An Agent-based SFC Model for Secular Stagnation in the USA

Theory and Empirical Evidence

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Summary

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Secular Stagnation in the ACE models: research questions

- Many economists refer to current times as a period of Secular Stagnation, since the achievement of adequate growth, capacity utilisation and financial stability appears hard at best (Summers, 2014).
- Little attention to the interplay between functional distribution of income, innovation and productivity: lack of a demand-side channel.
- Research questions: in which way does the distribution of income between wages and profits affect the innovative pattern of an economy and the subsequent attainments in productivity? Is it plausible that the decrease in the labour share impacted negatively on innovation activities and productivity through a demand channel? May Secular Stagnation have originated from that?
- In what follows, we frame Secular Stagnation in the ACE perspective, but is it really necessary? Does it allow to show insights not visible with standard methodologies?

Why agent-based models? I

The adoption of agent-based models needs to be justified ...

- Macro-to-micro channel: the social conflict occurs at the macro level and affects entrepreneurial decisions from a cost and a revenue side.
- Micro-to-macro channel: firms competitiveness, market structure affect innovation and productivity dynamics at the aggregate level. Secular Stagnation takes the specific form of productivity matter.
- ABM v. Representative-Agent Models: lack of micro-heterogeneity and Solow's call for more realistic micro-foundations.
- ABM v. Aggregate Models: micro-foundation is absent and similar aggregate outcomes can arise from very different micro-economic configurations.

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Relation with the literature

Several fields define the background literature ...

- Literature on Secular Stagnation (Gordon, 2015; Hein, 2016), here defined as the tendency to the long-term slowdown in the growth rates of labour productivity and TFP, started in the '70s.
- Schumpeterian and evolutionary literature (Aghion and Howitt, 2008; Bowles, 2009; Schumpeter, 1982) : innovation as an uncertain process; complex modes of behaviour.
- AB literature (Caiani et al., 2016b; Dosi et al., 2010): systems populated by many heterogenous agents without any central coordination; K + S models.
- AB-SFC literature (Caiani et al., 2016a): improvements of previous models.

Some data about wages, innovation and productivity I

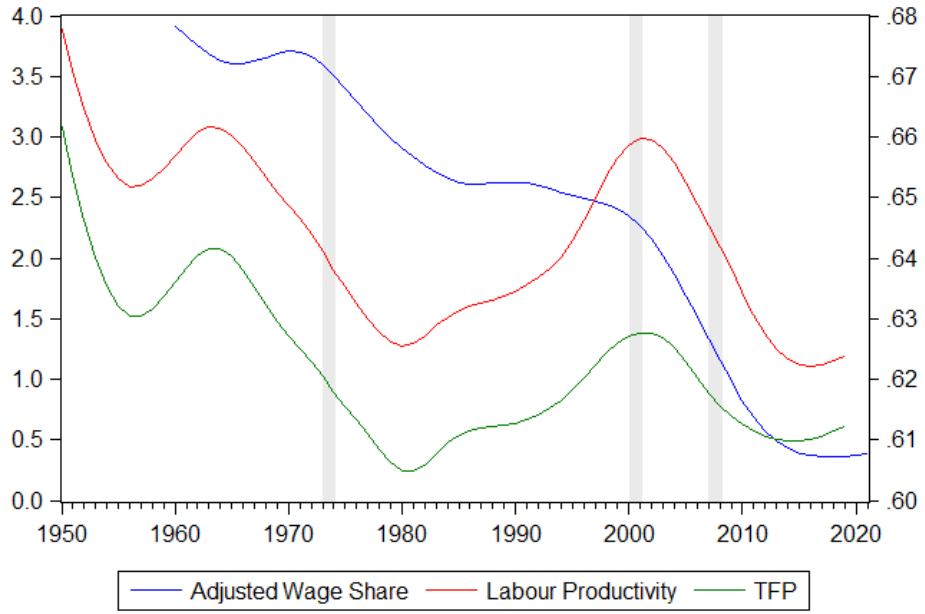

Figura: Left axis refers to productivity growth rates, right axis to the wage share. Source: Ameco and BLS data.

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Some data about wages, innovation and productivity II

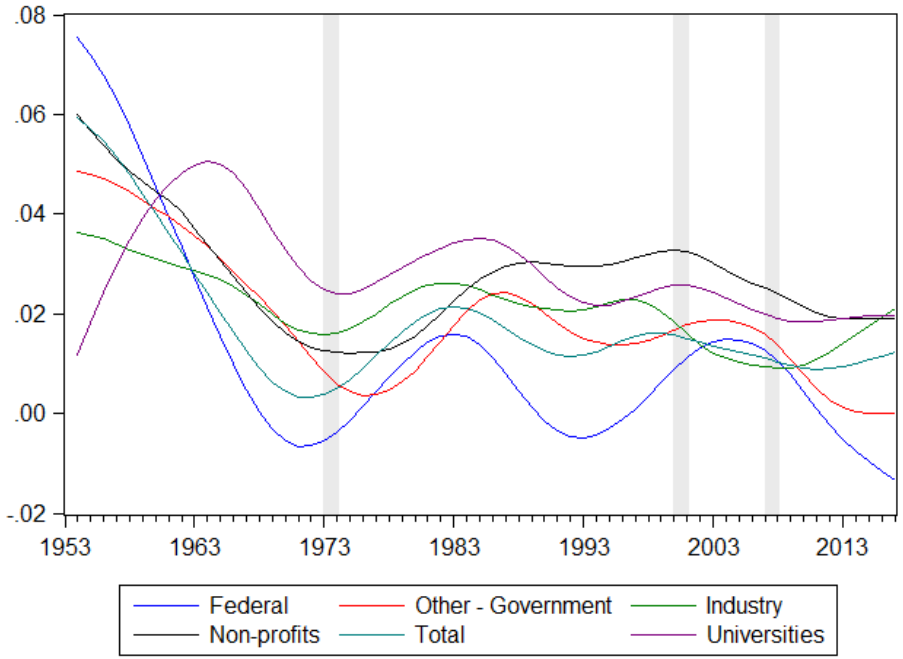

Figura: US R&D expenditures by source, 1953 – 2018. Source: AAAS data.

