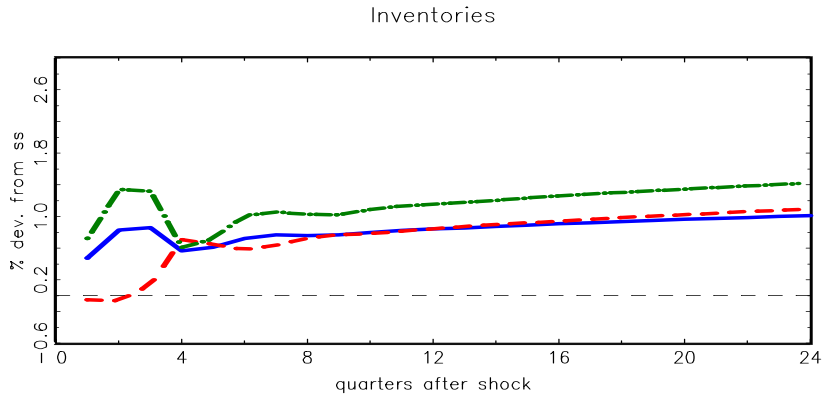


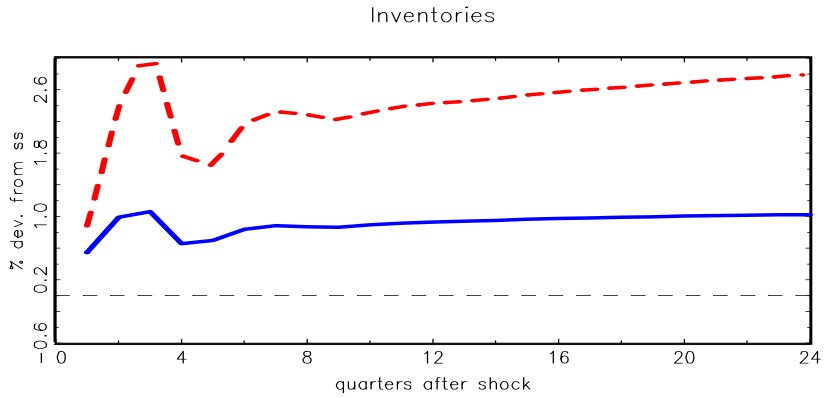


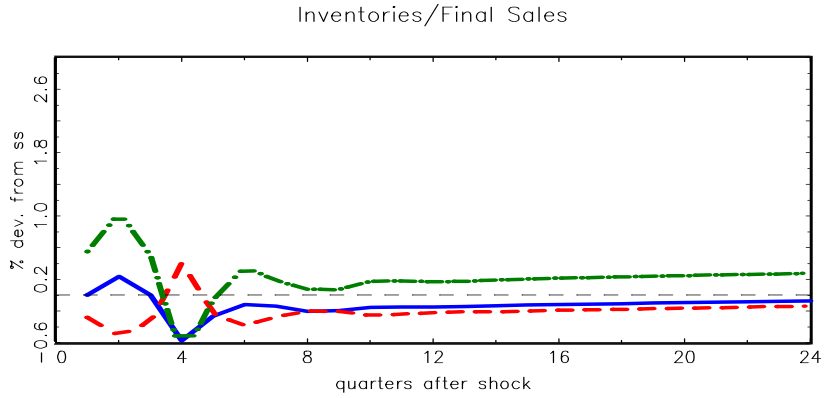
Impulse Response Functions, cont.

