Business cycle in a macromodel with oligopoly and agents heterogeneity: an agent-based approach – The making of the model

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Overview

Introduction

Let us describe how—concerning individual agents' behavior—the equations introduced in the analytical sections are here transformed, via a sequence of steps, into instructions for the agent-based simulation.

Introduction

The agent-based model uses the simulation shell SLAPP, online at `https://github.com/terna/SLAPP`.
SLAPP (Swarm-Like Agent Protocol in Python) has a Reference Handbook and it is deeply described in Chapters 2–7 in R. Boero, M. Morini, M. Sonnessa and P. Terna (2015), *Agent-based Models of the Economy–From Theories to Applications*, Palgrave Macmillan.

The calibration has been quite lengthy, spanning over the whole construction of the model, in five successive configurations documented at `https://github.com/terna/oligopoly`, where we report the "making of" the model, with all the calculating routines.

Overview

Introduction

Sequence

make/adaptProductionPlan, hireFireWithProduction
workTroubles, produce
planConsumptionInValue (entrepreneurs and workers)
setMarketPrice, evaluateProfit
toEntrepreneur, toWorker
fullEmploymentEffectOnWages, incumbentActionOnWages

Two tals of fifty cycles

The sequence, repeated at each time step (1/2)

1. entrepreneurs makeProductionPlan
2. entrepreneurs adaptProductionPlan
3. entrepreneurs hireFireWithProduction
4. entrepreneurs (with probability 0.05) workTroubles
5. entrepreneurs produce
6. entrepreneurs, workers planConsumptionInValue
7. WorldState setMarketPrice
8. entrepreneurs evaluateProfit
9. workers toEntrepreneur
10. entrepreneurs toWorker
11. WorldState fullEmploymentEffectOnWages
12. WorldState incumbentActionOnWages

The sequence, repeated at each time step (2/2)

The `methods` or commands are sent to the agents of the model in a ordered way, at each time step.

The agents act in random order; if a probability is set, it is applied to each agent, to decide if to activate or not the method.

`WorldState` is an abstract agent that acts defining or modifying the general data of the world

We have 10 initial *entrepreneurs* and 10,000 initial *workers* (at $time = 0$, unemployed)

make/adaptProductionPlan, $t = 1$

The method (or command) `makeProductionPlan`, acting only if $time = 1$, sent to the i^{th} of the `entrepreneurs`, orders it to guess its production for the initial period. The production plan $\widehat{\varphi}_t^i$ is determined using a Poisson distribution, with mean ν.

$$\widehat{\varphi}_t^i \sim \ Pois(\nu) \tag{1}$$

with

$$\nu = \rho \frac{(N_{workers} + N_{entrepreneurs})}{N_{entrepreneurs}} \tag{2}$$

In this way about a ρ ratio of the agents is employed in the beginning, as one unit of production roughly requires one employee.

make/adaptProductionPlan, $t > 1$

The method `adaptProductionPlan`, sent to `entrepreneurs`, orders to the i^{th} firm to set its production plan to a fraction of the demand of the previous period, corrected with a random uniform correction in the interval $-v$ to v. Being $\widehat{\varphi}_t^i$ the planned production of firm i, with $u_t^i \sim \mathcal{U}(-v, v)$ we have:

- if $u_t^i \geq 0$

$$\widehat{\varphi}_t^i = \frac{\frac{D_{t-1}}{P_{t-2}}}{N_{entrepreneurs}}(1 + u_t^i) \tag{3}$$

- if $u_t^i < 0$

$$\widehat{\varphi}_t^i = \frac{\frac{D_{t-1}}{P_{t-2}}}{N_{entrepreneurs}}/(1 + |u_t^i|) \tag{4}$$

hireFireWithProduction

The method (or command) `hireFireWithProduction`, sent to the `entrepreneurs`, orders them to hire or fire, considering the labor forces required for the production plan $\widehat{\varphi}_t^i$ and the labor productivity π; the labor force required is (being L_t^i the current one):

$$\widehat{L}_t^i = \widehat{\varphi}_t^i / \pi \tag{5}$$

1. if $\widehat{L}_t^i = L_t^i$ nothing has to be done;
2. if $\widehat{L}_t^i > L_t^i$, the entrepreneur is hiring, with the limit of the number of unemployed workers;
3. if $\widehat{L}_t^i < L_t^i$, the entrepreneur is firing the workers in excess.

workTroubles (1/2)

For each entrepreneur at time t, so for each firm i, we generate a shock $\Psi_{i,t} > 0$ due to work troubles, with probability p_Ψ (set for all the entrepreneurs as a parameter of the model) and a value uniformly distributed between $V_\Psi/2$ and V_Ψ. The shock reduces the production of firm i, following:

$$\varphi_{c\,t}^{\,i} = \varphi_t^i(1 - \Psi_{i,t}) \tag{6}$$

where φ_c means *corrected production*.

workTroubles (2/2)

If a specific parameter is set to *True*, also the wages are cut in the same proportion of the production.