Some data about wages, innovation and productivity III

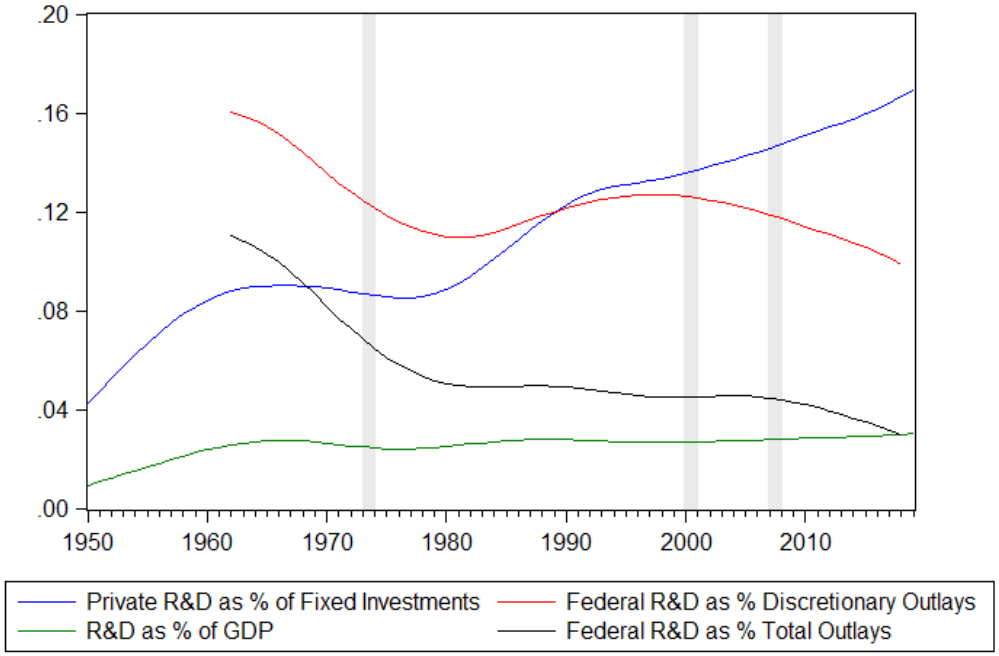

Figura: US R&D share, 1950 – 2018. Source: AAAS data.

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Cast of the model I

- One-good two-class closed economy with no government sector. The model is complex, adaptive and structural in line with (Tesfatsion, 2006)
- Homogeneous good either for consumption or for investment purposes.
- A collection N of households: $N - F$ workers and F capitalists. The status differs according to the propensity to save. Everybody consumes and saves.
- A collection F of firms owned by capitalists: they produce, invest and apply for loans.
- An accommodating bank supplies funds to firms and collects savings from households at given interest rates.

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Cast of the model II

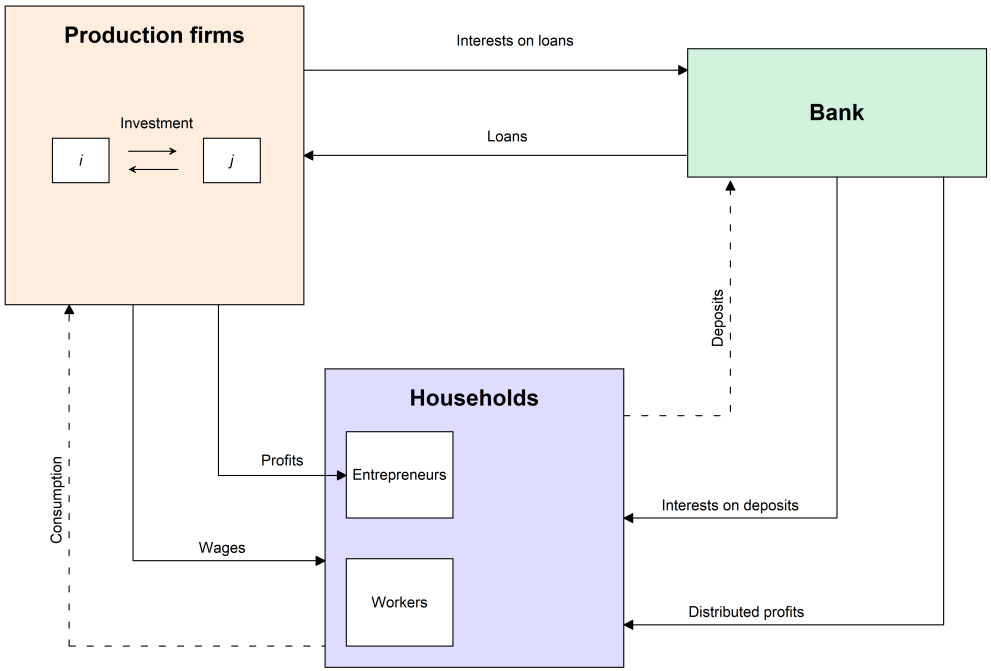

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Figura: Arrows point from paying sectors to receiving sectors.

Markets of interaction

Agents interact on five markets:

- (Capital) good market: firms interact with each other to buy and sell goods.
- (Consumption) good market: households purchase the good from firms.
- Labour market: entrepreneurs hire and fire workers. No full employment.
- Credit market: bank provides firms with loans.
- Deposit market: bank gathers households' savings as deposits.

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Timeline of events

Production firms receive a unit of (capital) good at $t = t_0$, thereafter:

- Firms compute their target level of capital stock.
- Capitalists draw from previous accumulated profits and borrow funds from the banking system to set up production.
- Workers receive a wage. Agents spend part of it for consumption and save what left.
- The bank collects interest payments from firms and pay interests to households. Managers receive a profit as residual claim.
- Firms update production plans and perform R&D. Achievements available at $t + 1$, if any.

Equations: production firms I

How do entrepreneurs take their decisions about production and investments?

- Production at firm level:

$$y_j = c_{f,j} + i_{s,j} + i_{rd,j} \tag{1}$$

- Leontief technology:

$$y_j^P = \min\left[\phi \cdot k_j; a_j \cdot N_s\right] \tag{2}$$

- Amortization fund for depreciation:

$$da_j = \delta \cdot k_{-1,j} = af_j \tag{3}$$

- R&D investment:

$$g_{ird,j} = \theta_0 \cdot \bar{g}_{y,j} + \theta_1 \cdot \left(\frac{\bar{\rho} - \rho}{\bar{\rho}}\right) \tag{4}$$

- Physical investment:

$$i_{k,j} = i_{0,j} + i_{1,j} \cdot \left(k_j^T - k_j\right) + af_j \tag{5}$$

Equations: production firms II

- Entrepreneurial profits:

$$f_j = y_j - af_j - int_{ld,j} - wb_j \tag{6}$$

- Investment demand:

$$i_{d,j} = i_{k,j} + i_{rd,j} \tag{7}$$

- Investment-good production:

$$i_{s,j} = \bar{i}_{k,j} \tag{8}$$

- Capital stock:

$$k_j = (1 - \delta) \cdot k_{-1,j} + i_{k,j} \tag{9}$$

- Change in loans demand:

$$dl_{d,j} = i_{d,j} - af_j - q \cdot mh_{-1,j,e} \tag{10}$$

Equations: labour market

Real wage does not clear the market in a Walrasian fashion to ensure the full employment of labour.

- Labour demand:

$$nd_j = \frac{y_j}{a_j} \tag{11}$$

- Wage evolution:

$$g_{w_r} = w_1 - w_2 \cdot u_{r,t-1} \tag{12}$$

- Wage rate

$$w_r = w_0 e^{g_{w_r} t} \cdot pr_t \tag{13}$$

- Wage bill at firm level

$$wb_j = w_r \cdot nd_j \tag{14}$$

Households and consumption I

Households are distinguished according to their propensity to save out of income.

