An Interregional-Intersector Agent-Based Model with Schumpeterian Growth and Keynesian Cycles

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IO Workshop
Osnabrück March 2020

Motivations

1. Heterogeneity as the key feature to understand regional economic dynamics
   - Micro behaviors and interactions giving rise to (relatively) smooth macro phenomena
   - Reconciling micro and macro evidence stemming from recent regional economic dynamics
   - Difficulties in foreseeing microeconomic characteristics in a macroeconomic setup for ex ante policy evaluation
2. Globalization, technical change and interregional inequality
   - Interregional and international value chains as a defining characteristics of the world economy
3. Growth and cycles as intertwined economic phenomena

Building Blocks of ABMs

1. bottom-up perspective
2. heterogeneous agents
3. bounded rationality
4. learning
5. direct, endogenous interactions
6. evolving complex system approach
7. non linearity
8. "true" dynamics
9. endogenous and persistent novelty
10. selection-based market mechanisms

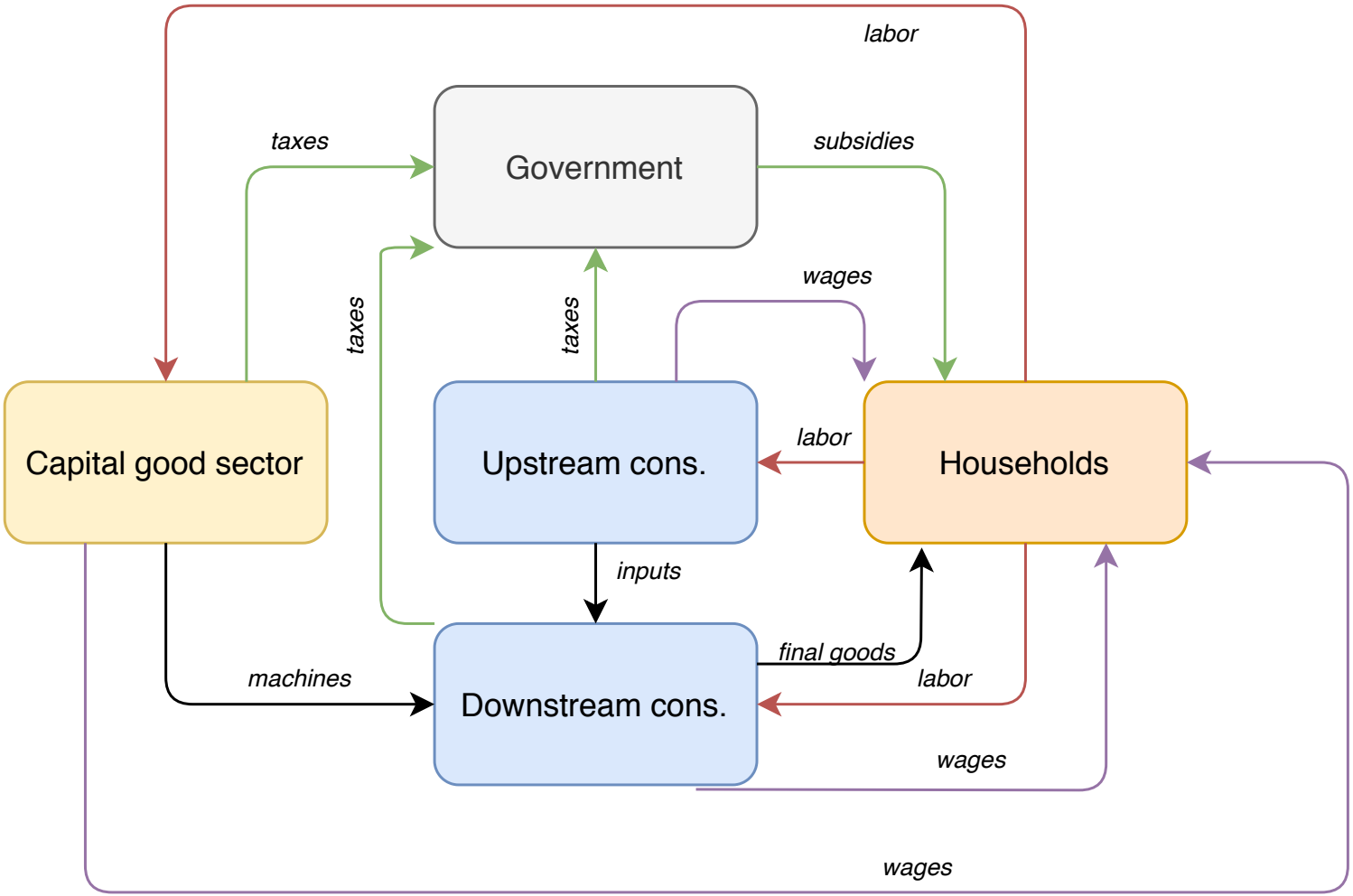
The Basic Structure of a macroeconomic ABM

1. Time $t = 0, 1, 2, ..., T$
2. Sets of agents $I_t = 1, 2, ..., N_t$
3. Initial conditions $\underline{x}_{i,0}$
4. Micro decision rules
5. Vectors of micro-parameters $\underline{\theta}_i$
6. Interaction structures
7. Sets of micro states $\underline{x}_{i,t}$
8. Vector of macro-parameters $\underline{\Theta}$
9. Aggregate variables $\underline{X}_t$