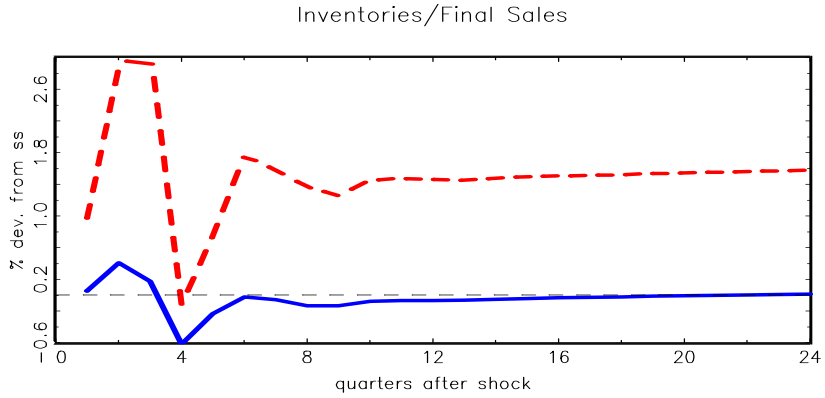












Moments - Correlations

Table 3. Cumulative Contribution of Wedges to Business Cycle Correlations

	Efficiency	+ Labor	+ Investment	Data
	a. Output per Hour and Output			
Pre-1984	0.90	0.54	0.66	0.65
Post-1984	0.87	0.64	0.13	0.13
	b. Output per Hour and Hours			
Pre-1984	0.55	0.23	0.18	0.14
Post-1984	0.16	0.13	-0.38	-0.38
	c. Inventory/Sales and Output			
Pre-1984	-0.26	-0.27	-0.63	-0.58
Post-1984	-0.45	-0.49	0.07	0.01