- Disposable income:

$$\mathrm{ydh_i} = \begin{cases} \mathrm{w_r} + \sigma_{\mathrm{mh,i}} \cdot \mathrm{F_{b,t}} + \mathrm{int_{mh,i}} & \text{if i is worker} \\ \mathrm{f_i} + \sigma_{\mathrm{mh,i}} \cdot \mathrm{F_{b,t}} + \mathrm{int_{mh,i}} & \text{if i is capitalist} \end{cases} \tag{15}$$

- Consumption functions:

$$\mathrm{c_{inc,i}} = \begin{cases} \alpha_0 + \alpha_{1,\mathrm{i}} \cdot \mathrm{w_{r,-1}} + \alpha_{3,\mathrm{i}} \cdot \left(\sigma_{\mathrm{mh,i}} \cdot \mathrm{F_{b,t}} + \mathrm{int_{mh,i}}\right) & \text{if i is worker} \\ \alpha_0 + \alpha_{2,\mathrm{i}} \cdot \mathrm{f_{i,-1}} + +\alpha_{3,\mathrm{i}} \cdot \left(\sigma_{\mathrm{mh,i}} \cdot \mathrm{F_{b,t}} + \mathrm{int_{mh,i}}\right) & \text{if i is capitalist} \end{cases} \tag{16}$$

$$\mathrm{c_{wea,i}} = \alpha_{3,\mathrm{i}} \cdot \mathrm{m_{h,-1,i}} \tag{17}$$

$$\mathrm{c_i} = \mathrm{c_{inc,i}} + \mathrm{c_{wea,i}} \tag{18}$$

Households and consumption II

- Savings:

$$dm_{h,i} = ydh_i - c_i \tag{19}$$

- Deposits:

$$m_{h,i} = \begin{cases} m_{h,-1,i} + dm_{h,i} & \text{if} \quad i \quad \text{is worker} \\ m_{h,-1,i} + dm_{h,i} - q \cdot m_{h,-1,i} & \text{if} \quad i \quad \text{is capitalist} \end{cases} \tag{20}$$

- Firms-consumers matching protocol:

$$\text{Prob} = \begin{cases} 1 - e^{\chi_1 \cdot \frac{p_{new} - p_{old}}{p_{new}}} & \text{if} \quad p_{new} < p_{old} \\ 0 & \text{otherwise} \end{cases} \tag{21}$$

Equations: innovation dynamics I

- Firms invest on R&D to earn (extra-)profits and save manpower.
- Schumpeterian innovation and Knightian uncertainty.
- Some definition:
  - a_j = effective labour productivity of the j^{th} firm at t.
  - a_{jj} = labour productivity of the j^{th} firm as result of own R&D
  - a_{ji} = labour productivity of the j^{th} firm due to imitation.
  - $a_j = a_{jj} = a_{ji} = 1$ at $t = t_0$.
- Logistic law of innovation:

$$\lambda_j = \frac{1}{1 + e^{-\epsilon \cdot \sum_1^t i_{rd,j}}} \tag{22}$$

- If $p_{inn} < \lambda_j$, then labour productivity becomes:

$$a_{jj} = a_{-1,jj} \cdot e^{g_{ird,-1,j}} \tag{23}$$

Equations: innovation dynamics II

- Imitation process: random meetings. Once a link is established, each firm has a probability to imitate following the same law above. No free-rider. Finally, the firm chooses whether to imitate:

$$a_j = \max\left[a_{jj}; a_{ji}\right] \tag{24}$$

Equations: banking system

To keep things as simple as possible, a big bank accommodates demand for loans from business sector:

- Interests on loans:

$$\mathrm{int}_{\mathrm{ld,j}} = \mathrm{r_l} \cdot \sigma_{\mathrm{ld,j}} \cdot \mathrm{L_{d,t-1}} \tag{25}$$

- Interests on deposits:

$$\mathrm{int}_{\mathrm{mh,j}} = \mathrm{r_h} \cdot \sigma_{\mathrm{mh,j}} \cdot \mathrm{M_{h,t-1}} \tag{26}$$

- Bank profits:

$$\mathrm{F_{h,t}} = \mathrm{r_l} \cdot \mathrm{L_{d,t-1}} - \mathrm{r_h} \cdot \mathrm{M_{h,t-1}} \tag{27}$$

Equations: pricing and inflation expectations I

How do firms set prices?

- Unit price:

$$p_j = (1 + \mu_j) \cdot \frac{w_r}{a_j} \tag{28}$$

- Mark-up evolution:

$$g_{\mu,j} = v \cdot (\sigma_{m,j} - \bar{\sigma}) \tag{29}$$

- Average price level:

$$\bar{p}_t = \frac{1}{F} \sum_j^F p_j \tag{30}$$

- Inflation rate:

$$\pi_t = \frac{\bar{p}_t}{\bar{p}_{t-1}} - 1 \tag{31}$$

Equations: pricing and inflation expectations II

- Regressive inflation expectations:

$$\pi^{e} = \psi_0 + \psi_1 \cdot \left(\pi^{T} - \pi_{t-1}\right) + \pi_{t-1} \tag{32}$$

- Expected price level

$$p_t^{e} = (1 + \pi^{e}) \cdot \bar{p}_{t-1} \tag{33}$$

- Inflationary-correcting term for k^{T} and w_r:

$$pr_t = \frac{p_t^{e}}{\bar{p}_t} \tag{34}$$

Notes on the baseline setting

Empirical validation:

- 400 simulations on quarterly basis with 100 Monte Carlo runs.
- System of equations with no closed-form solutions.
- SFC norms are respected either on aggregate or on micro level.
- The model exhibits endogenous and self-sustained growth.
- Capability to match a wide spectrum of stylized facts.

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Stylized facts: a recap

Tabella: Stylized facts matched by the model

Stylized facts	References
Micro-economic level (firms)	
Skewness and heavy tailed-ness in firm size distribution	Bottazzi and Secchi (2003, 2006)
Moments of size distribution are stationary (but not the mean)	Bottazzi and Secchi (2003); Dosi et al. (2010)
Heterogeneous productivity and Laplace-distributed growth rates	Bartelsman and Doms (2000); Bottazzi and Secchi (2003)
Investment heterogeneity and lumpiness	Caballero (1999); Doms and Dunne (1998)
Persistence of R&D	Caballero and Hammour (1991); Harhoff (2000); Le Bas and Scellato (2014)
Macro-economic level (aggregate)	
Endogenous and self-sustained growth	Caiani et al. (2019); Dosi et al. (2010)
Fluctuations at business-cycle level	Caiani et al. (2016a); Dosi et al. (2010); Stock and Watson (1999)
Stock-flow consistency	Godley and Lavoie (2006)
Output, investment, consumption and unemployment are non-stationary	Blanchard and Summers (1986); Hamilton (2020); Nelson and Plosser (1982)
Cross-correlation among macro-variables	Stock and Watson (1999)
Pro-cyclical R&D	Wälde and Woitek (2004)
Volatility of output, investment, consumption and unemployment	Caiani et al. (2016a); Dosi et al. (2010); Stock and Watson (1999)

