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Technical Change, Finance, and Public Policies in an Evolutionary Model of Endogenous Growth and Fluctuations

Giovanni Dosi[1,2]

[1]Sant'Anna School of Advanced Studies, Pisa

[2]Visiting Professor, Friedrich-Schiller-Universität, Jena

Motivations I

- **The puzzling dichotomy between growth and business cycle theories**
  - growth literature (Neoclassical and Evolutionary) has serious difficulties to explain short-run macro phenomena
  - new Keynesian DSGE literature on business cycles does not address explicitly long-run problems
  - Dichotomy between short and long-run issues is also present in models with financial-market imperfections
- **Consequences:**
  - Schumpeterian theory of growth never meets Keynesian theory of effective demand and aggregate business cycles
  - a peculiar schizophrenia between macro fiscal and monetary policy, if any, for the “short run” and “structural” policies for the long run

Motivations II

- **Macroeconomic Policy and Agent-Based Models**
  - Great potential for ABMs in addressing policy-oriented analysis
  - The economic crisis as a crisis for economic theory: DSGE vs. complex-system approaches to economics (Kirman, 2010; Colander et al., 2010)
  - Still a lot of work to do, especially in macroeconomics
- **Our proposal: a new family of models which**
  - begins to bridge short- and long-run dynamics.
  - allows to assess both the short- and long-run implications of public polices and the related cross-frequency interactions

Related Literature

- **Schumpeterian and Evolutionary-Growth Models**
  - From Nelson & Winter (1982) to the **K+S model (2006, 2008, 2010)**
- **Vintage Keynes (1936) and Cambridge Keynesians**
  - From J. Robinson to Kaldor and Harrod
- **Post-Walrasian, Empirically-Based Macroeconomics**
  - See Colander (2006) and Colander et al. (2008)
- **Agent-Based Computational Economics**
  - Tesfatsion; Gintis; Dawid, Neugart et al. (EURACE); Delli Gatti, Gallegati and co-authors; and many many others!
- **Financial Market Imperfections and Business Cycles**
  - Greenwald & Stiglitz (1993,2003), Delli Gatti, Gallegati et al. (2005)

Assessing the Impact of Different Policies

1. **Develop a model able to robustly reproduce an ensemble of microeconomic and macroeconomic "stylized facts"**
2. **Choose specific policy combinations**
3. **Evaluate the long- and short-run impact of policies upon**
    - GDP growth rate
    - GDP volatility
    - Unemployment dynamics

The Model

- **Close antecedents:**
  - **The Keynes+Schumpeter model** (**“K+S model”**, 2006, 2008, 2010) on endogenous growth and business cycles

- **The basic structure of the economy**
  - Two industries
  - $F1$ consumption-good firms $j = 1, 2, \ldots, F1$
  - $F2$ machine-tool firms $i = 1, 2, \ldots, F2$
  - N consumers/workers
  - Banking sector (one bank)
  - Public sector
  - Discrete time $t = 1, 2, \ldots, T$

Agents

- **Capital-good firms:**
  - perform R&D
  - produce heterogeneous capital goods using labor only
- **Consumption-good firms:**
  - produce homogeneous consumption goods using machine tools and labor
- **Consumers/workers:**
  - inelastically sell labor services to firms
  - fully consume their income

The Sequence of Microeconomic Decisions

- **Model Dynamics:**
  1) capital-good firms perform R&D
  2) capital-good firms advertise their machines sending "brochures" to consumption-good firms
  3) consumption-good firms decide how much to produce, choose their supplier for next period machines and order machines
  4) firms hire workers according to their production plans (wages are advanced), using internal funds and credit provided by the banking sector
  5) production in both sectors begins
  6) consumption-good market opens
  7) entry and exit take place
  8) consumption-good firms receive the machines they ordered and pay them using internal funds and external credit

