

AN EVOLUTIONARY MODEL OF ENDOGENOUS BUSINESS CYCLES

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Motivations

- There are many robust stylized facts concerning
 - I. Business Cycles
 - II. Firm Productivity Dynamics
 - III. Firm Size Distributions
 - IV. Firms' Investment Decisions
- Theoretical Explanations
 - Lack of models that starting from investment stylized facts are able to jointly explain business cycles, firm productivity dynamics and firm size distribution stylized facts.
 - In this paper: An evolutionary model depicting a two-industry dynamic economy that explains SF I, II and III starting from SF IV.

Outline of the Talk

1. Stylized Facts
2. Theoretical Roots and Antecedents
3. Evolutionary/ACE vs. Neoclassical Paradigm
4. The Model
5. Simulation Results
6. Conclusions

Stylized Facts (1/2)

- **Business Cycles stylized facts**

(e.g. Stock and Watson, 1999; Napoletano, Roventini and Sapio, 2004)

- **SF1:** Investment considerably more volatile than GDP
- **SF2:** Consumption less volatile than GDP
- **SF3:** Investment, Consumption and Change in Stocks procyclical and coincident variables
- **SF4:** Employment and Unemployment Rate lagging variables. Aggregate Employment procyclical; Unemployment Rate anticyclical

- **Investment stylized facts**

- **SF5:** Investment is lumpy (Doms and Dunne, 1998)
- **SF6:** Investment is influenced by firms' financial structure (e.g. Fazzari, Hubbard and Petersen 1988)

Variance and Auto-Correlation Structure of GDP and of its components for the U.S. economy

Series	Std. Dev.		Cross-correlations with GDP (lags)								
	Abs.	Rel.	-4	-3	-2	-1	0	1	2	3	4
GDP	1.66	1.00	0.03	0.33	0.66	0.91	1	0.91	0.66	0.33	0.03
Investment	4.97	2.99	0.04	0.32	0.61	0.82	0.89	0.83	0.65	0.41	0.18
Consumption	1.26	0.76	-0.07	0.21	0.51	0.76	0.90	0.89	0.75	0.53	0.29
Change in Inventories	0.38	-	-0.32	-0.04	0.28	0.57	0.73	0.72	0.56	0.32	0.08
Employment	1.39	0.84	0.49	0.72	0.89	0.92	0.81	0.57	0.24	-0.07	-0.33
Unemployment rate	0.76	0.46	-0.27	-0.55	-0.80	-0.93	-0.89	-0.69	-0.39	-0.07	0.19

Quarterly data have been detrended with a bandpass filter (6,32,12).

Source: Stock & Watson, 1999

Stylized Facts (2/2)

- Firm Productivity Dynamics (e.g. Bartelsman and Dooms, 2000)
 - **SF10:** Productivity dispersion among firms is considerably large
 - **SF11:** Inter-firm productivity differentials are quite persistent over time
- Firm Size Distributions (e.g. Bottazzi and Secchi, 2003; 2004)
 - **SF12:** Firm size distributions tend to be considerably right-skewed, with upper-tails made of few large firms. These patterns vary considerably across different sectors.
 - **SF13:** Firms growth-rate distributions are not Gaussian and can be well proxied by fat-tailed, tent-shaped densities

Theoretical Roots and Antecedents (1/2)

⇒ **Models explaining investment stylized facts**

- Investment Lumpiness
 - Non-convex adjustment costs
(e.g. Caballero, Engel and Haltiwanger, 1995; Caballero and Engel 1999; Cooper, Haltiwanger and Power (1999))

- Financial Constraints
 - Imperfect information
(e.g. Evans and Jovanovic, 1989; Fazzari, Hubbard and Petersen, 1996)

Theoretical Roots and Antecedents (2/2)

⇒ **Macro theories and Micro models at the root of our model**

- Keynesian Theory of Trade Cycles (Keynes, 1936)
 - Investment instability as the main cause of economic fluctuations
 - Multiplier and Investment accelerator
- Evolutionary model of industry dynamics
 - Silverberg, Dosi and Orsenigo (1988)
 - Chiaromonte and Dosi (1993)

The Model (1/10)

- The Economy

- Two industries and a (unmodeled) non-market sector

- F_1 consumption-good firms $j = 1, 2, \dots, F_1$

- F_2 machine-tool firms $i = 1, 2, \dots, F_2$

- N consumers/workers

- Discrete time $t = 0, 1, 2, \dots, T$

The Model (2/10)

- Consumption-good firms
 - invest in machine tools
 - produce homogenous consumption good
- Machine-tool firms
 - produce heterogeneous capital goods
 - perform R&D
- Consumers/workers
 - inelastically sell labor to firms
 - fully consume their income

The Model (3/10)

- Model Dynamics
 1. Consumption-good firms take their production and investment decisions
 2. Capital-good market opens
 3. Consumption-good market opens
 4. Entry, exit and technical change take place

The Model (4/10)

1. Investment

a) Expansion investment is lumpy

- Source of Lumpiness → bounded rationality (i.e. animal spirits)
- (S,s) Investment Routine:
 - Demand Expectations (D_j^e) → Desired Level of Production (Q_j^d)
 - Desired Level of Production → Desired Capital Stock (K_j^d)
 - Trigger Capital Stock → $K_j^{\text{trig}}(t) = K_j(t) * (1 + \alpha)$
 - Expansion Investment =
$$\begin{cases} 0 & \text{if } K_j^d(t) < K_j^{\text{trig}}(t) \\ K_j^{\text{trig}}(t) - K_j(t) & \text{if } K_j^d(t) \geq K_j^{\text{trig}}(t) \end{cases}$$

The Model (5/10)

b) Replacement investment

- Payback period routine:
 - c unit labor cost of an incumbent machine
 - p^*, c^* average price and unit labor cost of new machines
 - an incumbent machine is scrapped $\Leftrightarrow \frac{p^*}{c - c^*} \leq b, b > 0$

c) Financial structure does matter!