Macroeconomic stylized facts I

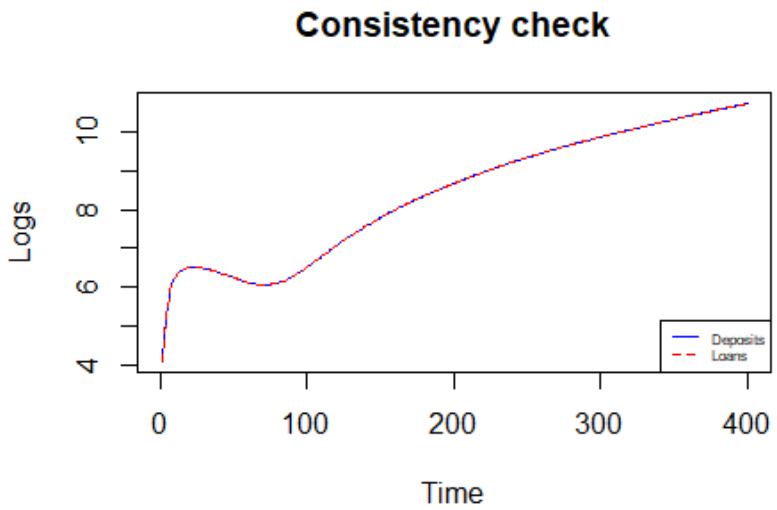

Figura: Stock-flow consistency

- Deposits equal loans every period.

Macroeconomic stylized facts II

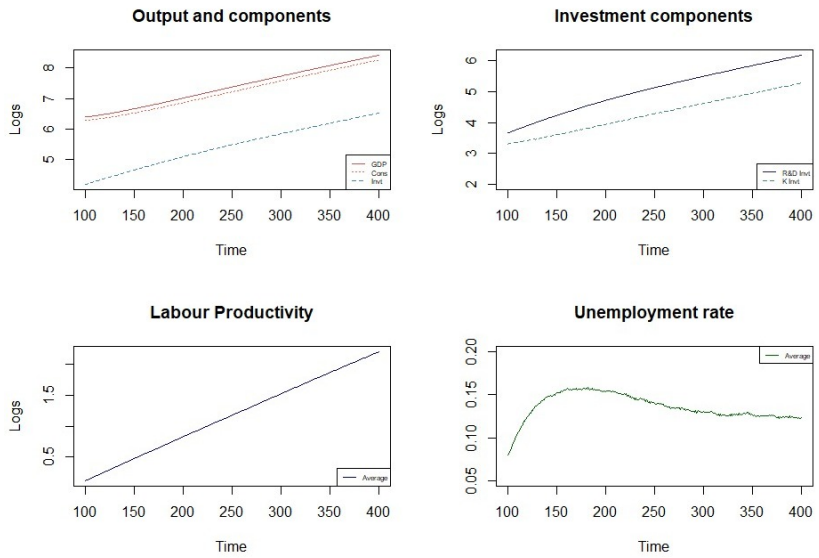

Figura: Baseline model: levels in log terms

- Endogenous and self-sustaining growth path with fluctuations at business-cycle frequencies; Harrod instability does not arise.

Macroeconomic stylized facts III

Tabella: Output, investment, consumption and unemployment statistics

	Output	Investment	Consumption	Unemployment
Average	0.011	0.006	0.008	0.125
ADF test	−0.832	−0.094	−1.649	−1.365
	(0.809)	(0.948)	(0.457)	(0.60)
KPSS test	2.472	2.474	2.472	0.359
	(0.739)	(0.739)	(0.739)	(0.347)

Note: averages refer to growth rates for output and its components. P-values and critical value at 1% in brackets for the ADF and the KPSS tests, respectively. For what concerns to the unemployment rate, KPSS critical value corresponds to 10% significance level.

- Simulated time series present strictly positive average growth rates and exhibit a unit root.

Macroeconomic stylized facts IV

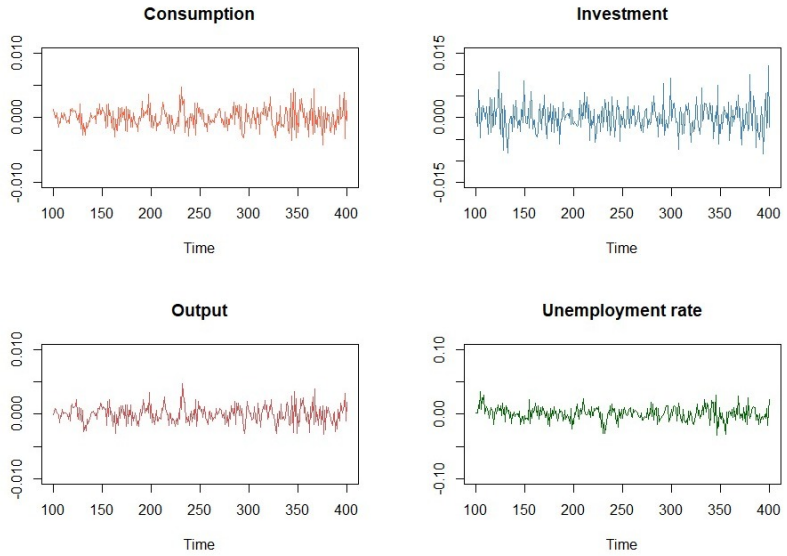

Figura: Cyclical components of simulated time series for some aggregate variables

- Unemployment and investments are more volatile than output and consumption (look at the y-axis!).

Macroeconomic stylized facts V

Tabella: Correlation structure

Series (HP cycle)	Output (HP cycle)										
	t − 5	t − 4	t − 3	t − 2	t − 1	t	t + 1	t + 2	t + 3	t + 4	t + 5
Consumption	−0.035	0.045	0.268*	0.401*	0.814*	0.88*	0.578*	0.36*	0.172*	0.036	−0.066
Investment	0.103	0.155*	0.326*	0.391*	0.696*	0.601*	0.13*	−0.051	−0.208*	−0.264*	−0.28*
Output	−0.07	0.045	0.214*	0.429*	0.724*	1*	0.724*	0.429*	0.214*	0.045	−0.07
K Investment	0.108	0.166*	0.323*	0.405*	0.685*	0.632*	0.287*	0.007	−0.232*	−0.323*	−0.354*
R&D Investment	0.077	0.11	0.273*	0.3*	0.593*	0.447*	−0.15*	−0.139*	−0.131*	−0.121	−0.11
Productivity	0.078	0.11	0.273*	0.299*	0.595*	0.445*	−0.154*	−0.141*	−0.132*	−0.122*	−0.109
Unemployment rate	0.137*	0.085	0.124*	−0.009	0.071	−0.286*	−0.737*	−0.485*	−0.314*	−0.165*	−0.067

Note: star for statistical significance at 5%.

- Investments and labour productivity are pro-cyclical and leading, while consumption synchronize with the business cycle.
- Unemployment is counter-cyclical and lagging.
- R&D is pro-cyclical.