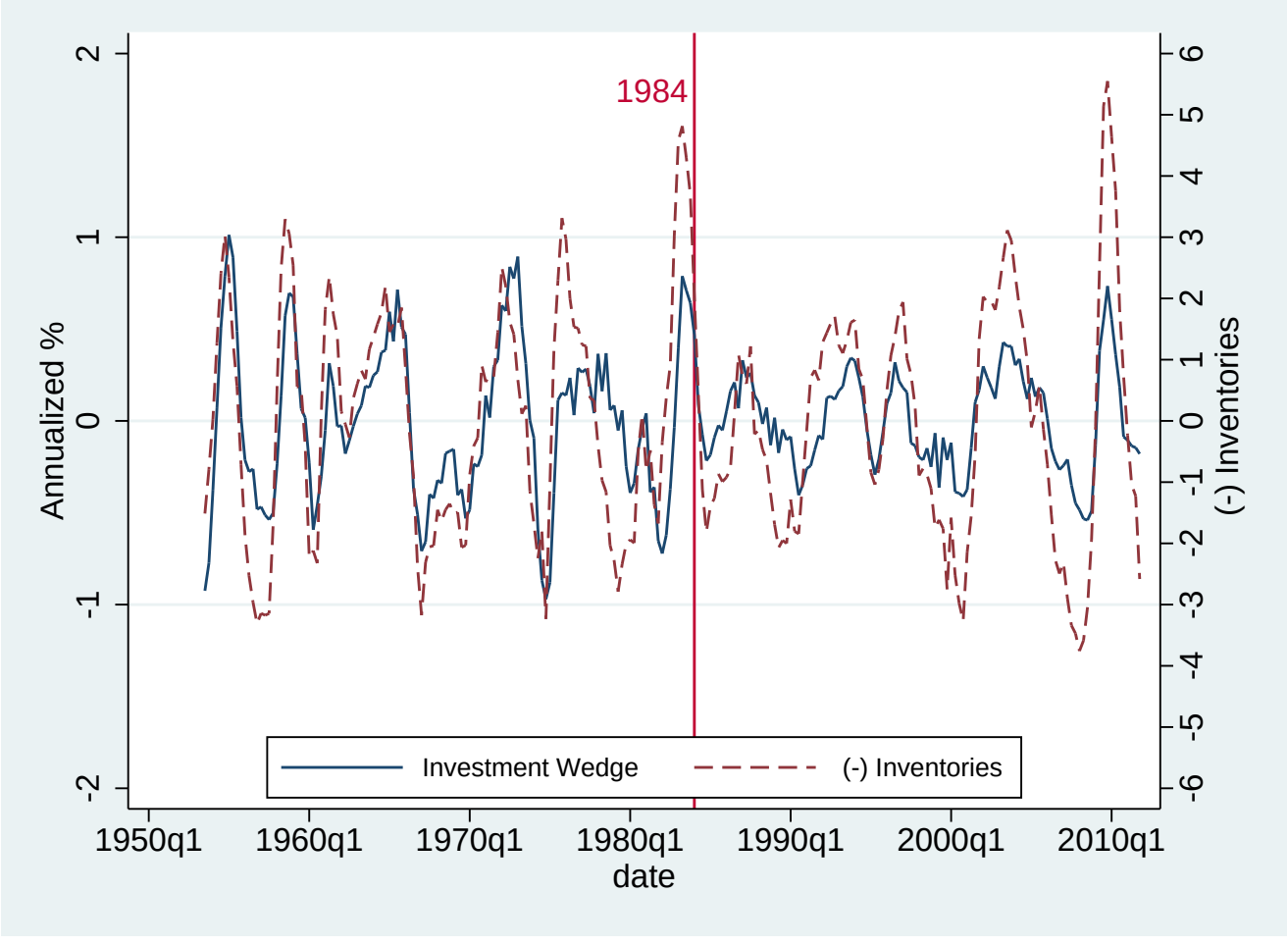
Moments - Volatilities

Table 4. Cumulative Contribution of Wedges to Business Cycle Volatilities

	Efficiency	+ Labor	+ Investment	Data
		a. Output		
Pre-1984	2.46	3.25	2.53	2.61
Post-1984	1.34	1.60	1.67	1.67
		b. Hours / Output		
Pre-1984	0.51	0.87	0.76	0.77
Post-1984	0.51	0.78	1.07	1.07
		c. Inventories / Output		
Pre-1984	0.96	0.91	0.71	0.74
Post-1984	0.86	0.79	1.15	1.15

Deconstructing the Results

Figure: **Time Series for the Investment Wedge as Compared with Inventories**



Deconstructing the Results (cont.)

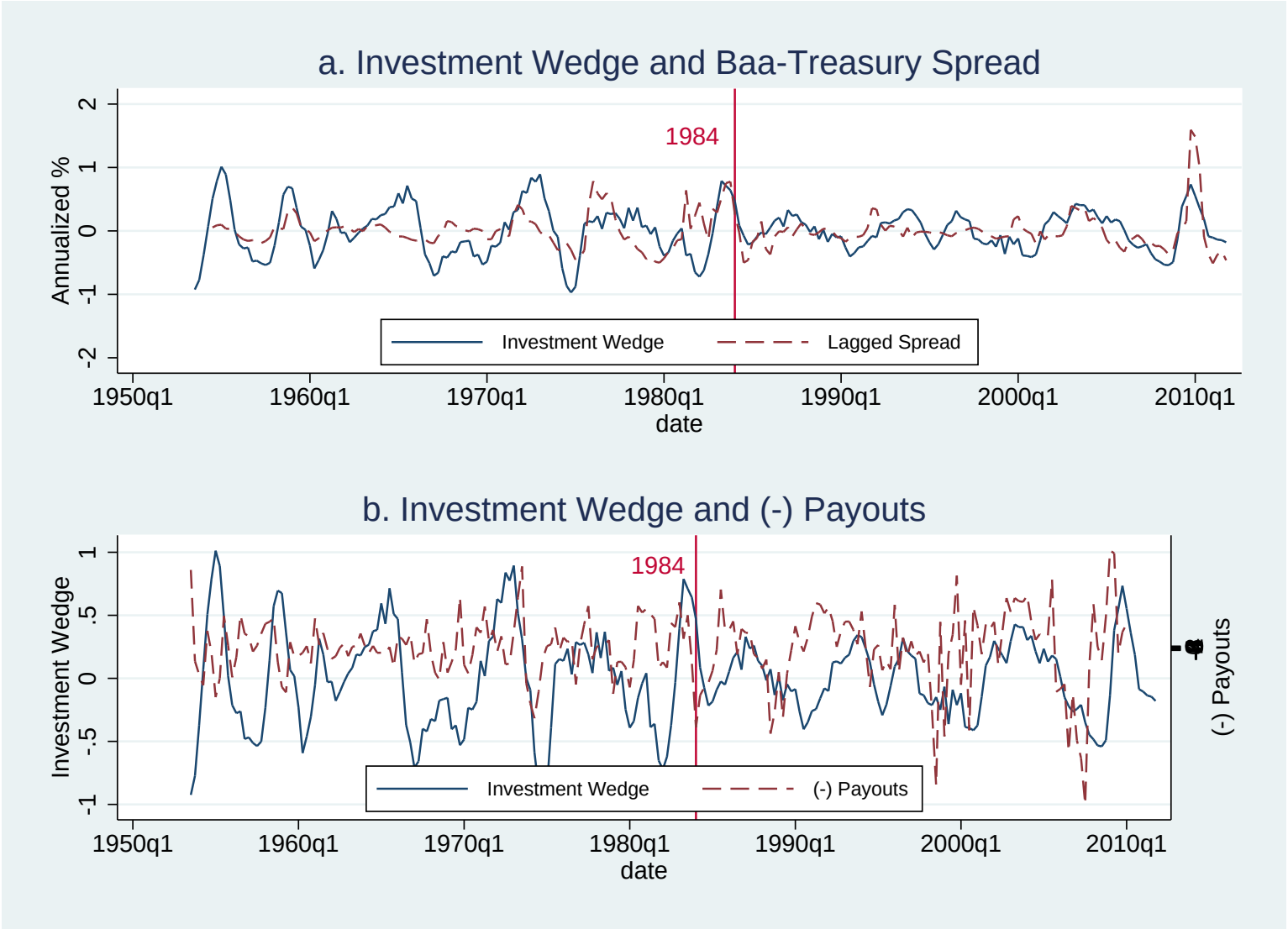
	Labor Wedge		Investment Wedge	
	pre 1984	post 1984	pre 1984	post 1984
	a. Benchmark Generalized Wedge			
Std(Wedge)/Std(GDP)	0.85	0.86	0.16	0.16
Corr. with GDP	-0.75	-0.66	0.27	-0.49
	b. Minus ϕ			
Std(Wedge)/Std(GDP)	0.72	1.24	0.16	0.16
Corr. with GDP	-0.75	-0.65	0.28	-0.49
	c. Aggregate Productivity			
Std(Wedge)/Std(GDP)	0.72	1.24	0.28	0.25
Corr. with GDP	-0.42	-0.66	0.38	-0.37
	d. Fixed Relative Prices			
Std(Wedge)/Std(GDP)	0.72	1.24	0.06	0.04
Corr. with GDP	-0.42	-0.66	-0.34	-0.40
	e. Re-estimated: One sector Growth Model			
Std(Wedge)/Std(GDP)	0.72	1.25	0.03	0.02
Corr. with GDP	-0.42	-0.66	0.40	0.65