- Production and investment decisions of firms may be constrained by the financial situation of firms

The Model (6/10)

2. Capital- and Consumption-Good Markets

- Imperfect competition (prices \rightarrow mark-up on unit cost of production)
- Supply:
 - Constant returns to scale
 - Machine-tool firms produce on demand
 - Consumption-good firms first produce and then try to sell their products
 - \rightarrow Inventories

The Model (7/10)

- Demand:

- Machine-tool industry → consumption-good firms' investment
- Consumption-good firms → workers' consumption
- Allocated according to market shares (f)

- Market shares evolving according to replicator dynamics

$$f_k(t) = f_k(t-1) * \left(1 + \chi \frac{E_k(t) - \bar{E}^k(t)}{\bar{E}^k(t)} \right), \quad \text{with } k = i \text{ OR } j$$

E_k : competitiveness of firm k; \bar{E} : avg. competitiveness of the industry; $\chi \geq 0$

- Competitiveness (E) depends on price and unfilled demand

The Model (8/10)

3. Entry, Exit and Technical Change

- Exit → zero market share OR negative net worth
- Entry → random copy of an existing firm
- Technical change → machine tools stochastically improving

The Model (9/10)

4. Macro level

- Labor market:
 - Exogenous Labor Supply (L) growing at a constant rate
 - Wage (w) determined by avg. productivity (\bar{A}), inflation (cpi) and unemployment (U):

$$w(t) = w(t-1) * \left(1 + \psi_1 \frac{\text{cpi}(t) - \text{cpi}(t-1)}{\text{cpi}(t-1)} + \psi_2 \frac{\bar{A}(t) - \bar{A}(t-1)}{\bar{A}(t-1)} - \psi_3 \frac{U(t) - U(t-1)}{U(t-1)} \right),$$

with $0 \leq \psi_{1,2,3} \leq 1$

- Involuntary unemployment

The Model (10/10)

- Aggregate Consumption
 - Aggregate consumption (C) depends on the market wage and on the total level of employment (Emp).
 - It depends also on the demand stemming from a non-market sector (e.g. government services) which is proportional to the total labor force and the aggregate wage bill.
 - $C(t) = w(t)*Emp + \varphi*w(t)*L$, with $0 < \varphi < 1$.
- Employment, Consumption, Investment, Change in Stocks and GDP →
obtained by aggregating agent quantities

Expectation Scenarios

- Demand expectations:

- Perfectly Myopic → $D_j^e(t) = D_j(t-1)$

- Autoregressive

- $D_j^e(t) = \beta_1 D_j(t-1) + \beta_2 D_j(t-2) + \beta_3 D_j(t-3) + \beta_4 D_j(t-4)$ with $0 \leq \beta_{1,2,3,4} < 1$

- Accelerative → $D_j^e(t) = [1 + \beta_5 \Delta D_j(t-1)] D_j(t-1)$ with $0 < \beta_5 < 1$

- Adaptive → $D_j^e(t) = D_j^e(t-1) + \beta_6 [D_j(t-1) - D_j^e(t-1)]$ with $\beta_6 > 0$

- Micro-Macro

- $D_j^e(t) = [1 + \beta_7 \Delta D_j(t-1) + \beta_8 \Delta \text{GDP}(t-1)] D_j(t-1)$ with $0 < \beta_{7,8} < 1$

Simulation Strategy (1/2)

- Choose initial conditions, systems parameters and expectation scenario
- Generate a simulation run for $t = 1, \dots, 600$
 1. Analyze qualitative results
(e.g. self-sustaining growth, fluctuations)
 2. Study quantitative results
(e.g. stationarity test, standard deviations, correlations)

Simulation Strategy (2/2)

- One should perform a Montecarlo analysis to:
 1. study how different initial conditions and system parameters affect the statistics of interest
 - different initial conditions (within a “canonical set”) do not alter our results
 - analysis of system parameters
 2. wash away across-simulations variability introduced by stochastic components
 - only one stochastic component (i.e. technical change)
 - negligible across-simulations stochastic variability
 - limited number of replications as robust proxy for time-series behavior

Simulation Results (1/4)