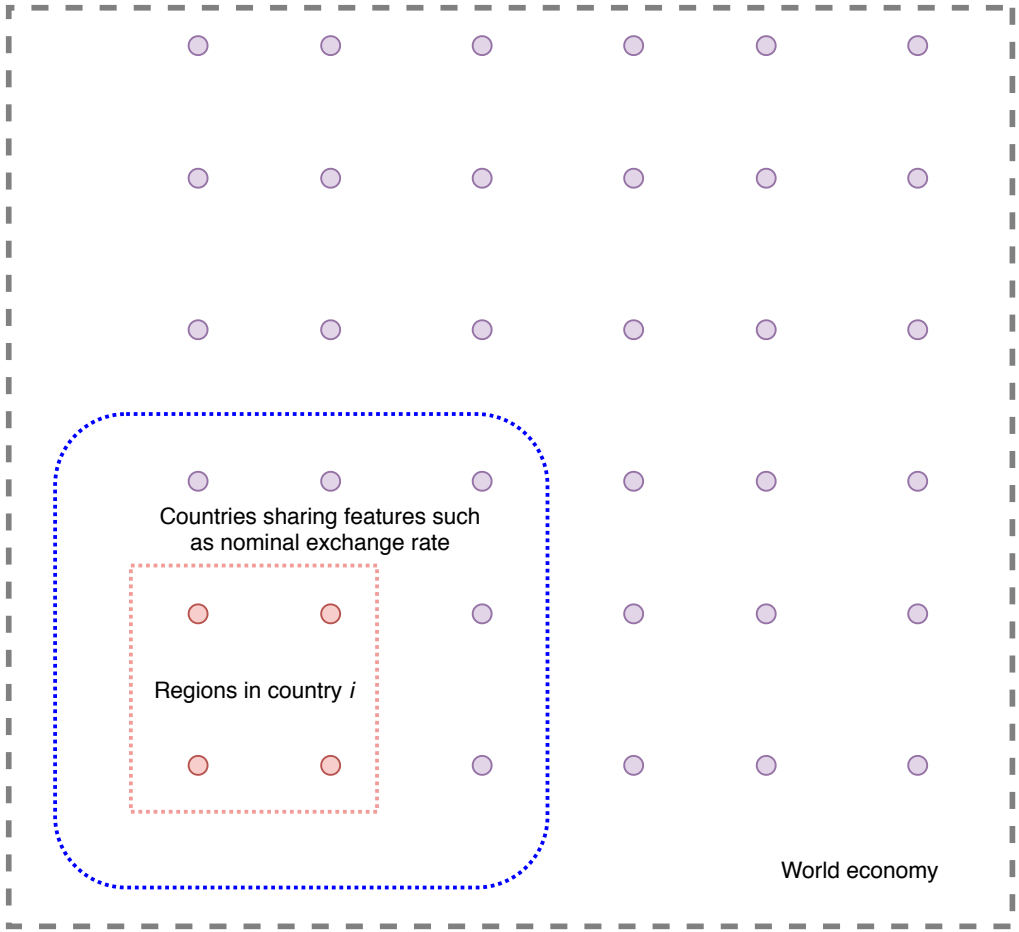
Our work

1. We design an interregional-intersector agent-based model starting from the K+S agent-based model (ABM, Dosi, Fagiolo & Roventini, 2010)
2. We implement the intersector core of the ABM and:
   - demonstrate that the model is able to replicate a large number of macro and micro stylized facts (validation)
   - perform a bunch of experiments so as to assess both the long-run and the short-run engines of the model
3. We define an agenda for implementing the interregional module

An intersector K+S ABM



The interregional structure on the lattice



→ Distances, nominal exchange rates, tariffs, infrastructures, information and communication technologies

Timeline of events

1. Machine-tool firms and intermediate good firms perform R&D
2. Capital-good firms and intermediate good firms advertise their machines and intermediates to downstream firms, after selecting their preferred suppliers
3. Downstream firms decide how much to produce, invest, demand in terms of intermediate goods.
4. If investment is positive, downstream firms choose their suppliers and send their orders.
5. Downstream firms set the demand to intermediate good firms.
6. The intermediate good firms, on the basis of received orders, decide how much to produce.
7. Workers are hired by downstream firms, intermediate good firms and capital good firms and start production.
8. Imperfectly competitive downstream good market opens. The market shares of firms evolve according to their price competitiveness.
9. Entry and exit take places in downstream, intermediate and capital good sectors.
10. Machines ordered at the beginning of the period are delivered and become part of the capital stock at time $t + 1$

Capital goods: 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):

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

Capital goods: 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)

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 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

Intermediates: Technical change I

- **Intermediate-good firms search for more efficient production techniques**
  - $B_z(t)$: productivity of production technique of firm z
  - $B_z(t)$ determines the technology of firm z at time t

- **R&D:**
  - R&D investment (RD) is a fraction of firm sales (S):

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Intermediates: 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 $IN_z(t)$:
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  $$\theta_2(t) = 1 - e^{-o_2 IM_z(t)} \qquad o_2 > 0$$
  2) firms are more likely to imitate competitors with similar technologies (Euclidean distance)
- **Brochure:** Each time period intermediate good firms send brochures communicating the price to a subset of potential clients.