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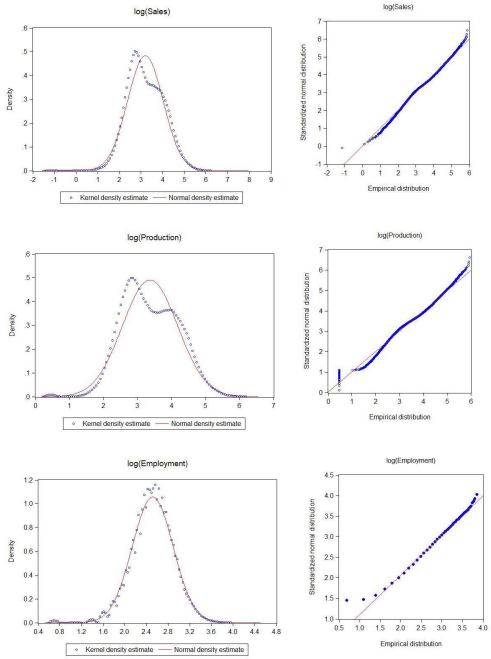
Microeconomic stylized facts I



- Firms' size follows a log-normal shape.

Microeconomic stylized facts II

Tabella: Moments of (log)size distribution

	Consumption		Production		Employment	
	Trend β	ADF test	Trend β	ADF test	Trend β	ADF test
Mean	0.006	0.791	0.006	0.876	−0.0001	−4.109
	(0.000)	(0.994)	(0.000)	(0.995)	(0.014)	(−0.001)
Standard deviation	0.003	−4.812	0.0002	−5.527	0.0001	−8.429
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Skewness	0.001	−18.765	0.001	−10.828	0.001	−10.978
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Kurtosis	8.10E − 05	−18.426	0.0003	−17.820	0.001	−17.815
	(0.900)	(0.000)	(0.390)	(0.000)	(0.106)	(0.000)

Note: p-values in brackets.

Microeconomic stylized facts III

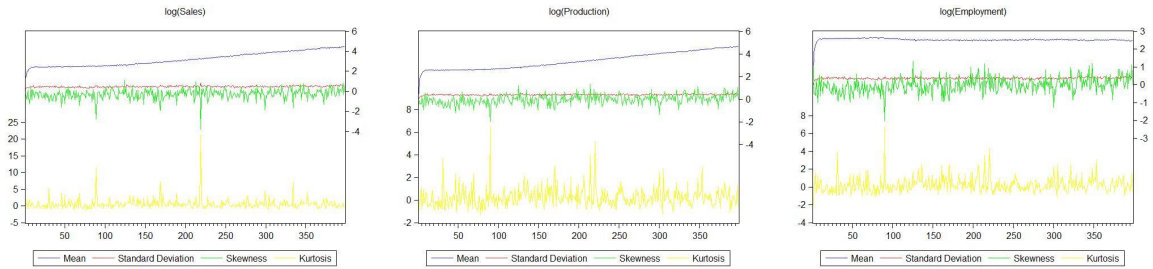


Figura: Moments of firm size distribution

- All moments but mean are stationary processes.

Microeconomic stylized facts IV

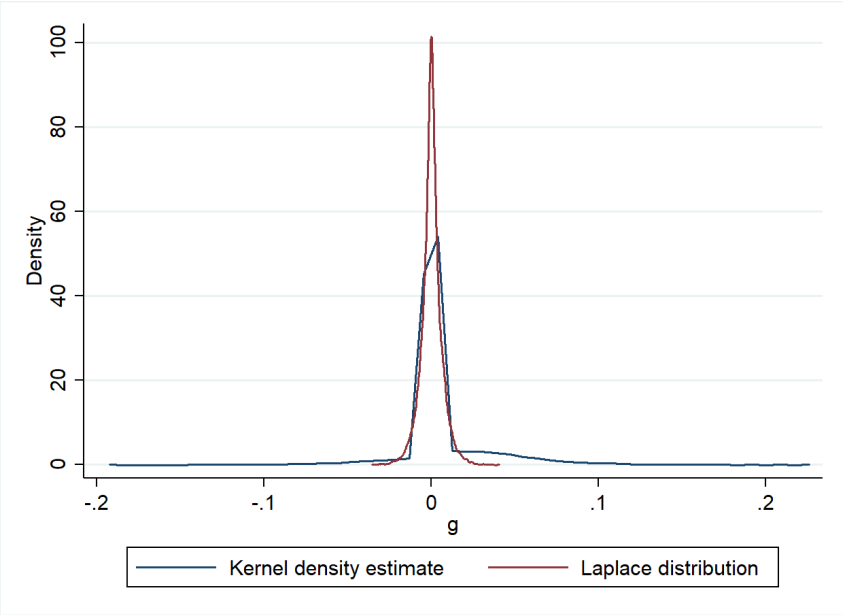


Figura: Productivity growth distribution

- Productivity at firm-level follows a Laplace distribution.

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Microeconomic stylized facts V

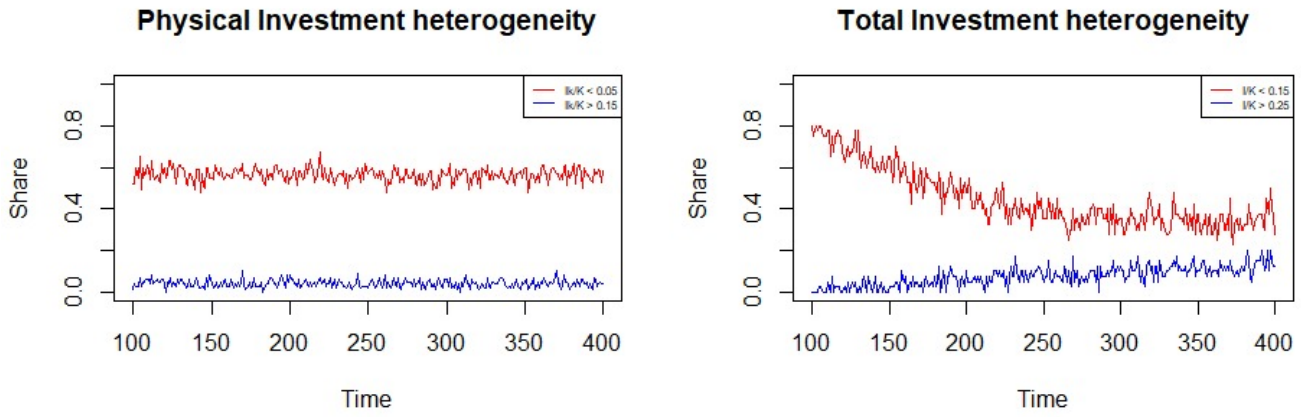

Figura: Investment heterogeneity

- Firms experiencing investment spikes co-exist with firms having near-zero investment.