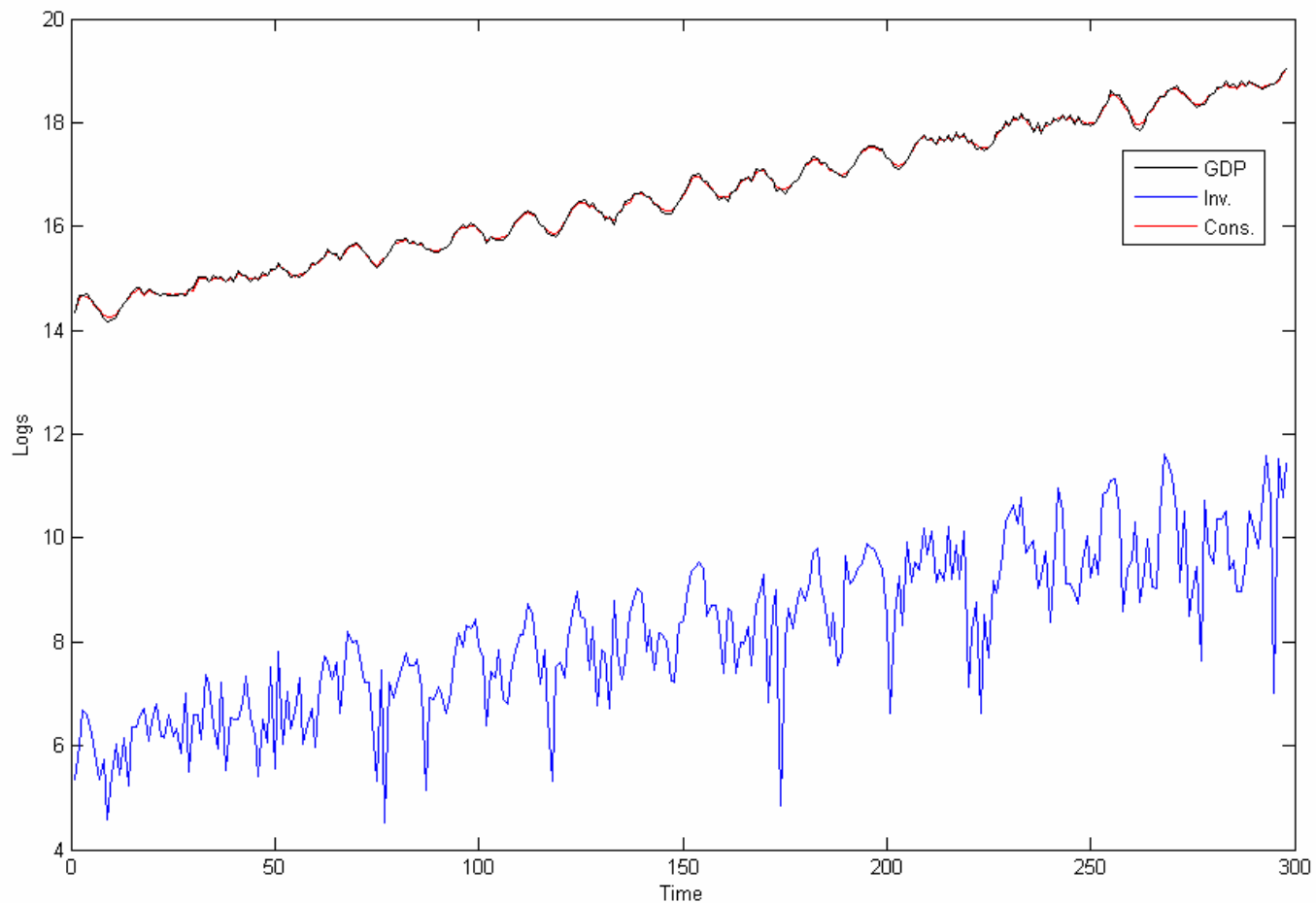
1. Perfectly Myopic Expectations

- Self-sustaining growth does emerge
- Endogenous business cycles do emerge
- Investment more volatile than GDP (SF1)
- Consumption seems less volatile than GDP (SF2)
- Investment and Consumption seem procyclical (SF3)
- Expansion investment more volatile than replacement investment

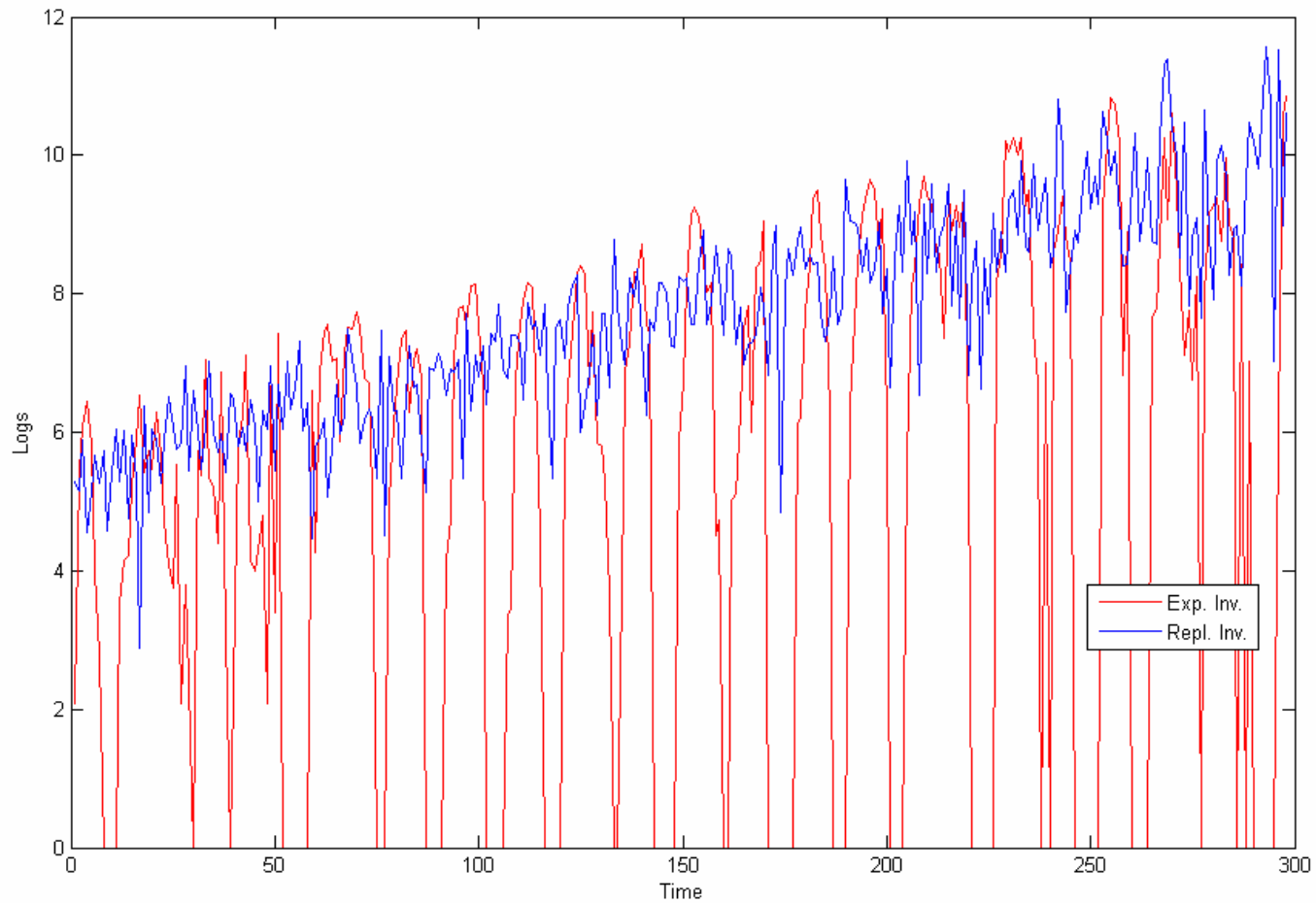
2. Other Expectation Regimes

- Very similar results
- Output and aggregate investment seem less volatile under autoregressive expectation regimes
- Expansion investment is less lumpy under autoregressive and accelerative expectation set-ups

Perfectly Myopic Expectations. GDP, Investment and Consumption (logs)



Perfectly Myopic Expectations. Exp. and Repl. Investment (logs)



Simulation Results (1/4)