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):

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

Consumption-Good Markets

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

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

$$c_j = \frac{w * \eta_l}{A_i} + p^{z,j} * \eta_z$$

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

  $\alpha > 0$; 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):

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

Entry Scenarios

1. **Fully random:**
   - entrant is a random copy of an incumbent

2. **More complex:**
   - 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

Labor Market

- Exogenous labor supply
- Wage dynamics determined by avg. productivity, inflation and unemployment

$$\frac{\Delta w(t)}{w(t-1)} = \pi^T + \psi_1 * (\pi_t - \pi^T) + \psi_2 * \frac{\Delta \overline{AB}(t)}{\overline{AB}(t-1)} - \psi_3 * \frac{\Delta U(t)}{U(t-1)}$$

- Involuntary unemployment + possibility of labor rationing

Closing the Model: The Macro Framework

- **Fiscal policy and the public budget:**
  - constant tax and unemployment-subsidy rate
  - the public deficit in each period is:

$$Def_t = -Tax_t + G_t$$

  - In more complex versions of K+S: government bonds
- **Monetary policy:**
  - fixed baseline interest rate
  - fixed spread on loans
  - In more complex versions of K+S: monetary rules
- **Employment, consumption, investment, inventories and GDP are obtained by aggregating micro quantities**

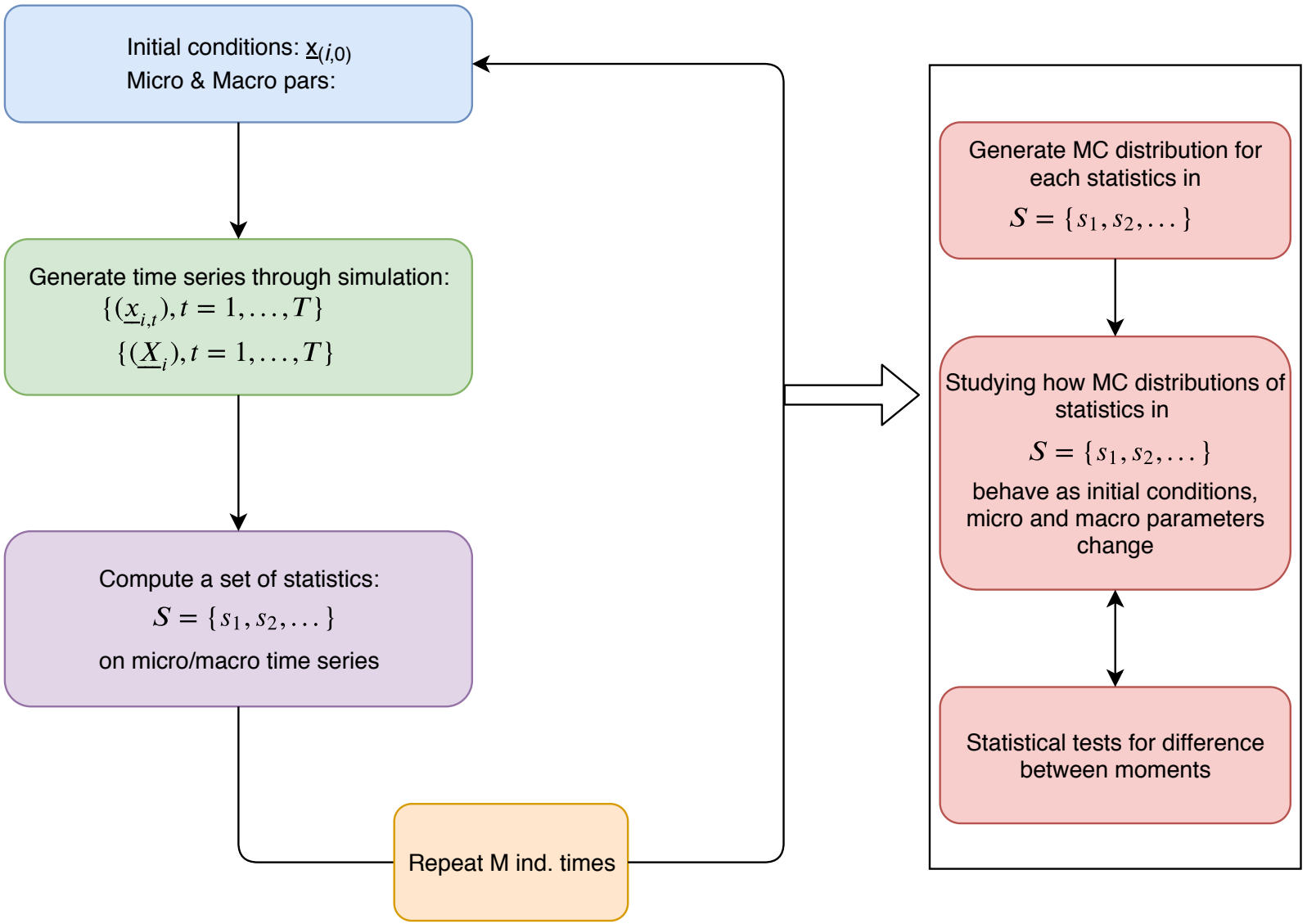
Benchmark parameters

Description	Symbol	Value
Number of firms in capital-good industry	F_1	50
Number of firms in consumption-good industry	F_2	200