Technical Change I

- **Capital-good firms search for better machines and for more efficient production techniques**
  - $A_i(t)$: productivity of machine manufactured by firm i
  - $B_i(t)$: productivity of production technique of firm i
  - $A_i(t)$ and $B_i(t)$ determine the technology of firm i at time t
- **R&D:**
  - R&D investment (RD) is a fraction of firm sales (S):

$$RD_i(t) = \upsilon S_i(t-1) \qquad \upsilon > 0$$

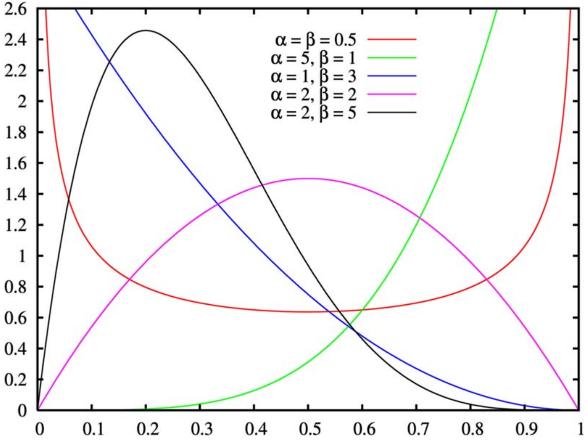
  - capital-good firms allocate R&D funds between innovation (IN) and imitation (IM):

$$IN_i(t) = \xi RD_i(t) \qquad IM_i(t) = (1-\xi) RD_i(t) \qquad \xi \epsilon [0,1]$$

Technical Change II

- **Innovation and imitation: two steps procedure**
- **Innovation:**
  1) firm successfully innovates or not through a draw from a Bernoulli($\theta_1(t)$), where $\theta_1(t)$ depends on $IN_i(t)$:
  $$\theta_1(t) = 1 - e^{-o_1 IN_i(t)} \qquad o_1 > 0$$
  2) search space: the new technology is obtained multiplying the current technology by $(1 + x_i(t))$, where $x_i(t) \sim Beta$ over the support (x_0, x_1) with $x_0 < 0, x_1 > 0$
- **Imitation**
  1) firm successfully imitates or not through a draw from a Bernoulli($\theta_2(t)$), where $\theta_2(t)$ depends on $IM_i(t)$:
  $$\theta_2(t) = 1 - e^{-o_2 IM_i(t)} \qquad o_2 > 0$$
  2) firms are more likely to imitate competitors with similar technologies (Euclidean distance)

Beta Distribution



Capital-Good Market

- **Capital-good firms:**
  - if they successfully innovate and/or imitate, they choose to manufacture the machine with the lowest $p_i + c_i^1 b$
    - p_i: machine price;
    - c_i^1: unit labor cost of production entailed by machine in consumption-good sector;
    - b: payback period parameter
  - fix prices applying a mark-up on unit cost of production
  - send a "brochure" with the price and the productivity of their machines to both their historical and some potential new customers
- **Consumption-good firms:**
  - choose as supplier the capital-good firm producing the machine with the lowest $p_i + c_i^1 b$ according to the information contained in the "brochures"
  - send their orders to their supplier according to their investment decisions

Investment

- **Expansion investment**
  - demand expectations (D^e) determine the desired level of production (Q^d) and the desired capital stock (K^d)
  - firm invests (EI) if the desired capital stock is higher than the current capital stock (K):

$$EI = K^d - K$$

- **Replacement investment**
  - payback period routine:
    - an incumbent machine is scrapped if

$$\frac{p^*}{c(\tau) - c^*} \leqslant b, \qquad b > 0$$

    - $c(\tau)$ unit labor cost of an incumbent machine;
    - p^*, c^* price and unit labor cost of new machines
  - also machine older than Λ periods are replaced