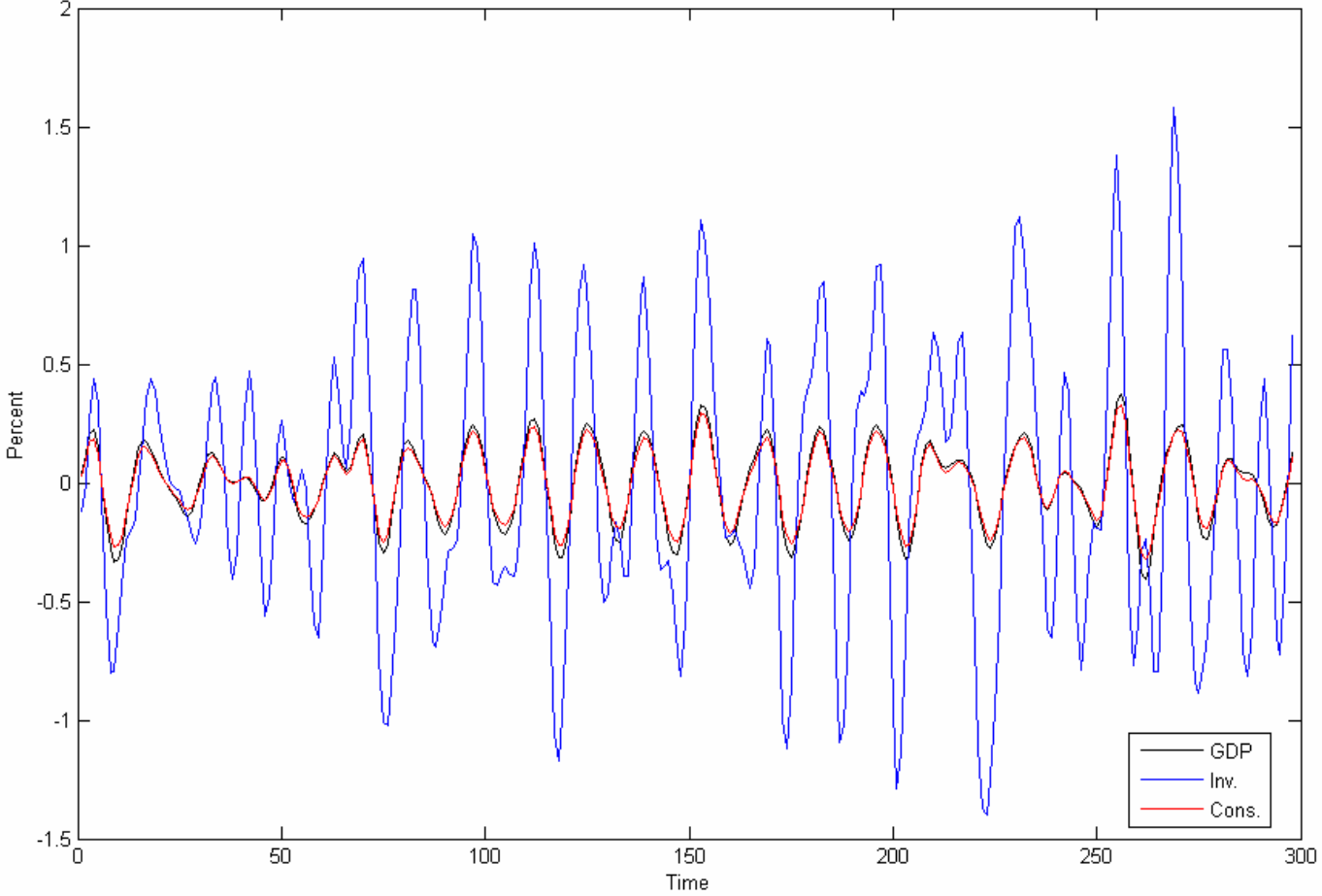
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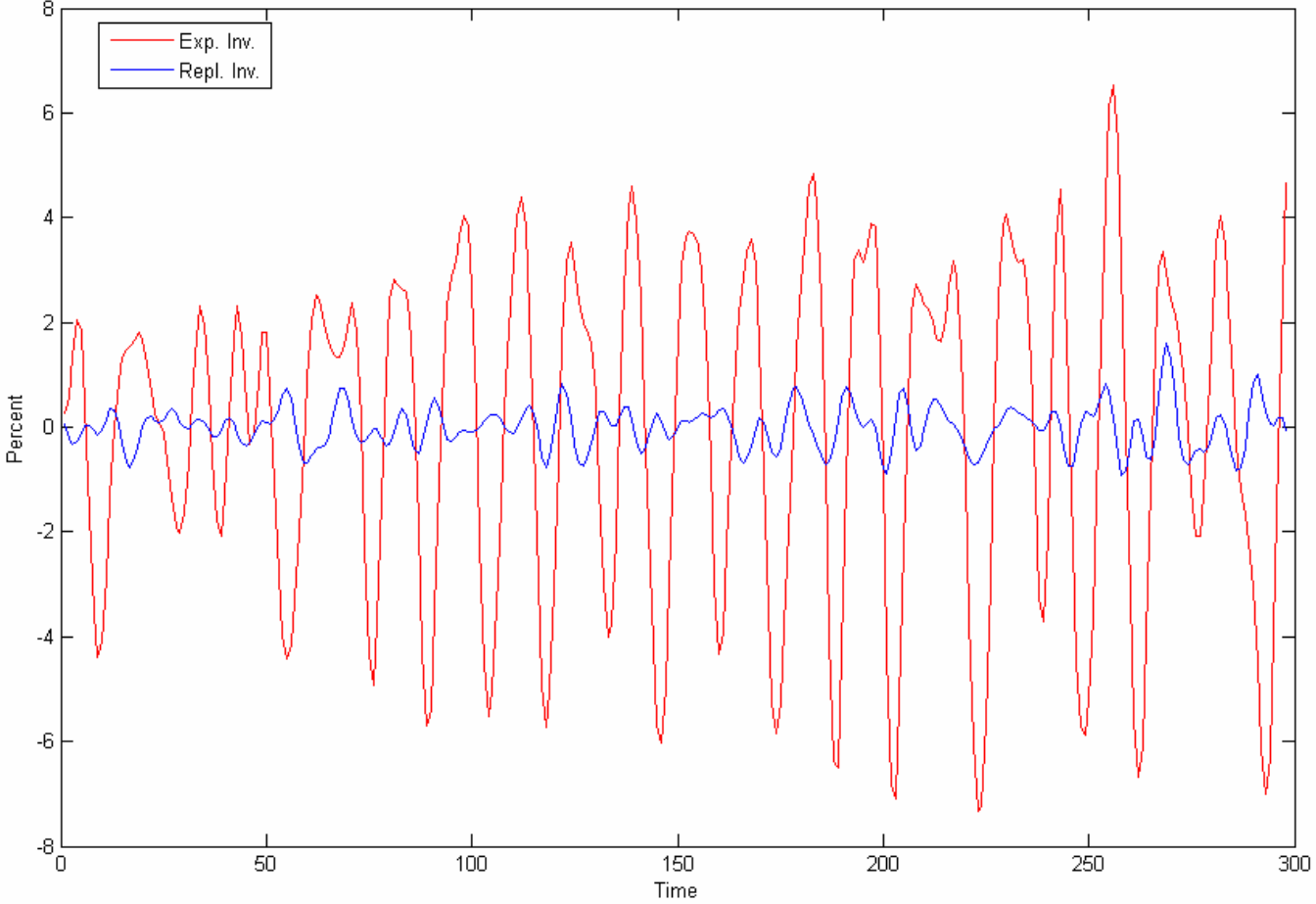
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Perfectly Myopic Expectations. Bandpass-filtered GDP, Investment and Consumption