Other Measures of Credit Frictions

Table 5. Correlations of Credit Conditions and Macroeconomic Aggregates in the Post-War Era (HP-Filtered Series)

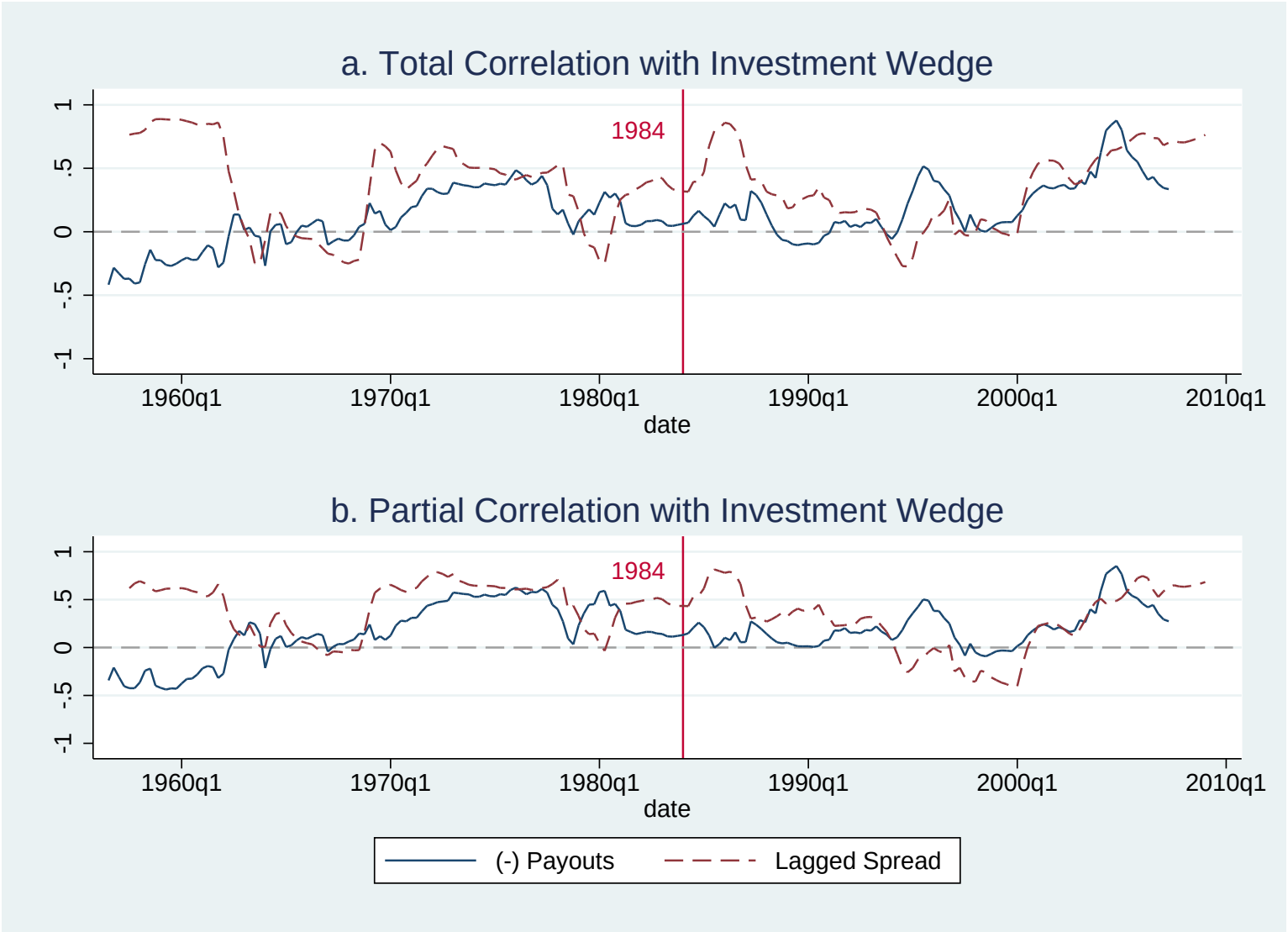
	1953-1983	1984-2008	2008-2012
	a. Lagged Bond Spread (Baa - 10 year Treas)		
Output	-0.28	-0.48	-0.51
Fixed Investment	-0.29	-0.51	-0.60
Inventories	-0.61	-0.50	-0.79
	b. Payouts to Business Owners (Total)		
Output	0.13	0.55	0.79
Fixed Investment	0.13	0.53	0.81
Inventories	0.21	0.55	0.82

Comparison with other measures of credit frictions (cont.)



Comparison with other measures of credit frictions (cont.)

6 years rolling correlation



Comparison with other measures of credit frictions (cont.)