Financial Structure

- **Production and investment decisions of consumption-good firms may be constrained by their financial balances**
  - consumption-good firms first rely on their stock of liquid assets and then on more expensive external funds provided by the banking sector
  - credit ceiling: the stock of debt (*Deb*) of consumption-good firms is limited by their gross cash flows (= sales *S*):

$$Deb_j(t) \leqslant \kappa S_j(t-1), \quad \kappa \geqslant 1$$

Credit and the Banking Sector

- **Deposits and Credit**
  - A single bank gathers deposits (from both sectors) and provides credit to firms
  - Deposits are equal to total net assets of all firms
  - Credit is allocated to firms on a pecking-order base
  - Pecking order depends on the ratio between net worth and sales

$$NW_j(t-1)/S_j(t-1)$$

Credit and the Banking Sector

- **Credit Supply Scenarios**
  - Total Credit supply $TC(t)$ is determined according to two different scenarios

    (1) Fractional-Reserves Scenario: Credit is a multiple of total net-assets of firms, entirely deposited in the bank
    (2) Basel Capital-Adequacy Scenario: Credit can be constrained by capital-adequacy requirements (i.e., by the ratio between internal funds and total credit of the bank, set by the regulatory authority)

Consumption-Good Markets

- **Supply:**
  - imperfect competition: prices (p_j) $\Rightarrow$ variable mark-up (mi_j) on unit cost of production (c_j)

$$p_j(t) = (1 + mi_j(t))c_j(t);$$

$$mi_j(t) = mi_j(t-1)\left(1 + \alpha \frac{f_j(t-1) - f_j(t-2)}{f_j(t-2)}\right);$$

  $\alpha > 0$; f_j: market share of firm j
  - firms first produce and then try to sell their production (inventories)

Consumption-Good Markets

- **Market dynamics:**
  - market shares evolve according to a “quasi” replicator dynamics:

$$f_j(t) = f_j(t-1)\left(1 + \chi \frac{E_j(t) - \overline{E}(t)}{\overline{E}(t)}\right); \quad \chi \geqslant 0$$

E_j: competitiveness of firm j; $\overline{E}$: avg. competitiveness of consumption-good industry;

  - firm competitiveness depends on price and unfilled demand (l_j):

$$E_j(t) = -\omega_1 p_j(t) - \omega_2 l_j(t), \quad \omega_{1,2} > 0$$

Exit and Entry

- **Exit:**
  - (near) zero market share or negative net worth
- **Entry:**
  - each entrant replaces a dead firm
  - entrants' net worth (NW_e) is a fraction of the average net worth of incumbents ($\overline{NW}$):

$$NW_e = \lambda_1 \overline{NW}, \qquad \text{with } \lambda_1 \sim U[\iota_1, \iota_2], \qquad \iota_{1,2} > 0$$

  - the technology of capital-good firms is obtained applying a coefficient extracted from a *Beta* distribution to an endogenously evolving technology frontier
  - the capital stock of consumption-good entrant (K_e) is a fraction of the capital stock of incumbents ($\overline{K}$):

$$K_e = \lambda_2 \overline{K}, \qquad \text{with } \lambda_2 \sim U[\iota_3, \iota_4], \qquad \iota_{3,4} > 0$$

  - consumption-good firms buy K_e in the next period

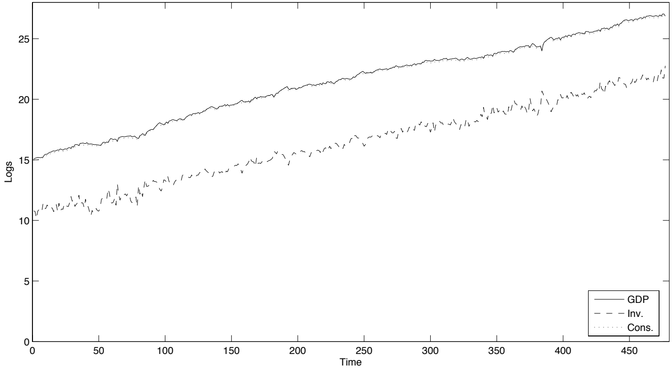
Macro Level

- **Public sector**
  - levies taxes on firms' profits and workers' wages or on profits only
  - gives a fraction of the market wage to unemployed workers
- **Labor Market**
  - exogenous labor supply
  - wage dynamics determined by avg. productivity, inflation and unemployment
  - involuntary unemployment + possibility of labor rationing
- **Employment, consumption, investment, inventories and GDP are obtained by aggregating micro quantities**