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Microeconomic stylized facts VI

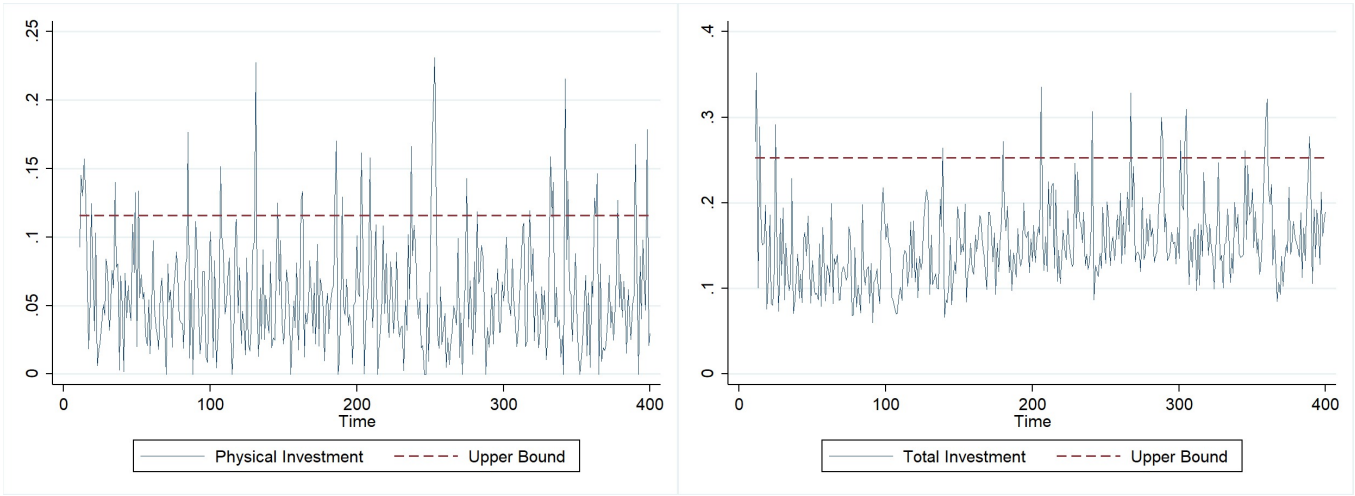

Figura: Investment lumpiness

- Investment lumpiness: how can it arise with linear physical-investment function?
- Discontinuities owing to firms-consumers matching and innovation diffusion.

Microeconomic stylized facts VII

Tabella: R&D persistence at firm level

Panel unit root test	LLC	IPS	ADF-Fisher χ^2	PP-Fisher χ^2
R&D	32.422	13.322	1.229	72.702
	(1.000)	(1.000)	(1.000)	(0.706)

Note: numbers in brackets denote p-values; we adopt the Schwarz-Bayesian criterion to select the optimal lag length. The null hypothesis assumes a common unit root process in the LLC test, while individual unit root process in the others.

- Evidence of R&D persistence at firm-level: tendency to smooth innovative spending over than business cycle.

Policy Experiments and scenarios

Two policy experiments:

1. a variety of values for the exogenous coefficient of the wage equation, w_1;
2. a variety of values for the interest rate on loans, r_l;

The role of income distribution: policy experiment on w_1 (a)

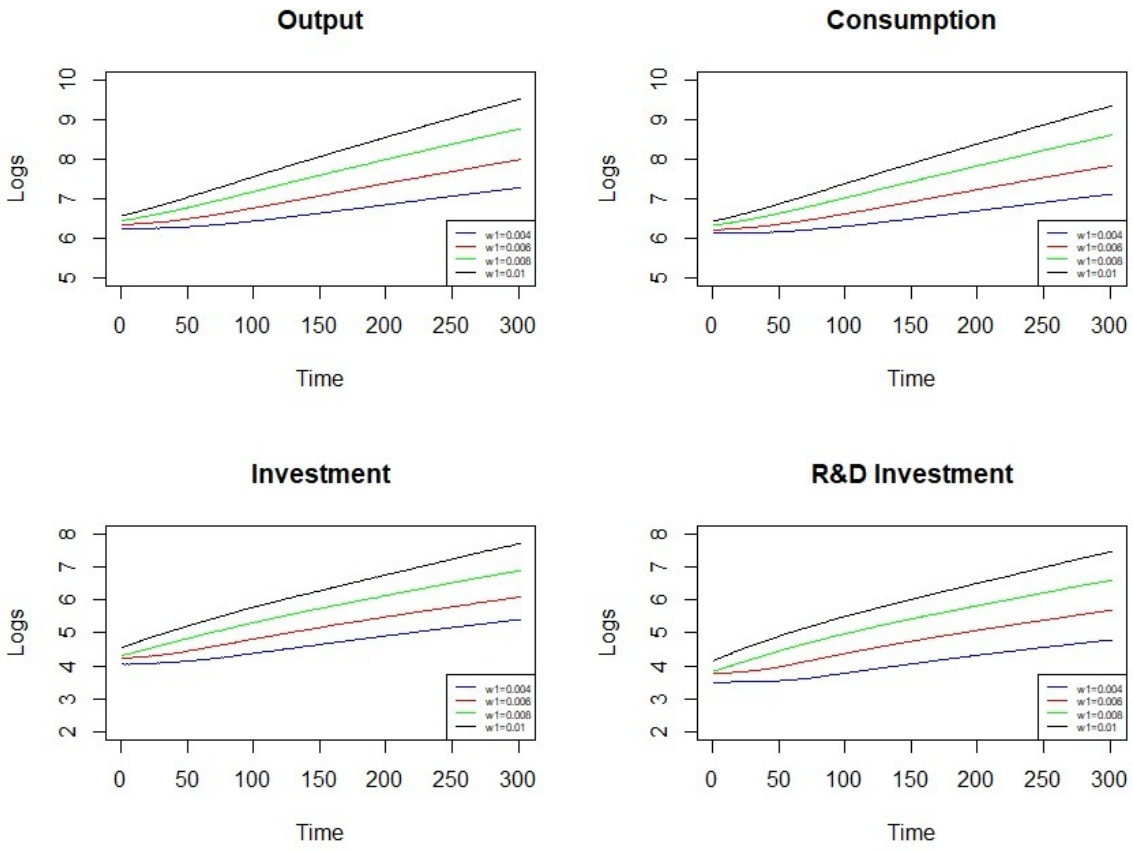

Figura: Change in the parameter w_1.