With W indicating the constant basic wage level, cW_t^i is the corrected value at time t and for firm i:

$$cW_t^i = W(1 - \Psi_{i,t}) \tag{7}$$

This correction is superimposed to the other possible corrections, due to (i) full employment or (ii) to artificial barrier creation.

PRODUCE (1/2)

The method (or command) `produce`, sent to the `entrepreneurs`, orders them—in a deterministic way, in each unit of time—to produce proportionally to their labour force, obtaining the profit Π_t^i, where i identifies the firm and t the time.
L_t^i is the number of workers of firm i at time t. We add 1 to L_t^i, to account for the entrepreneur as a worker. π is the labor productivity, with its value set to 1 (in this version of the model not changing with t).

φ_t^i is the production of firm i at time t:

$$\varphi_t^i = \pi(L_t^i + 1) \tag{8}$$

PRODUCE (2/2)

With eq. (6) above, the production is finally corrected for work troubles, calculating the value ${\varphi_c}_t^i$.

The production of the firm i is added to the total production of the time step.

planConsumptionInValue, sent to entrepreneurs or to workers (1/2)

The method (or command) `planConsumptionInValue` operates both with the `entrepreneurs` and the `workers`, with the function below. [The description is unique for both the cases.]

Considering the individual i of the group k, we have:

$$C_i = a_j + b_j Y_i + u \tag{9}$$

with $u \sim \mathcal{N}(0, consumptionRandomComponentSD)$.

planConsumptionInValue, sent to entrepreneurs or to workers (2/2)

About k, the individual i can be:

1. an entrepreneur, with $Y_i = \Pi_{i,t-1} + W$ and $j = 1$;
2. an employed worker, with $Y_i = W$ and the special case $Y_i = cW_t^i$, with cW_t^i defined in eq. 7, and $j = 2$;
3. an unemployed workers, with $Y_i = sW$ (social wage) and $j = 3$.

The a_j and b_j values are set as parameters of the model.

setMarketPrice (1/2)

The method (or command) `setMarketPrice`, sent to the `WorldState` abstract agent, orders it to evaluate the market clearing price considering each agent behavior and an *external shock, potentially large*.
The shock Ξ is uniformly distributed between $-L$ and $+L$ where L is a rate on base 1, e.g., 0.10.
With (simplified solution in the current version of the model):

- P_t, clearing market price at time t;
- D_t total demand in value at time t (obtained summing up agents' decisions);
- O_t, total offer in quantity (obtained summing up firms' actions) at time t.

setMarketPrice (2/2)

If the shock Ξ is (≥ 0):

$$P_t = \frac{D_t(1+\Xi)}{O_t} \tag{10}$$

if the shock Ξ is (< 0):

$$P_t = \frac{D_t/(1+|\Xi|)}{O_t} \tag{11}$$

evaluateProfit (1/3)

The method (or command) `evaluateProfit`, sent to the `entrepreneurs`, orders them to calculate their profit.
The production $\varphi_{c_t}^{i}$ accounts for: (i) the production plan; (ii) the limits in hiring, if any; (iii) the work troubles, if any.
P_t is the `price` clearing the market at time t.
W is the `wage` per employee and time unit, not changing with t, but for work troubles and for events as:

- wage rise due to full employment or
- to the creation of barriers against new entrants .

γ are extra costs for new entrant firms.

evaluateProfit (2/3)

In presence of work troubles the firm i has to accept a reduction of its price (amount of the reduction: pv_t^i), to compensate its customers, having undermined their confidence in the implicit commitment of producing a given quantity (the production plan).

Currently (April 2017) we set $pv_t^i = 0$

EVALUATEPROFIT (3/3)

$$\Pi_t^i = P_t(1 - pv_t^i)\varphi_{c}{}_t^i - W(1 - \Psi_{i,t})(L_t^i - 1) - 1W - \gamma \qquad (12)$$

The $-1w$ addendum represents the pay of the entrepreneur, unmodified.

The new entrant firms have extra cost γ to be supported for n periods.

toEntrepreneur

With `toEntrepreneur`, workers decide to become an entrepreneur at time t, if their employer had a relative profit $\geq$ a given *threshold* at time $t-1$.

In actual business world, the decision is a quite rare one, so we have to match a higher level control, that we define with the parameter
`max new entrant number in a time step`.