Empirical Validation I

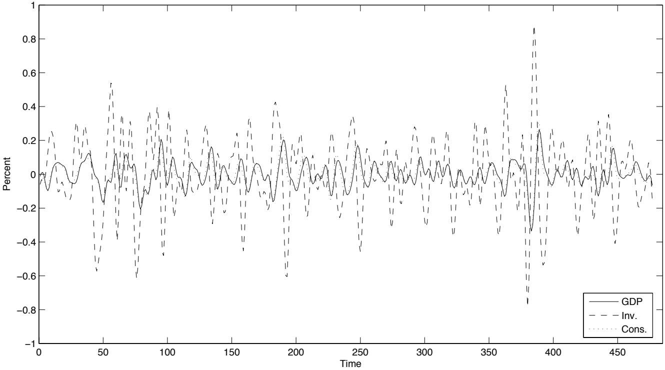
The model is able to account for a rich ensemble of macro stylized facts

(1) Self-sustained, endogenous growth...



Bandpassfiltered GDP, Consumption, and Investment

...with endogenous business cycles



GDP, Consumption and Investment Statistics

(2) Investment more volatile than GDP; consumption less volatile than GDP

	Output	**Consumption**	**Investment**
Avg. growth rate	0.0254	0.0252	0.0275
	(0.0002)	(0.0002)	(0.0004)
Dickey-Fuller test (logs)	6.7714	9.4807	0.2106
Dickey-Fuller test (Bpf)	-6.2564^*	-5.8910^*	-6.8640^*
Std. Dev. (Bpf)	0.0809	0.0679	0.4685
	(0.0007)	(0.0005)	(0.0266)
Rel. Std. Dev. (output)	1	0.8389	5.7880

Table: Monte Carlo simulation standard errors in parentheses. Asterisks (*): Significative at 95% level

Correlation Structure

(3) Consumption, net investment and change in inventories procyclical and coincident variables

(4) Countercyclical unemployment

(5) Procyclical productivity

(6) Countercyclical prices; procyclical inflation

(7) Countercyclical mark-ups

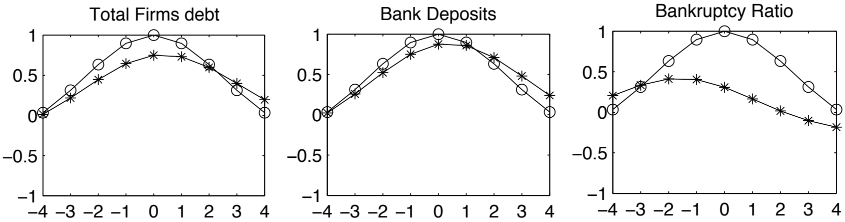
Correlation Structure

Series bpf 6,32,12	t-3	t-2	t-1	Output (bpf 6,32,12) t	t+1	t+2	t+3
Output	0.177	0.548	0.870	1	0.870	0.548	0.177
Consumption	0.098	0.426	0.756	0.953	0.925	0.685	0.339
Investment	-0.312	-0.265	-0.086	0.184	0.447	0.595	0.576
Net Investment	0.039	0.219	0.401	0.511	0.504	0.385	0.210
Ch. in Invent.	0.118	0.235	0.295	0.257	0.133	-0.020	-0.132
Employment	-0.190	0.080	0.408	0.669	0.756	0.645	0.407
Unempl. Rate	0.208	-0.060	-0.392	-0.6601	-0.755	-0.649	-0.411
Productivity	0.308	0.532	0.711	0.767	0.666	0.438	0.166
Price	0.318	0.270	0.092	-0.164	-0.395	-0.507	-0.469
Inflation	0.084	0.311	0.446	0.402	0.197	-0.063	-0.248
Mark-up	0.160	0.041	-0.099	-0.204	-0.236	-0.197	-0.123