Number of firms in upstream industry	F_3	50
R&D investment propensity	υ	0.04
R&D allocation to innovative search	ξ	0.50
Firm search capabilities parameters	$o_{1,2}$	0.30
Beta distribution parameters(innovation process)	$(\alpha_1, \beta_!)$	(3,3)
Beta distribution support(innovation process)	$[\overline{\chi_1}, \underline{\chi_1}]$	[-0.15,0.15]
New-customer sample parameter	γ	0.50
Capital-good firm mark-up	μ_1	0.04
Upstream firm mark-up	μ_3	0.04
Labor coefficient	η_l	1
Input coefficient (intermediates)	η_z	0.3
Desired inventories	ι	0.10
Mark-up coefficient	α	0.04
Competitiveness weights	$\omega_{1,2}$	1
Replicator dynamics coefficient	χ	1
Maximum debt/sales ratio	κ	2
Baseline interest rate	ir	0
Spread on baseline interest rate	r	0.01
Uniform distribution supports (consumption-good entrant capital)	$[\phi_1, \phi_2]$	[0.10,0.90]
Uniform distribution supports (entrant stock of liquid assets)	$[\phi_3, \phi_4]$	[0.10,0.90]
Beta distribution parameters (capital-good entrants technology)	(α_2, β_2)	(2,4)
Wage setting ΔAB weight	ψ_1	1
Wage setting Δcpi weight	ψ_2	0
Wage setting ΔU weight	ψ_3	0
Tax rate	tr	0.10
Unemployment subsidy rate	φ	0.40

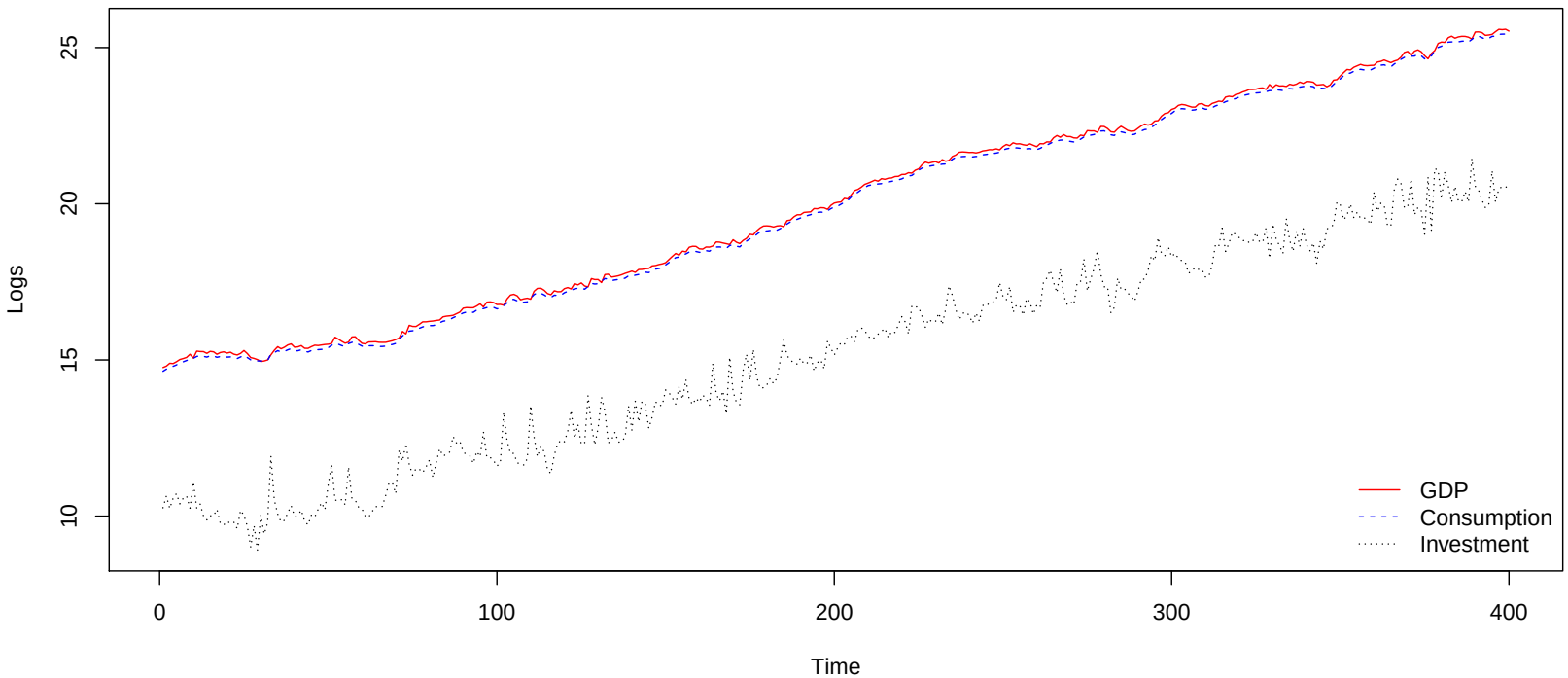
Validating an ABM

- **ABMs are much more complex than standard mainstream, e.g. RBC, macroeconomic models**
- **The model should then be able at least to match the same macroeconomic stylized facts of standard models**
- **The model should also be able to match the largest possible number of microeconomic stylized facts**
- **This is relevant because standard macroeconomic models are not usually able to match any microeconomic stylized fact**