This parameter represents a *potential max number of new entrepreneurs* in each cycle.

toWorker

With the method (or command) `toWorker`, an entrepreneur moves to be an unemployed worker if its relative profit (reported to the total of the costs) at time t is $\leq$ a given *threshold*.

fullEmploymentEffectOnWage

The method `fullEmploymentEffectOnWages`, sent to the `WorldState`, orders it to modify wages accordingly to full employment situation, in a reversible way.
Being U_t the unemployment rate at time t, ζ the unemployment threshold to recognize the *full employment* situation, s the proportional increase step (reversible) of the wage level and W_t the wage level at time t (being W_b the basic level), we have:

$$\begin{cases} W_t = W_b(1+s) \text{ if } U_t \leq \zeta \\ W_t = W_b \text{ if } U_t > \zeta \end{cases} \tag{13}$$

incumbentActionOnWages (1/2)

The method `incumbentActionOnWages`, orders to `WorldState` to modify the wage level for one period, accordingly to the attempt of the incumbent oligopolists of creating an entry barrier when new firms are observed into the market.
The current number of entrepreneurs H_t is calculated by the model and the previous one H_{t-1} is extracted from the structural data-frame generated while the model is running.
We have here two levels:

- K as the (relative) threshold of entrepreneur presence to determine the reaction on wages;
- k as the relative increment of wages;

incumbentActionOnWages (2/2)

Formally,:

$$\begin{cases} W_t = W_0(1+k) \text{ if } \dfrac{H_t}{H_{t-1}} - 1 > K \\ W_t = W_0 \text{ if } \dfrac{H_t}{H_{t-1}} - 1 \leq K \end{cases} \tag{14}$$

Overview

Two tales of fifty cycles (1/2)

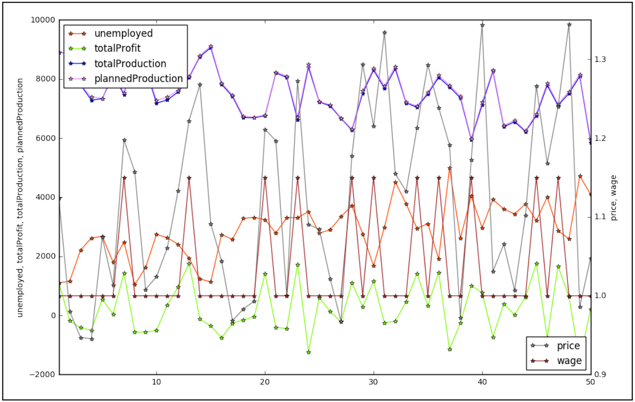

Figure: 50 cycles with entry/exit

Correlation matrix (1/2)

	unempl.	totalProfit	totalProd.	plannedP.	price	wage
unemployed	1.00	-0.18	-0.57	-0.56	-0.02	-0.02
totalProfit	-0.18	1.00	-0.36	-0.37	0.53	0.77
totalProduction	-0.57	-0.36	1.00	1.00	0.02	-0.25
plannedProduction	-0.56	-0.37	1.00	1.00	0.02	-0.25
price	-0.02	0.53	0.02	0.02	1.00	0.46
wage	-0.02	0.77	-0.25	-0.25	0.46	1.00

Table: Correlations among the time series of the model, with new entrant firms

Two tales of fifty cycles (2/2)

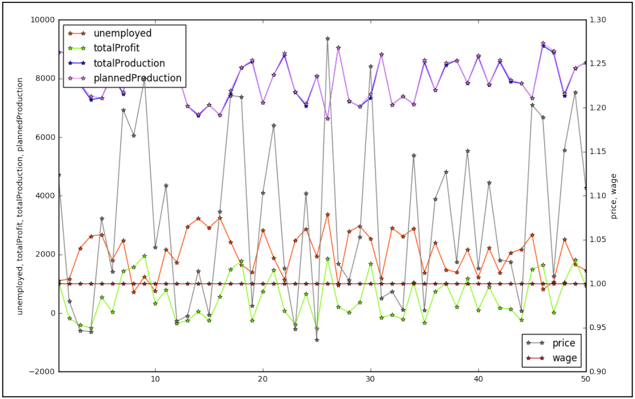

Figure: 50 cycles with entry/exit

Correlation matrix

	unempl.	totalProfit	totalProd.	plannedP.	price	wage
unemployed	1.00	-0.02	-1.00	-1.00	0.05	NaN
totalProfit	-0.02	1.00	0.02	0.02	0.99	NaN
totalProduction	-1.00	0.02	1.00	1.00	-0.05	NaN
plannedProduction	-1.00	0.02	1.00	1.00	-0.05	NaN
price	0.05	0.99	-0.05	-0.05	1.00	NaN
wage	NaN	NaN	NaN	NaN	NaN	NaN

Table: Correlations among the time series of the model, without new entrant firms (wages never moving, so the NaNs)

Overview

CONCLUDING REMARKS

- The agent-based simulations show that the model can generate cyclical fluctuations in the economy, as an effect of the entry/exit mechanism associated to the social mobility and informational shocks.
- The simulations also show that the model provides an explanation for countercyclical markups.