Credit Variables

(8) Total credit is pro-cyclical and coincident

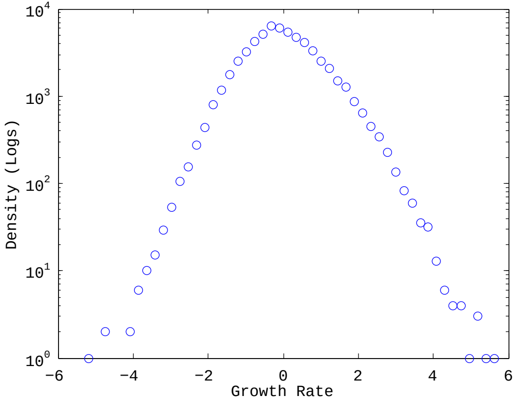
(9) Bankruptcy rates are pro-cyclical and lagging GDP dynamics



Average cross-correlations with GDP at different leads and lags (circles) together with average GDP autocorrelation (diamonds)

Output Growth-Rate Distributions

(10) Quasi-Laplace fat-tailed distributions (see Fagiolo, Napoletano and Roventini, 2008, J. of Appl. Econometrics, and Bottazzi and Secchi, 2011, ICC)



Empirical Validation II

The model is able to account for a rich ensemble of micro (firm-level) stylized facts (Dosi, 2007)

(1) Productivity dispersion among firms is large

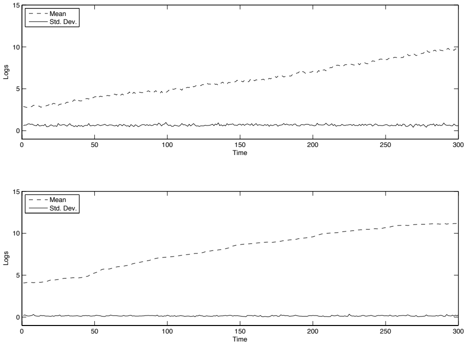


Figure: 1st panel: capital-good firms; 2nd panel: consumption-good firms

Persistence of Productivity Differentials

(2) Inter-firm productivity differentials are persistent over time

Industry	**t-1**	**t-2**
Capital-good	0.5433 (0.1821)	0.3700 (0.2140)
Consumption-good	0.5974 (0.2407)	0.3465 (0.2535)

Table: *Standard deviations in parentheses*

Firm Size Distributions: Are Distributions Log-Normal?

(3) Firm size distributions are more right-skewed than log-normal distributions

Industry	Jarque-Bera		Lilliefors		Anderson-Darling	
	stat.	p-value	stat.	p-value	stat.	p-value
Capital-good	20.7982	0	0.0464	0	4.4282	0
Consumption-good	3129.7817	0	0.0670	0	191.0805	0

Growth-Rate Distributions: Subbotin Estimation

(4) Firms growth rates are proxied by fat-tailed, tent-shaped densities

Series	**Subbotin Parameters**			
	b	**std. dev.**	**a**	**std. dev.**
Capital-good firms	0.5285	0.0024	0.4410	0.0189
Consumption-good firms	0.4249	0.0051	0.0289	0.0037
Output	1.4673	0.0122	0.0775	0.0004

Investment Lumpiness

(5) Coexistence of firms investing a lot and investing almost-zero (see Gourio & Kayshap, J. Mon. Econ., 2007)

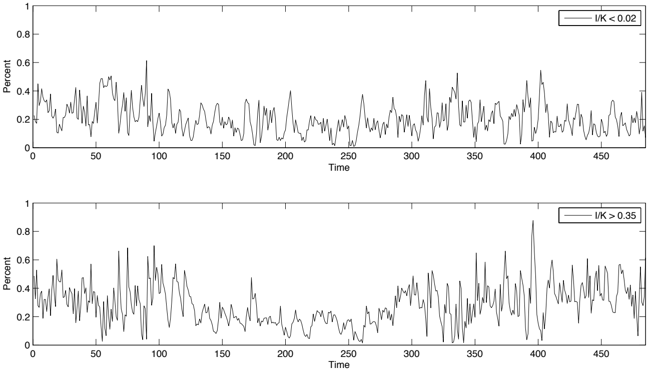
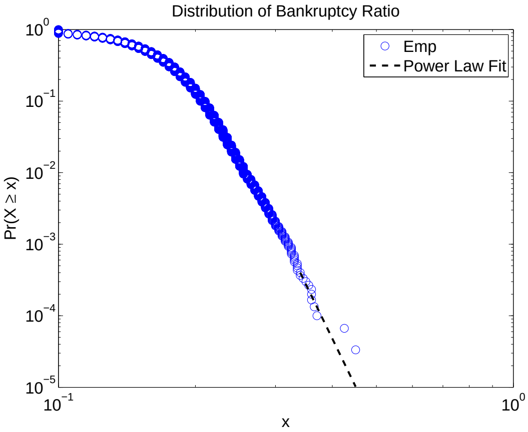