The role of income distribution: policy experiment on w_1 (b)

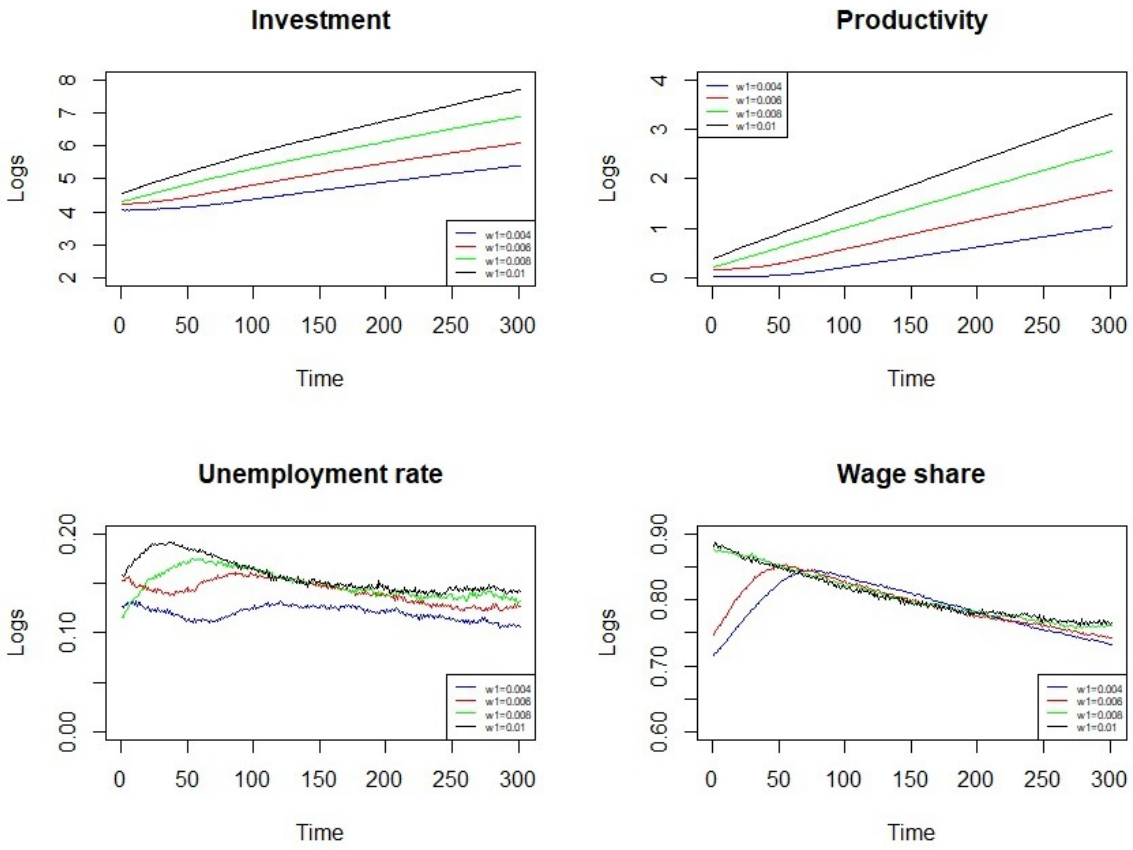

Figura: Change in the parameter w_1

The role of interest rates: policy experiment on r_l (a)

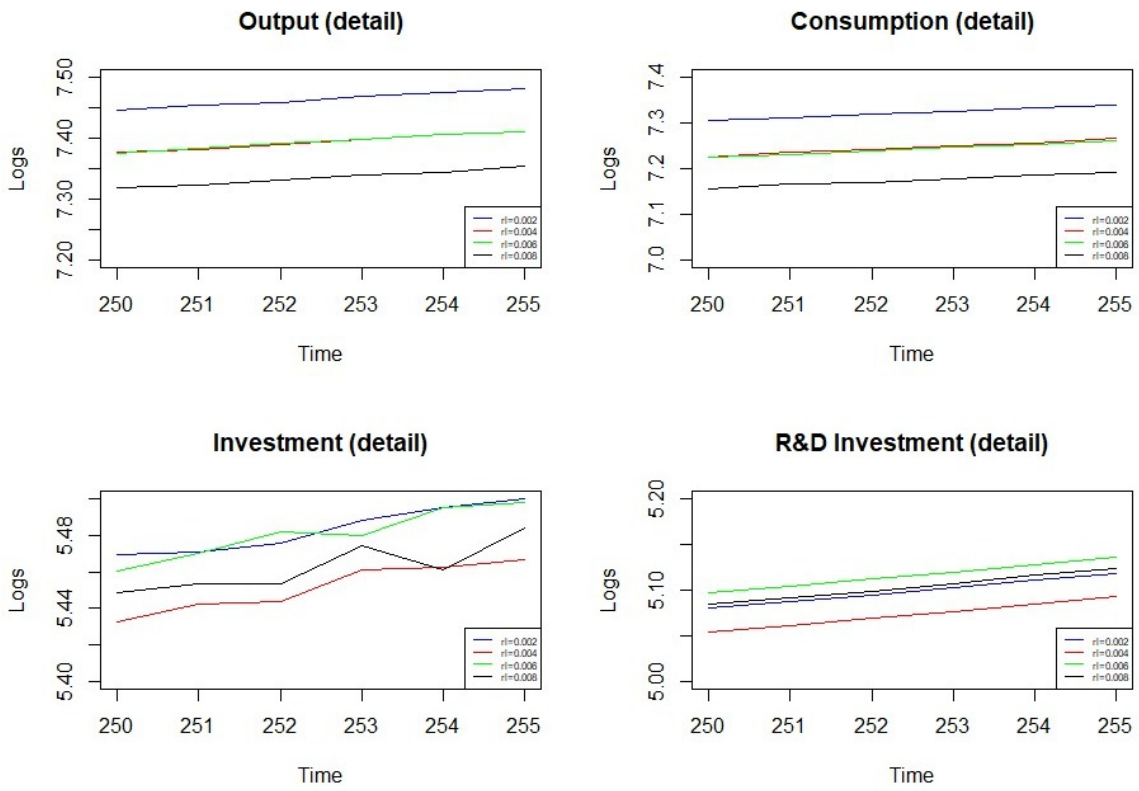

Figura: Change in the parameter r_l

The role of interest rates: policy experiment on r_l (b)