Perfectly Myopic Expectations. Bandpass-filtered Exp. and Repl. Investment



Simulation Results (1/4)

1. Qualitative Results. Perfectly Myopic Expectations

- Self-sustaining growth does emerge
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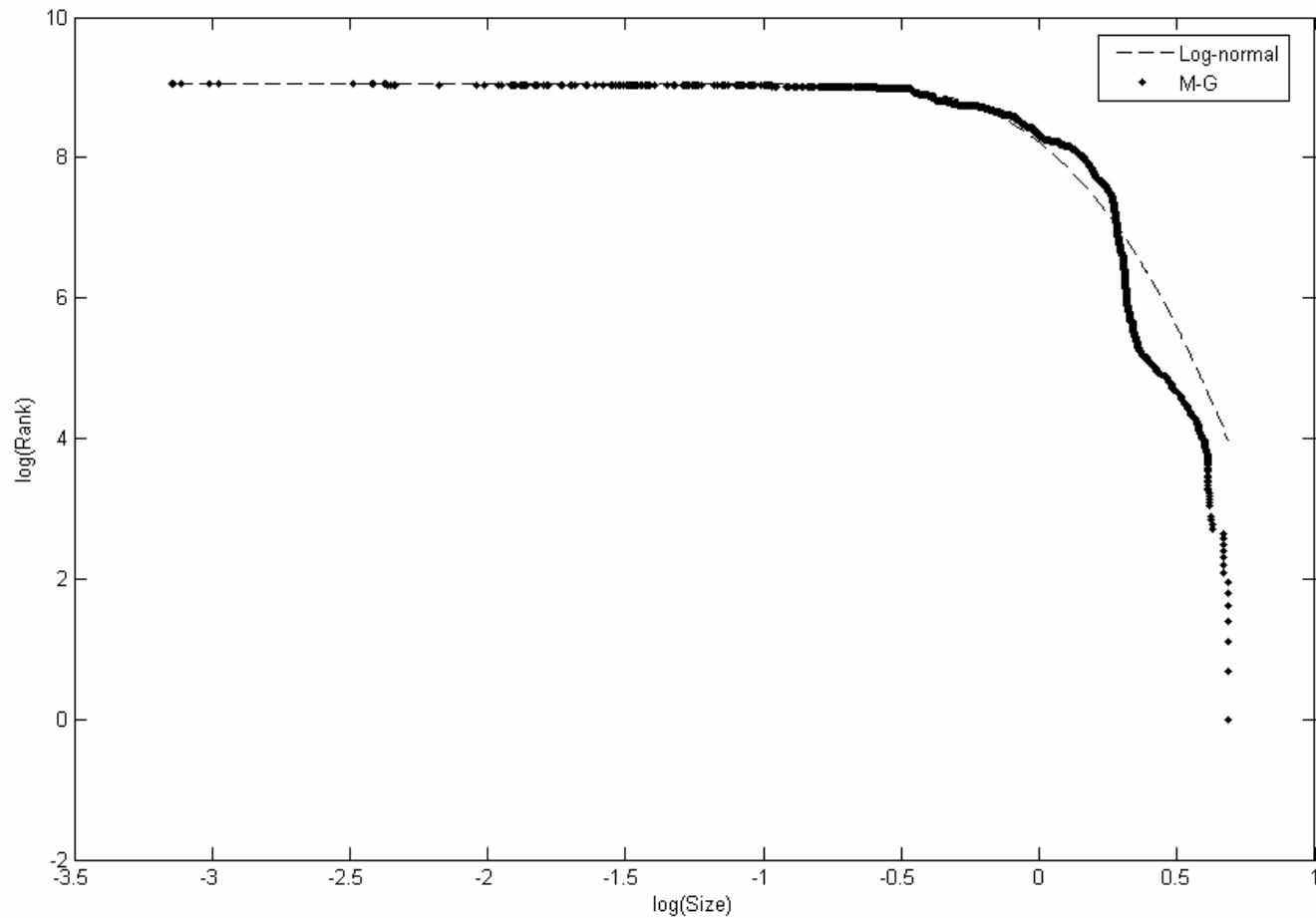
Simulation Results (2/4)