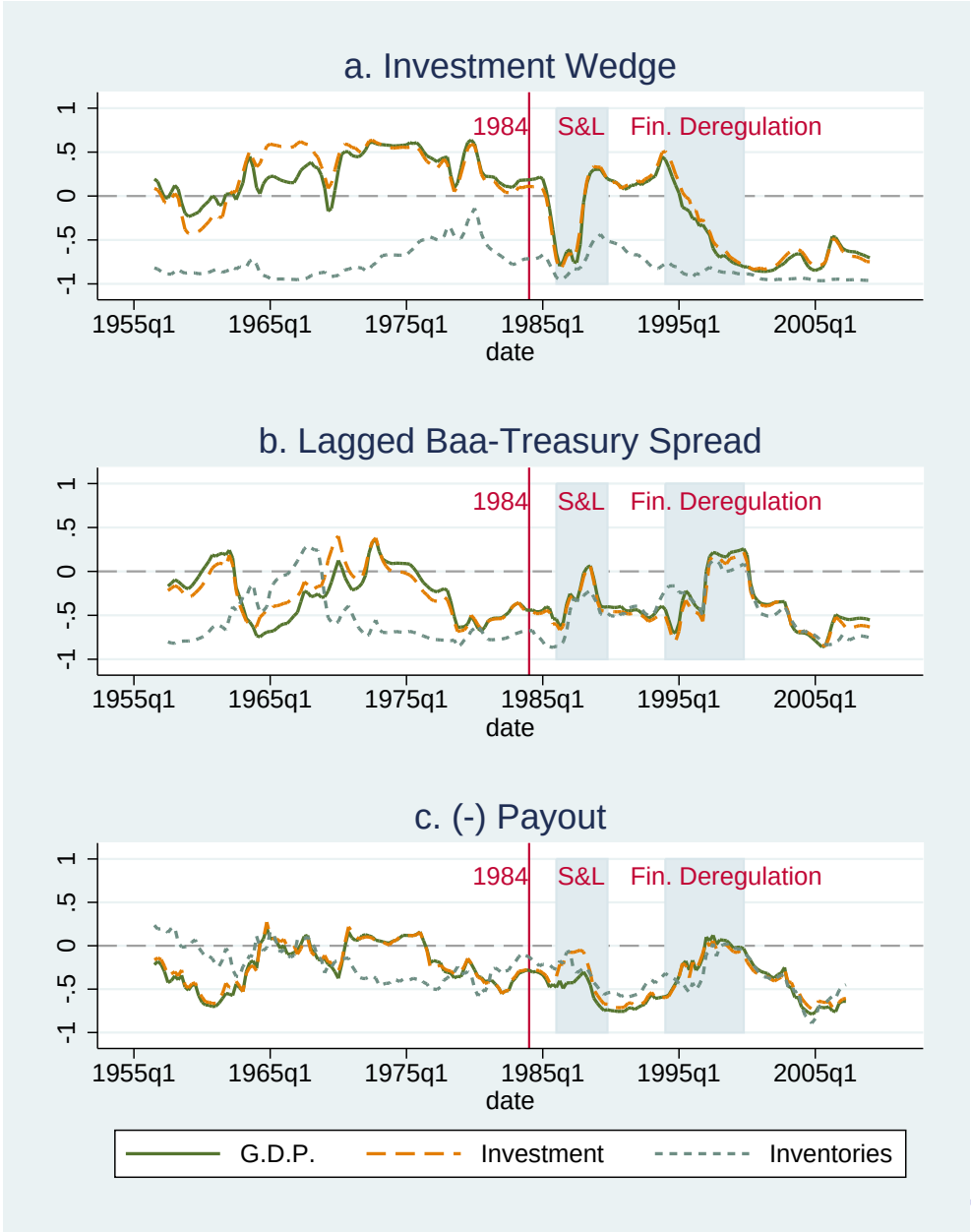
	1953-1983	1984-2007	2008-2012
	a. Total Correlations		
Lagged Baa-Treasury Spread	0.37	0.38	0.78
Lagged Baa-Aaa Spread	0.49	0.64	0.84
Lagged Aaa-Treasury Spread	0.50	0.62	0.86
Lagged GZ Spread	-	0.53	0.79
Lagged GZ Excess Spread	-	0.44	0.74
(-) Payouts (total)	0.10	0.49	0.80
(-) Payouts (corporate)	0.20	0.48	0.56
Debt Repurchases	-0.10	0.39	0.71

Comparison with other measures of credit frictions (cont.)

	1953-1983	1984-2007	2008-2012
	b. Partial Correlations		
Lagged Baa-Treasury Spread	0.53	0.57	0.72
Lagged Baa-Aaa Spread	0.46	0.24	0.66
Lagged Aaa-Treasury Spread	0.48	0.59	0.73
Lagged GZ Spread	-	0.44	0.60
Lagged GZ Excess Spread	-	0.32	0.70
(-) Payouts (total)	0.14	0.36	0.58
(-) Payouts (corporate)	0.31	0.36	0.03
Debt Repurchases	0.10	0.17	0.22

Comparison with other measures of credit frictions (cont.)

6 years rolling correlation



Conclusion

- Great Moderation is also "Great Re-synchronization", which lasts longer than the Great Moderation itself.
- Productivity driven business cycles are out of synch, need to add shocks.
- Labor market frictions play a role.
- **But** also a role for financial frictions.
- Research program: What accounts for the change in behavior of the investment wedge after 1984?