Figure: 1st panel: share of firms with (near) zero investment; 2nd panel: share of firms with investment spikes

Firm Bankruptcy

(6) Firm bankruptcy rates can be proxied by power-law densities (see Fujiwara, 2004, Di Guilmi et al. 2003)



Policy Combinations

- **Schumpeterian innovation policies affecting**
  - opportunities (e.g. expected value of innovation draws)
  - firm search capabilities (e.g. R&D productivity)
  - appropriability conditions (e.g. patents; imitation)
- **Entry and competition policies affecting market structure:**
  - competition policies (e.g. antitrust policy)
  - entry and exit (e.g. barrier to entry and/or exit)
- **Keynesian demand macro management policies:**
  - public expenditures
  - taxes
  - public debt
- **Monetary policies:**
  - interest rate
  - credit quantity constraints (mandatory reserve req.)

Experiment I: Vary Opportunities of Technological Innovation

- **Description of the experiment**
  - shift rightward and leftward the mass of the Beta distribution governing new technological draws
- **Results**
  - GDP growth rises unemployment fall with increasing technological opportunities

Description	**Avg. GDP Growth**	**GDP Std. Dev. (bpf)**	**Avg. Unempl.**
benchmark scenario	0.0252	0.0809	0.1072
	(0.0002)	(0.0007)	(0.0050)
low tech. opportunities	0.0195	0.0794	0.1357
	(0.0001)	(0.0008)	(0.0050)
high tech. opportunities	0.0315	0.0828	0.1025
	(0.0002)	(0.0007)	(0.0051)

Experiment II: Vary Firm Search Capabilities
(proxied by Firm R&D Productivity)

- **Description of the experiment**
  - Change the parameters affecting capital-good firm R&D productivity
- **Results**
  - GDP growth rises, GDP volatility and unemployment fall as the R&D productivity increases

Description	**Avg. GDP Growth**	**GDP Std. Dev. (bpf)**	**Avg. Unempl.**
benchmark scenario	0.0252	0.0809	0.1072
	(0.0002)	(0.0007)	(0.0050)
low search capabilities	0.0231	0.0825	0.1176
	(0.0002)	(0.0008)	(0.0059)
high search capabilities	0.0268	0.0775	0.1031
	(0.0002)	(0.0008)	(0.0048)

Experiment III: Vary Appropriability Conditions, Patent System

- **Description of the experiment**
  - patent length: firms that innovate cannot be imitated for a fixed number of periods
  - patent breadth: firms cannot innovate around other firms' technology
- **Results**
  - patents reduce average growth rate of GDP and increase unemployment
  - if we add patent breadth, GDP growth rate falls further and unemployment rises further

Description	Avg. GDP Growth	GDP Std. Dev. (bpf)	Avg. Unempl.
benchmark scenario	0.0252	0.0809	0.1072
	(0.0002)	(0.0007)	(0.0050)
patent (length only)	0.0242	0.0761	0.1132
	(0.0002)	(0.0008)	(0.0060)
patent (breadth, too)	0.0163	0.0631	0.1329
	(0.0001)	(0.0007)	(0.0067)