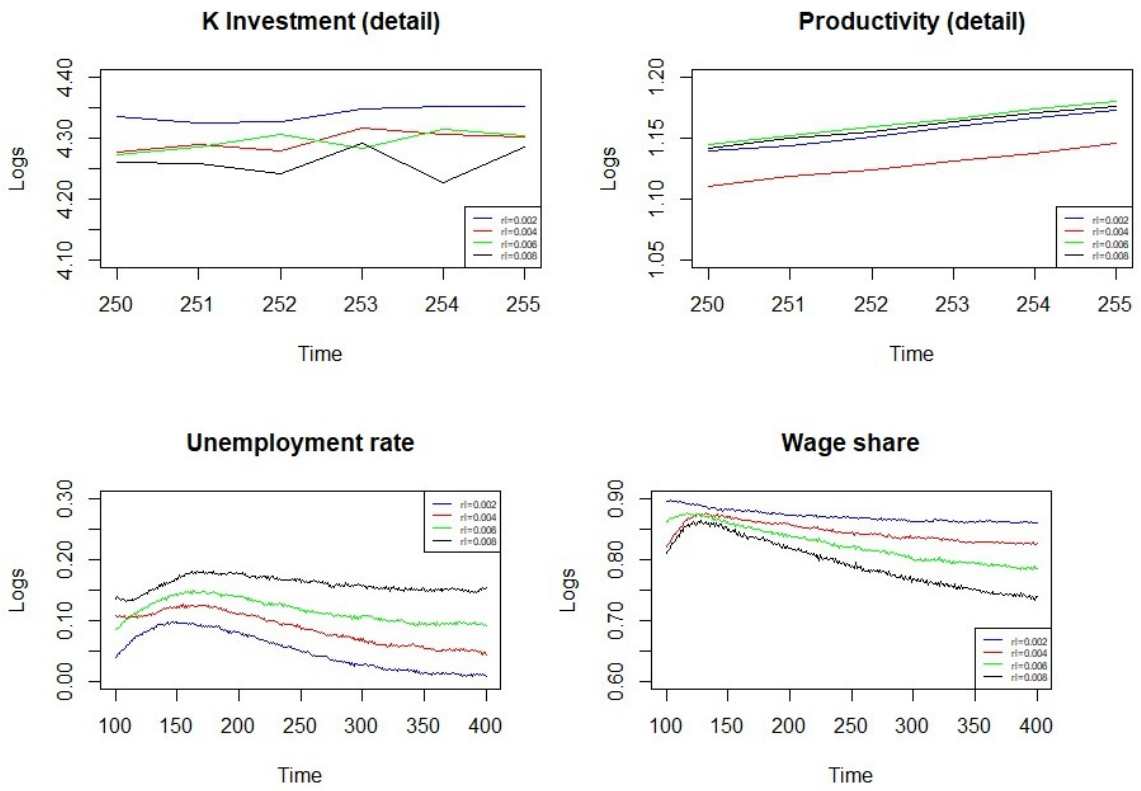

Figura: Change in the parameter r_l

(Main) Policy Experiments: a recap ...

All in all ...

- Pro-worker measures foster economic development, innovation, but not unemployment rates and lead to further capital accumulation.
- The interest rate has a non-linear and small effect upon innovation efforts: contrasting movement between revenue and cost components.
- Other admissible rationales from the literature: lower top marginal tax rates, increased low-skill immigration, rising trade with China and low-cost manufacturing countries, rise of superstar firms (Autor et al., 2020)

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Some econometrics ...

To corroborate our theoretical results on distributive policies, we carry out a simple panel cointegration analysis:

- 14 US ISIC-based manufacturing industries over the period $1958 - 2011$.
- R&D industrial expenditure data are from NSF SIRD and OECD Anberd surveys.
- Wages, productivity, shipments data are from NBER Manufacturing Productivity database.
- Econometric relationship:

$$\begin{aligned} \mathrm{rd}_{it} = \beta_{0,t} + \beta_{1,t}\mathrm{w}_{i,t} + \beta_{2,t}\mathrm{s}_{i,t} + \beta_{3,t}\mathrm{d73w}_{i,t} + \\ + \beta_{4,t}\mathrm{d07w}_{i,t} + \beta_{5,t}\mathrm{d73s}_{i,t} + \beta_{6,t}\mathrm{d07s}_{i,t} + \mu_i + \epsilon_{i,t} \end{aligned}$$

Panel cointegration: results

Tabella: Estimation results

Dependent variable: R&D	PMG		FOLS		DOLS	
	Model I	Model II	Model III	Model IV	Model V	Model VI
w	0.7195***	0.7849***	0.8538***	0.8123***	0.7836***	0.3299
	(0.1105)	(0.1238)	(0.1207)	(0.1609)	(0.1424)	(0.2989)
s	0.2728***	0.1562	0.1968	0.2446**	0.2449*	0.6007**
	(0.1084)	(0.1081)	(0.123)	(0.1249)	(0.1422)	(0.2704)
d73w		0.1257		−0.0002		0.0993
		(0.0914)		(0.1209)		0.2393
d07w		−0.2997**		0.0893		0.0085
		(0.01176)		(0.0907)		(0.1825)
d73s		0.0062		−0.0052		0.0097
		(0.0049)		(0.0081)		(0.0140)
d07s		0.0715**		0.0292		−0.0178
		(0.0293)		(0.0224)		0.1098
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Speed of adj, ϕ	−0.4320***	0.4319***				
	(0.0778)	(0.0844)				
Log likelihood	426.2998	481.2157				
Observations	606	606	622	622	619	622
Periods	53	53	53	53	53	53
Cross-sections	14	14	14	14	14	14

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Panel cointegration: robustness check

Tabella: Estimation results: robustness check

Dependent variable: R&D	PMG		FOLS		DOLS	
	Model I	Model II	Model III	Model IV	Model V	Model VI
w_{adj}	0.2624	1.1128^{***}	0.5202^{***}	0.4709^{*}	0.3226	3.4086^{*}
	(0.2264)	(0.3331)	(1.0264)	(0.2802)	(0.2530)	(1.9437)
s	1.0232^{***}	0.9458^{***}	1.0264^{***}	0.9599^{***}	1.0244^{***}	1.4508^{***}
	(0.0305)	(0.0391)	(0.0350)	(0.0433)	(0.0000)	(0.2138)
$d73w_{adj}$		0.0436		0.4807^{**}		-3.1643
		(0.2769)		(0.2291)		(1.9565)
$d07w_{adj}$		0.5039^{**}		0.3711^{***}		1.1510^{*}
		(0.2553)		(0.1452)		(0.6234)
d73s		0.0227		0.0582^{*}		-0.4852^{**}
		(0.0377)		(0.0321)		(0.2197)
d07s		0.0915^{***}		0.0787^{***}		0.1170
		(0.0331)		(0.0221)		(0.0800)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Speed of adj, ϕ	-0.4150^{***}	-0.4182^{***}				
	(0.0986)	(0.1006)				
Log likelihood	382.8508	433.3805				
Observations	606	606	622	622	616	622
Periods	53	53	53	53	53	53
Cross-sections	14	14	14	14	14	14

Panel cointegration: innovation and interest rates

Tabella: R&D and interest rates: Pedroni panel cointegration tests.

	R&D - effr		R&D - bplr	
	Statistics	(Weighted) Statistic	Statistics	(Weighted) Statistic
Panel v-stat	−1.5239	−1.6006	−1.9609	−1.9631
Panel ρ-stat	0.2014	0.2013	1.7243	1.7355
Panel PP-stat	−0.6616	−0.7286	1.2104	1.1888
Panel ADF-stat	−0.5265	−0.3897	1.5646	1.7473
Group ρ-stat	1.7623		3.0944	
Group PP-stat	0.0297		2.1218	
Group ADF-stat	0.1082		2.5287	

Conclusions and future steps

- Secular Stagnation set into an evolutionary framework and provided some insights to explain the problems that affect US economy since 1972.
- I developed a simple AB-SFC model to analyze the relationship between income distribution, innovation and productivity growth.
- Main result: redistributions of income more favourable to profits hamper firm's innovative activity and the system will experience lower growth rates in terms of productivity.
- As side result, the interest rate has non-linear effects either on innovative efforts and economic growth.
- I found favourable empirical evidence on a panel of US manufacturing industries since 1958 for our predictions.

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