3. Firm Size Distributions

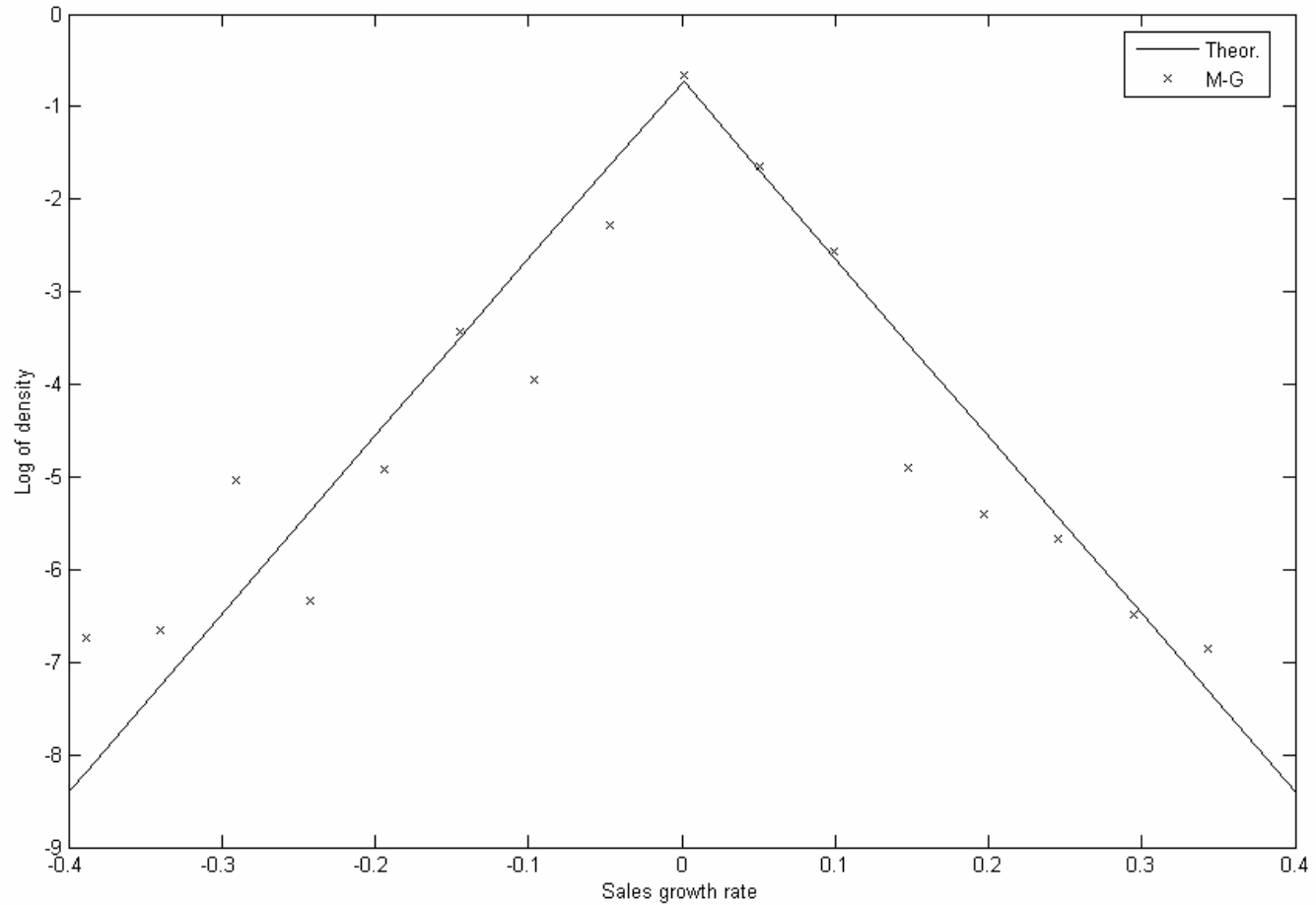
- Skewed Size Distribution (SF12)
- Firm Growth Rates exhibit "tent-shaped" patterns with tails fatter than the Gaussian distribution (SF13)
- Gibrat's Law does not hold

Pooled (Year-Standardized) Sales Distributions. Log Rank vs. Log Size Plots.

M-G: Model-Generated Distribution.



Pooled (Year-Standardized) Firm Growth Rates. Binned Densities of Simulated Growth Rates vs. Laplace Fit. M-G: Model-Generated Growth Rates.



Simulation Results (3/4)

4. Quantitative Results. Perfectly Myopic Expectations

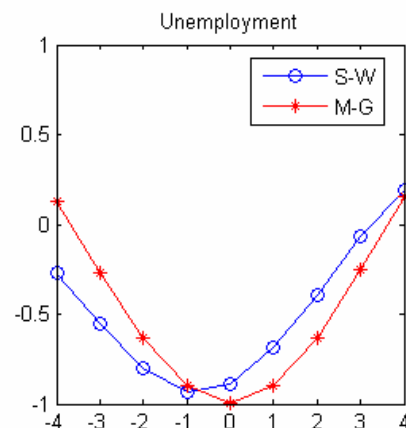
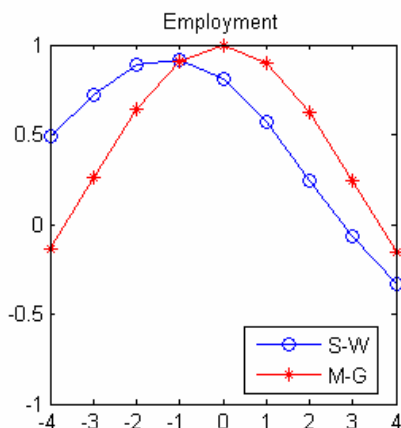
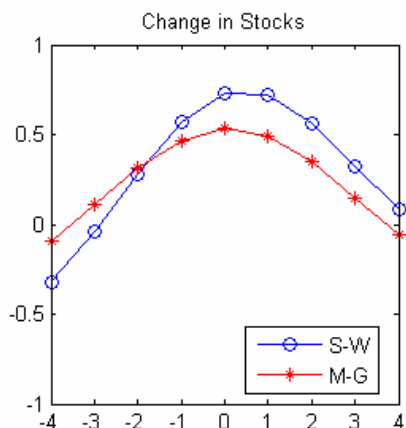
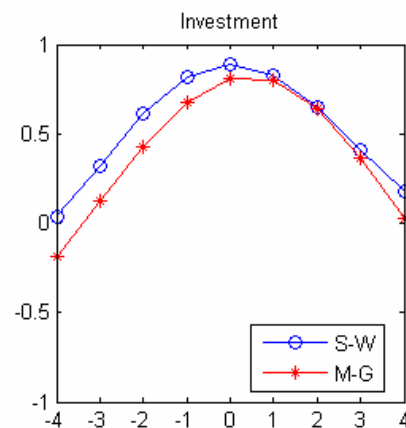
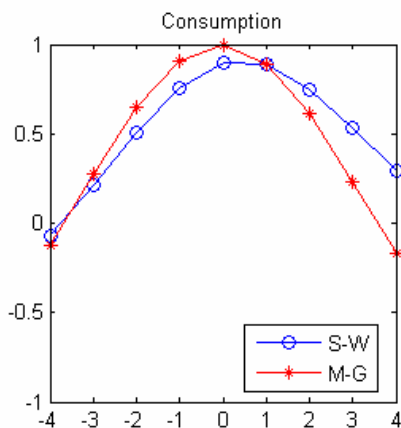
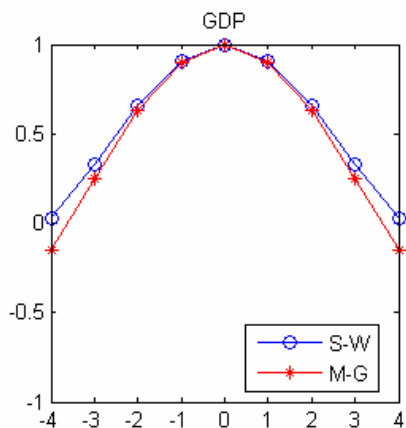
- Positive average rates of growth (1.5%)
- Dickey-Fuller test: GDP, Consumption and Investment non-stationary
- Relative standard deviations: investment more volatile than GDP (SF1); consumption less volatile than GDP (SF2)
- Cross-correlations: consumption, change in stocks, and investment procyclical and coincident variables (SF3)
- Employment and unemployment rate procyclical and coincident variables
- Simulated cross-correlations close to “real” cross-correlations (cf. Stock and Watson, 1999)