Experiment IV: Vary Entrants' Expected Productivity

- **Description of the experiment**
  - technological entry barriers are captured by the probability distribution over the "technological draw" of entrants
  - we change the expected productivity of entrants shifting the mass of the Beta distribution
- **Results**
  - GDP growth rises, GDP volatility and unemployment fall as the expected productivity of entrants increases

Description	Avg. GDP Growth	GDP Std. Dev. (bpf)	Avg. Unempl.
benchmark scenario	0.0252	0.0809	0.1072
	(0.0002)	(0.0007)	(0.0050)
low entrant exp. prod.	0.0183	0.0798	0.1402
	(0.0003)	(0.0012)	(0.0084)
high entrant exp. prod.	0.0376	0.0697	0.0853
	(0.0002)	(0.0006)	(0.0047)

Experiment V: Altering Selection Mechanisms

capital-good Industry: Antitrust Policy

- **Description of the experiment**
  - capital-good firms with a market share higher than a fixed threshold cannot add new customers
- **Results**
  - antitrust policy spurs GDP growth and it reduces both unemployment rate and output volatility

Description	Avg. GDP Growth	GDP Std. Dev. (bpf)	Avg. Unempl.
benchmark scenario	0.0252	0.0809	0.1072
	(0.0002)	(0.0007)	(0.0050)
weak antitrust	0.0265	0.0698	0.1036
	(0.0002)	(0.0006)	(0.0043)
strong antitrust	0.0273	0.0508	0.0837
	(0.0001)	(0.0005)	(0.0036)

Are Schumpeterian Technology Policies Enough?

- **So far we have found that Schumpeterian policies has both long-run and short-run effects**
- **However, such results are conditional on a “Keynesian machine” well in place**
- **What happen if we switch that off?**
- **More generally, do Keynesian fiscal policies have also long-run effects?**

Experiment VI: Keynesian Demand Macro Management Policies, Eliminate Public Sector

- **Description of the experiment:**
  - we begin eschewing the public sector from our model
  - we then “drug up” the economy with Schumpeterian policies (high opportunities and high search capabilities)
- **Results**
  - Evidence of multiple growth paths: Keynesian policies are necessary to support sustained long-run economic growth
  - Schumpeterian policies are not enough to push the economy away from low growth trajectories

Description	**Avg. GDP Growth**	**GDP Std. Dev. (bpf)**	**Avg. Unempl.**
benchmark scenario	0.0252	0.0809	0.1072
	(0.0002)	(0.0007)	(0.0050)
no fiscal policy	0.0035	1.5865	0.8868
	(0.0012)	(0.0319)	(0.0201)
Schumpeter drugged-up	0.0110	1.5511	0.7855
(no fiscal policy)	(0.0018)	(0.0427)	(0.0274)

Experiment VII: Keynesian Demand Policies, Changing Taxes and Unemployment Benefits

- **Description of the experiment**
  - we increase both taxes and unemployment benefits by the same amounts vis-à-vis the “canonic” parameterization
- **Results:**
  - tuning up fiscal demand management does delock the economy from the low growth trajectory and brings it to the high growth one
  - avg. GDP growth almost the same, but Keynesian policies have countercyclical effects dampening cyclical fluctuations and reducing unemployment
- **More generally, strong complementarity between “Keynesian” policies affecting demand and “Schumpeterian” policies affecting innovation**

Keynesian Demand Macro Management Policies

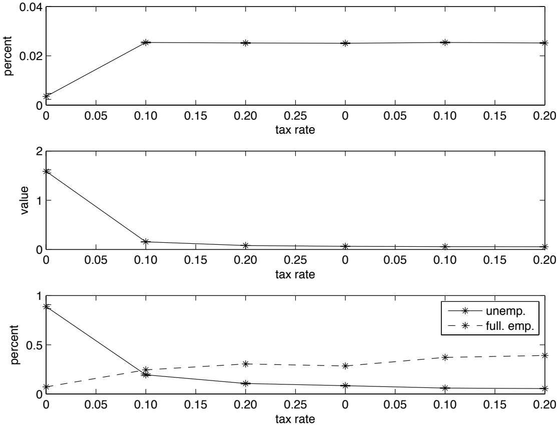


Figure: Results are obtained under balanced budget ratios of expenditures (taxes) to GDP.