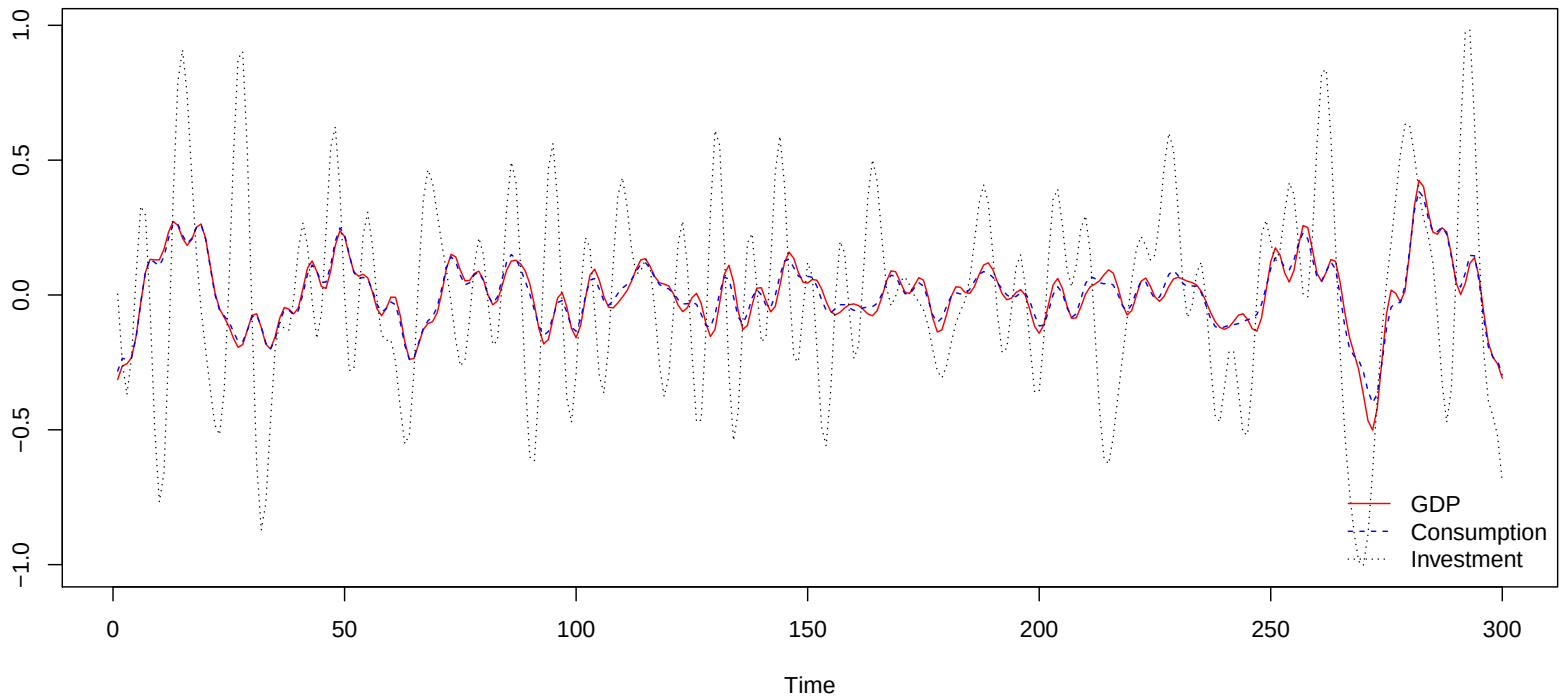
Validating an ABM



GDP, consumption and investment



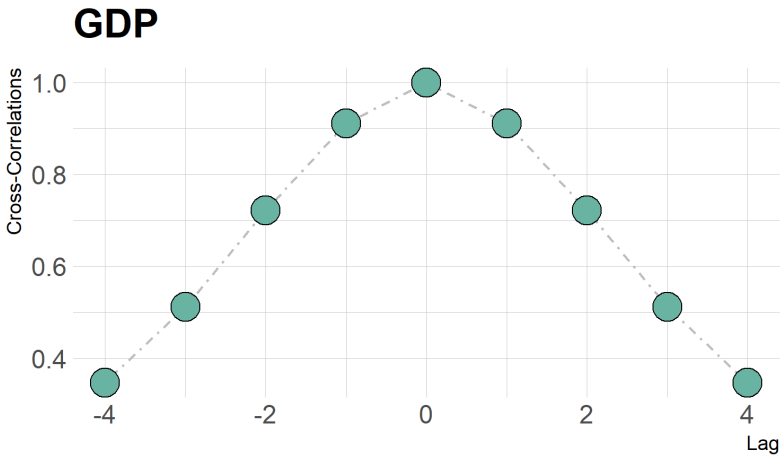
Business cycles

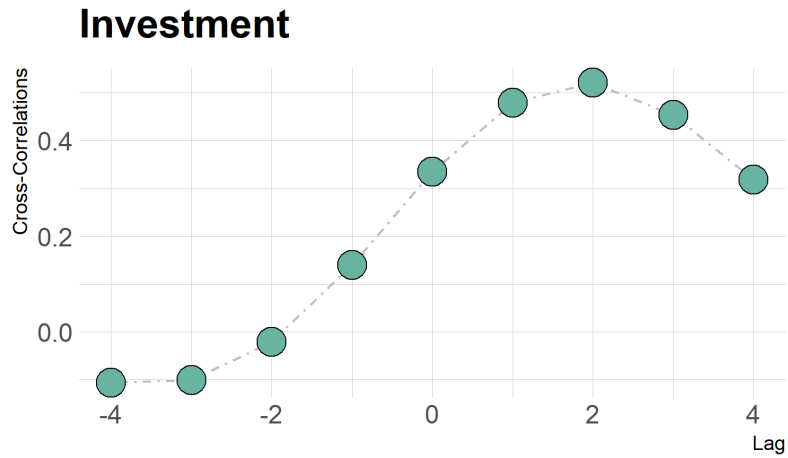


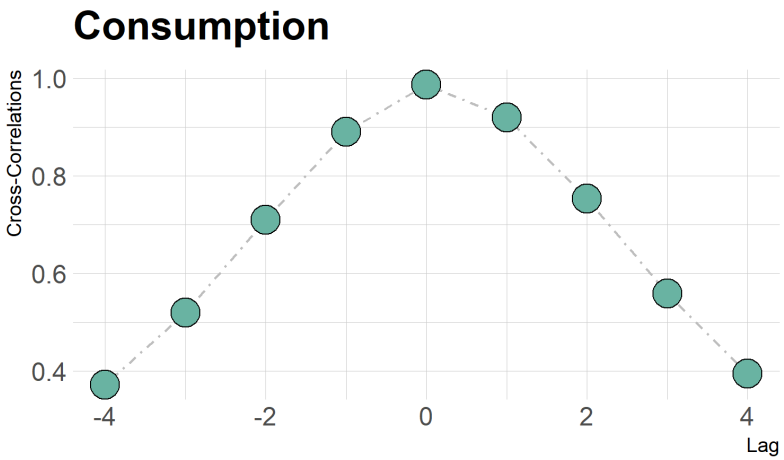
GDP, consumption and investment: growth and volatility

	GDP	Consumption	Investment
Avg. growth rate	0.0249	0.0250	0.0248
	(0.0002)	(0.0002)	(0.0003)
Dickey-Fuller test (logs)	-0.1867	-0.1542	-0.9109
	(0.0673)	(0.0756)	(0.0379)
Dickey-Fuller test (Bpf)	-2.7282	-3.1599	-3.9568
	(0.1102)	(0.0404)	(0.0337)
Std. dev. (Bpf)	0.1402	0.1320	0.3916
	(0.0012)	(0.0010)	(0.0084)
Rel. std. dev. (GDP)	1.0000	0.9429	2.8007