Perfectly Myopic Expectations. GDP, Consumption and Investment Statistics.			
	GDP	Consumption	Investment
Avg. growth rate (%)	1.50%	1.51%	1.54%
Dickey-Fuller test (logs)	2.8715	3.9986	-0.9186
Sign. level	1	1	1
Dickey-Fuller test (bpf 6,32,20)	-4.8703	-4.8040	-5.6382
Sign. level	0.01	0.01	0.01
Std. Dev. (bpf 6,32,20)	0.1931	0.1659	0.6089
Rel. Std. Dev. (GDP)	1	0.8590	3.1536

Perfectly Myopic Expectations. Correlation Structure

Series	Gdp (bpf 6,32,12)								
bpf 6,32,12	t-4	t-3	t-2	t-1	t	t+1	t+2	t+3	t+4
GDP	-0.1516	0.2493	0.6281	0.9001	1	0.9001	0.6281	0.2493	-0.1516
Consumption	-0.1227	0.2777	0.6481	0.9085	0.9975	0.8918	0.6159	0.2350	-0.1672
Investment	-0.1887	0.1226	0.4300	0.6767	0.8112	0.7998	0.6396	0.3622	0.0263
Ch. in Invent.	-0.0956	0.1067	0.3101	0.4669	0.5342	0.4913	0.3500	0.1493	-0.0615
Employment	-0.1397	0.2637	0.6389	0.9045	0.9981	0.8966	0.6248	0.2478	-0.1514
Unempl. rate	0.1274	-0.2663	-0.6327	-0.8949	-0.9916	-0.8966	-0.6296	-0.2519	0.1537

Perfectly Myopic expectations. Model Generated (M-G) vs. Empirical Data (S-W: Stock and Watson, 1999) Cross-Correlations



Simulation Results (4/4)

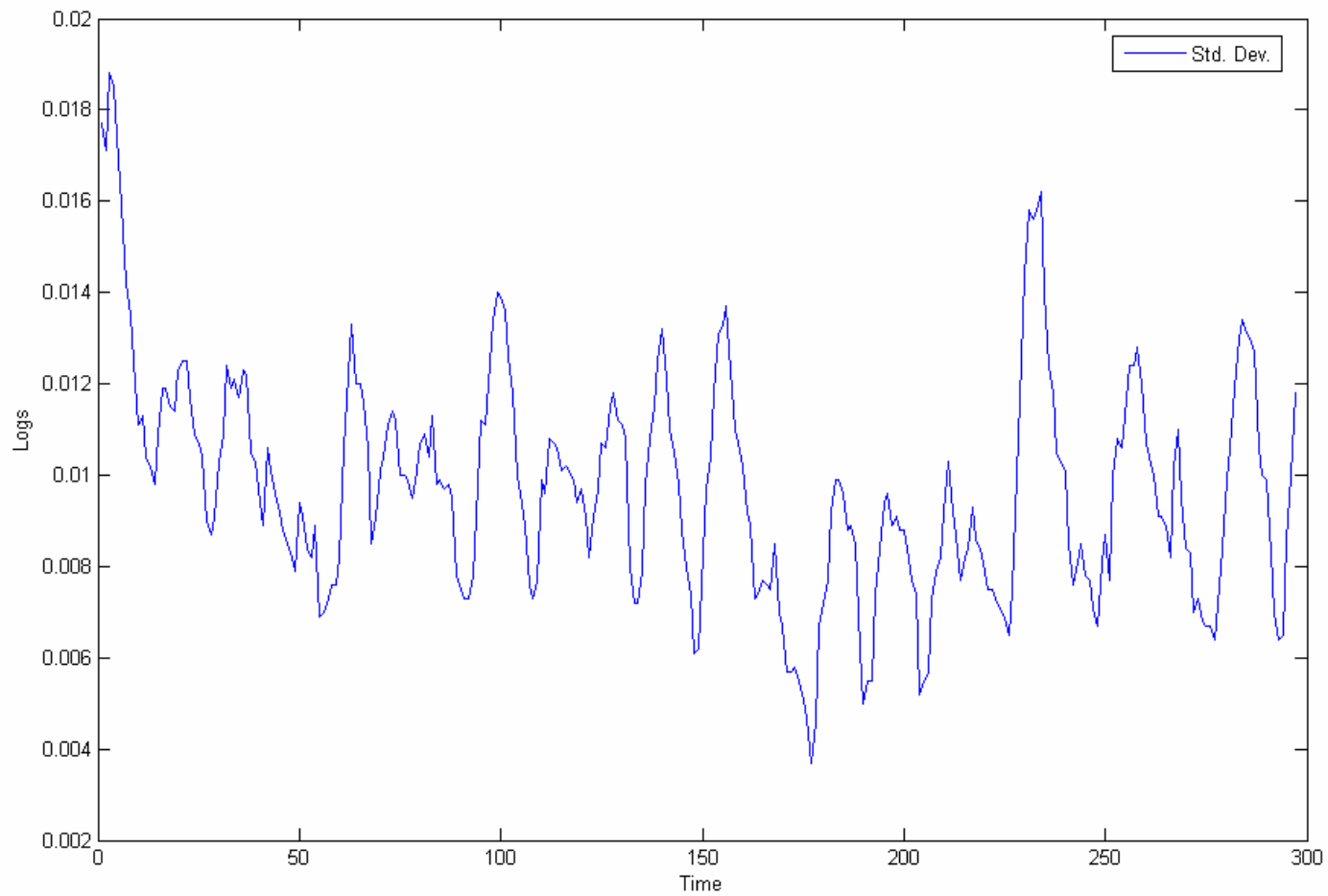
5. Other Expectation Regimes

- Increasing the rationality of agents DOES NOT lead to better results
 - Investment relative standard deviations higher with autoregressive expectations; lower with accelerative expectations (SF1 always matched).
 - Autoregressive expectation scenario. Investment slightly leading; Change in Inventories slightly lagging.