Experiment VIII: Monetary Policy, Changing the Interest Rate

- **Description of the experiment**
  - we tune the interest rate level in the “canonic” parametrization
  - we repeat the same experiment for different levels of firms’ mark-ups (0.10,0.20)
- **Results**
  - Rising (lowering) the interest rate increases (reduces), GDP volatility, the unemployment rate and the likelihood of crises.
  - Further evidence on multiple growth paths: high levels of interest rates lock the economy on a low-growth trajectory.
  - Conjectural evidence on output volatility: high levels of interest rates tend to exacerbate long-term fluctuations.
  - lower mark-up levels dampen business cycle fluctuations (redistributive effect).

Description	Avg. GDP Growth	GDP Std. Dev. (fd)	GDP Std. Dev. (bpf)	Avg. Unempl.	Prob. of large neg. growth (< -3%)
High Mark-Up (0.20)					
r=0.00001	0.0277	0.0773	0.0749	0.0382	0.1618
r=0.05	0.0277	0.0750	0.0739	0.0435	0.1488
r=0.1	0.0277	0.0772	0.0760	0.0538	0.1431
r=0.15	0.0288	0.1158	0.0777	0.0488	0.2102
r=0.2	0.0291	0.1796	0.0898	0.0604	0.2799
r=0.35	0.0250	0.2674	0.2056	0.1333	0.3699
r=0.4	**0.0144**	0.2658	0.3633	0.3549	0.3878
Low Mark-Up (0.10)					
r=0.00001	0.0274	0.0573	0.0541	0.0191	0.1012
r=0.05	0.0281	0.0540	0.0469	0.0145	0.0908
r=0.1	0.0290	0.0664	0.0505	0.0180	0.1329
r=0.15	0.0298	0.1464	0.0623	0.0217	0.2439
r=0.2	0.0288	0.3015	0.1460	0.0586	0.3885
r=0.35	**0.0099**	0.2798	0.4164	0.4546	0.4482
r=0.4	**0.0010**	0.2752	0.4268	0.6346	0.4711

Table: Effects of interest rate for different mark-up levels

Experiment IX: Monetary Policy, Changing Mandatory Reserve Rates

- **Description of the experiment**
  - we tune the mandatory reserve rate in the "canonic" parametrization
  - we repeat the same experiment for different levels of interest rates and firms' mark-ups (0.10,0.20)
- **Results:**
  - rising (lowering) the mandatory reserve rate reduces (increases), GDP volatility
  - the effects are more significant for lower level of mark-ups and higher level of interest rates
  - however, relatively low sensitivity of real variables to changes in reserve requirements

Summary

- **The misleading dichotomy between growth and business cycle theories (and related policies)**
- **What we did:**
    - develop an agent-based model (**K+S model**) able to reproduce a great deal of micro and macro stylized facts
    - employ the model to design different policies and study both their short- and long-run implications

Summary - Results

- **The K+S model robustly reproduces micro and macro regularities and can be successfully exploited to perform policy analyses**
- **Strong complementarity between Schumpeterian and Demand policies**
  - innovative opportunities as necessary but not sufficient condition for growth
  - Keynesian fiscal and monetary policies (especially interest rates) do not only stabilize but affect also the long-run.
- **Conjectures on interactions between income distribution and growth**
  - Lower mark-ups move the distribution of productivity gains towards wages, thus stabilizing consumption, aggregate demand and output
  - However, at the same time they reduce firms' internal funds thereby increasing the sensitivity of firms' balance sheets to changes in interest rates and to credit availability.

Future Works

1. **Extensions of the model:**
   - explicitly modelling labor markets
   - banking sector with heterogeneous banks
   - further explore the role of expectations
2. **Compare different institutional specifications:**
   - endogenous vs. exogenous technological frontier
3. **Performing other policy experiments:**
   - further monetary policy effects (e.g. Basel capital requirements)
   - poverty traps and development