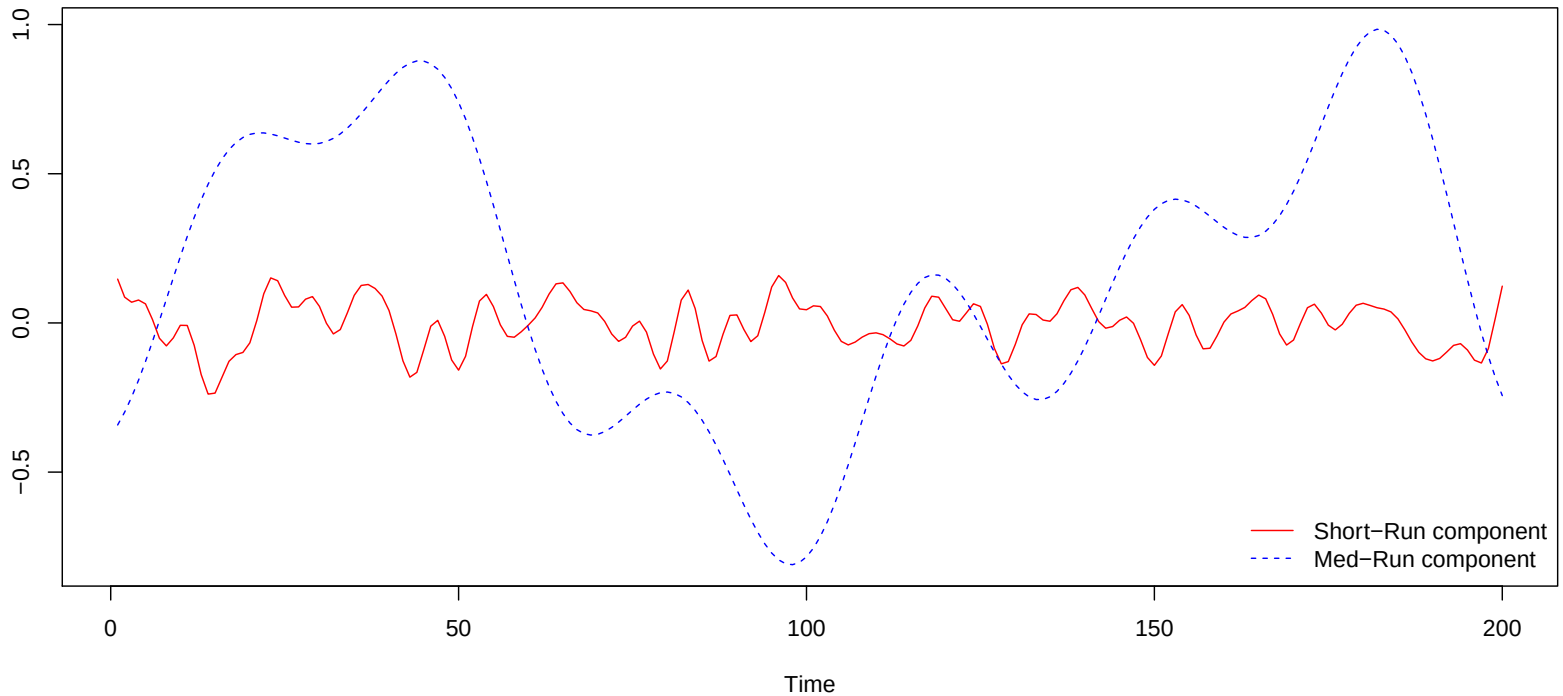
Cross-correlation coefficients





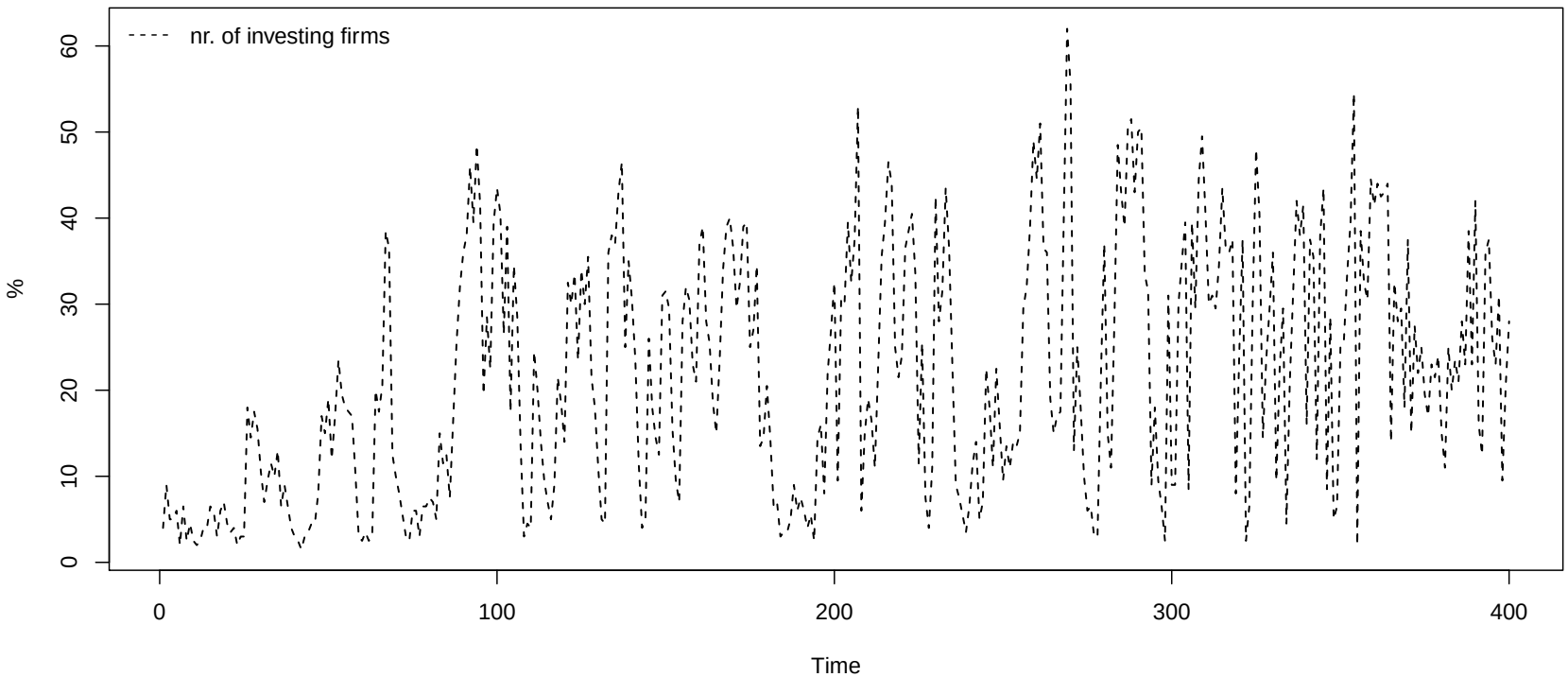


Medium term business cycles (Gertler & Comin, 2006)