6. Firm Productivity Dynamics

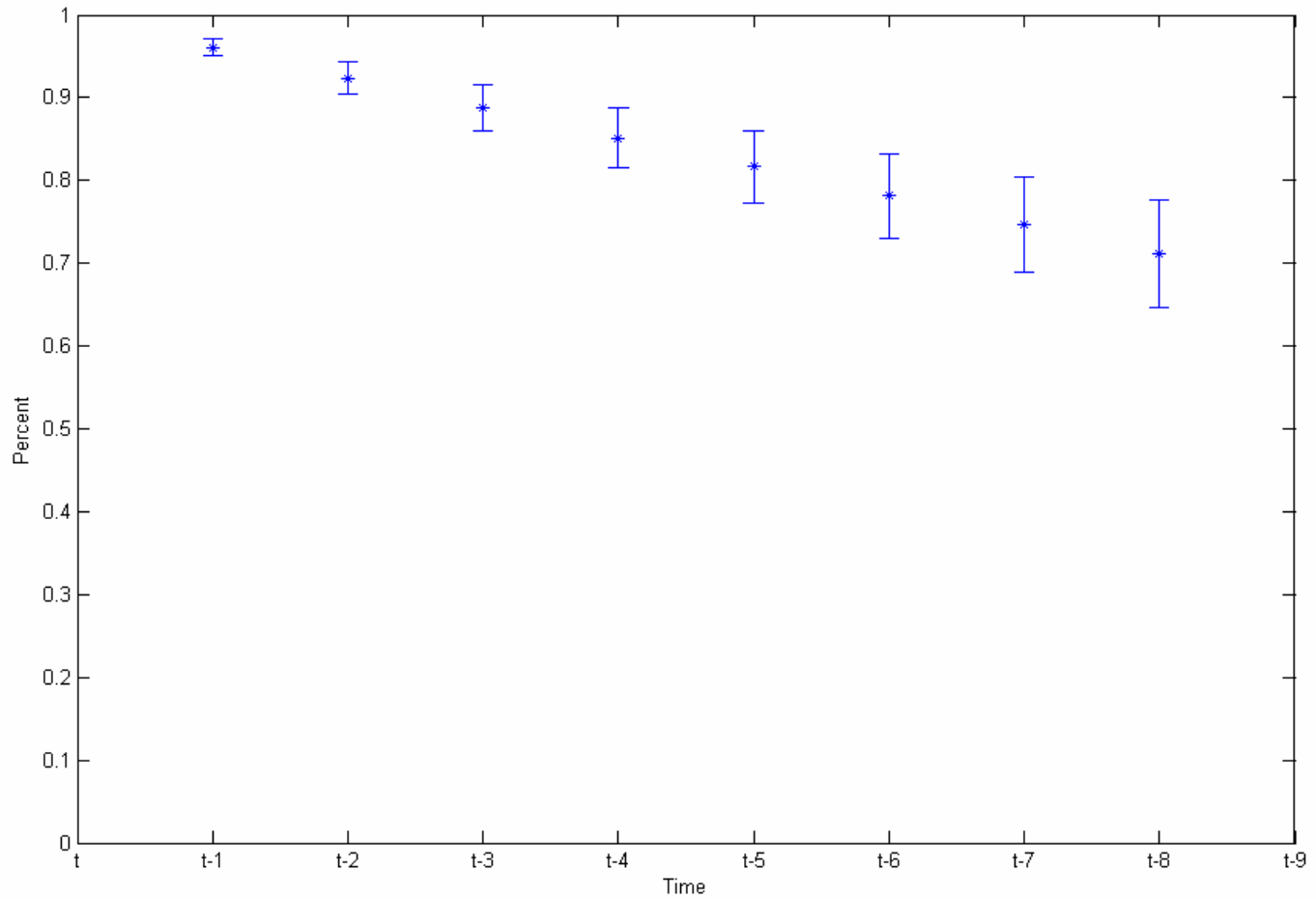
- Huge asymmetries in firm productivity (SF10)
- Persistency in inter-firm productivity differentials (SF11)

Standard Deviations of Consumption-Good Firm Productivity



Average Auto-Correlations of Consumption-Good Firm Productivity.

Error Bars: +/- Standard Deviation.



Conclusions (1/2)

■ Business cycles stylized facts

- Investment is more volatile than GDP (SF1) whereas consumption is less volatile than GDP (SF2)
- Investment, consumption and change in stocks procyclical and coincident variables (SF3). Employment and unemployment rate are lagging variables. Employment is procyclical, whereas unemployment is anticyclical (SF4).

■ Investment stylized facts

- Investment is lumpy (SF5) and is influenced by firms' financial structure (SF6).

■ Firm productivity dynamics stylized facts

- Firms are extremely heterogeneous in term of productivity (SF10).
- Inter-firm productivity differentials are persistent over time (SF11).

■ Firm size distribution stylized facts

- Firm size distributions tend to be considerably right-skewed (SF12) and firm growth rate can be well proxied by fat-tailed, tent-shaped densities (SF13).

Conclusions (2/2)

- No attempts in providing a model that JOINTLY explains SF1-SF4 and SF10-SF13 starting from SF5 and SF6

- We presented an evolutionary/ACE model
 - Machine-tool and manufacturing industries
 - Routines for expansion and replacement investment
 - Investment lumpiness grounded on bounded rationality
 - Financial structure of firms matters
 - Interactions within- and between-industry
 - Technological progress
 - Keynesian trade cycle theory

- We find that the model
 - delivers self-sustaining growth patterns
 - endogenously generates business cycles
 - reproduces macro stylized facts (SF1 – SF3)
 - increasing the rationality of firms does not lead to better results
 - matches micro stylized facts (SF10 – SF13)