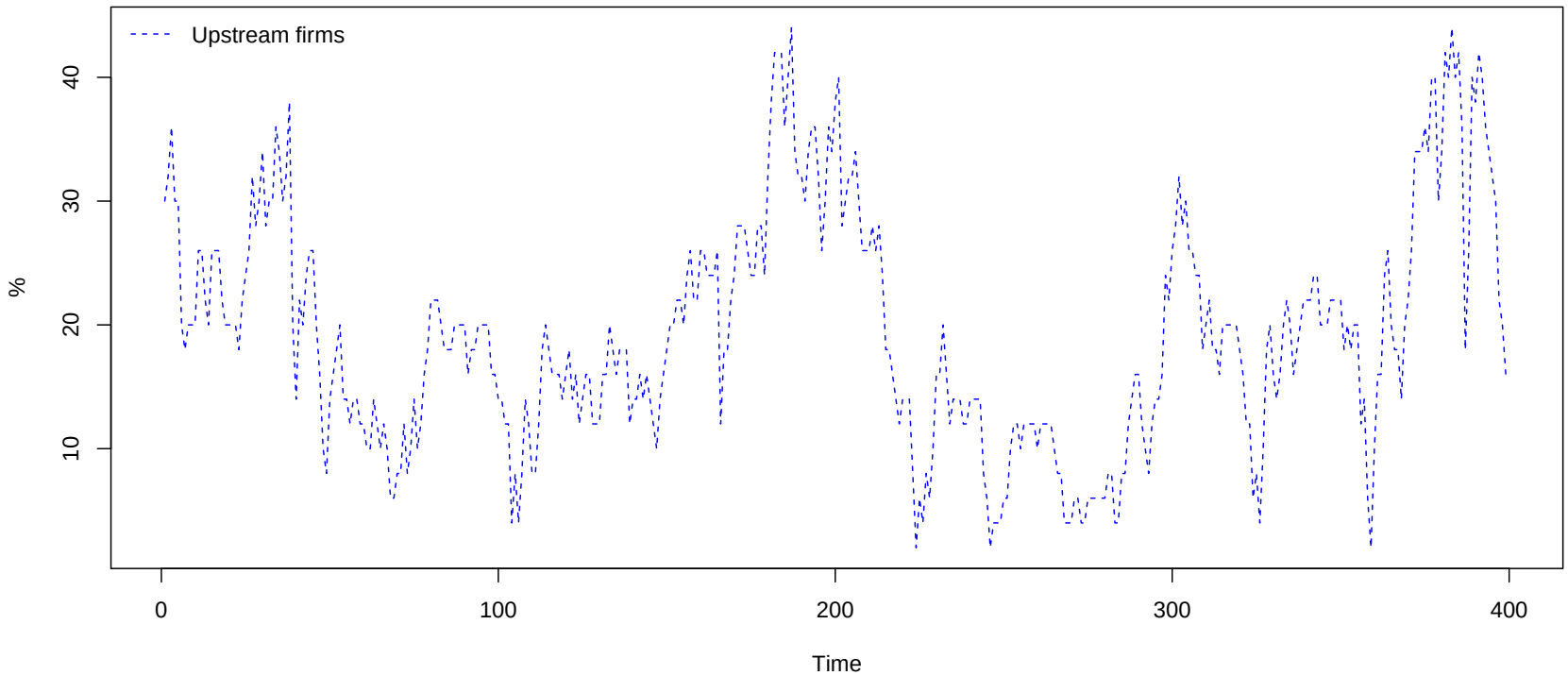


Cross-correlation with R&D expenditures in the mid-term: 0.85 (Capital good sector); 0.95 (Intermediate good sector)

Micro dynamics: investment is lumpy



Micro dynamics: mortality rates



MC avg. upstream firms: 12.3%

Scenario analysis

We analyze the model via a battery of alternative experiments so as to capture the role of the different engines of the simulated economy:

1. The Schumpeterian engine in the intermediate good sector: R&D expenditures and spending allocation between innovation and imitation
2. The role of fiscal policy: modifying taxes and unemployment benefits

Innovation in the intermediate-good sector

R&D	Innovation (vs. im.)	Avg. GDP growth	GDP std. dev. (Bpf)	Avg. Un.	Mortality (Upstream)
0.01	0.50	0.0249	0.1389	0.1102	
		(0.0002)	(0.0009)	(0.0067)	
0.04	0.50	0.0249	0.1402	0.1251	0.123
		(0.0002)	(0.0012)	(0.0066)	
0.10	0.50	0.0250	0.1389	0.1199	
		(0.0002)	(0.0010)	(0.0062)	
0.04	0.20	0.0249	0.1406	0.1145	
		(0.0002)	(0.0011)	(0.0064)	
0.04	0.80	0.0248	0.1386	0.1149	
		(0.0002)	(0.0010)	(0.0070)	
0.04	0.90	0.0255	0.1378	0.0928	0.157
		(0.0002)	(0.0010)	(0.0062)	

The role of fiscal policy

Tax rate	Un. subs.	Avg. GDP growth	GDP std. dev. (Bpf)	Avg. Un.
0.05	0.20	0.0252	0.1869	0.2097
		(0.0002)	(0.0025)	(0.0099)
0.10	0.40	0.0249	0.1402	0.1251
		(0.0002)	(0.0012)	(0.0066)
0.20	0.80	0.0254	0.1292	0.0540
		(0.0002)	(0.0007)	(0.0031)
0.25	1.00	0.0254	0.1287	0.0463
		(0.0002)	(0.0007)	(0.0025)

Preliminary conclusions and further steps

1. So far so good...
   - We presented a first version of an intersector ABM model designed to be the core of an interregional-intersector macroeconomic model
   - The model is able to replicate a set of macro and micro stylized facts
   - Via policy experiments we have demonstrated the power of the two engines (K+S) of the model
2. Next steps
   - The interregional side of the model: regions on the lattice
   - The energy sector and carbon emissions