Business cycle in a macromodel with oligopoly and agents' heterogeneity: an agent-based approach

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Etro and Colciago 2010

- Etro and Colciago DSGE model of business cycle (2010)
  - endogenous market structure
  - differentiated goods
  - full employment
  - benchmark cases:
    - price (Bertrand) competition
    - quantity (Cournot) competition

The nature of the equilibrium among the oligopolistic firms

- Gertner (1985): $\exists$ equilibrium
  - in mixed strategies
  - in an oligopolistic market
  - firms simultaneously decide prices and quantities
  - proved w/ symmetric firms, cons. and incr. marg. costs
- Maskin (1986): extends Gertner's results (duopolistic market, finite number of oligopolistic firms)
  - firms' symmetry is not required
  - rather general costs functions.
- Harsanyi (1973): mixed strategies may be interpreted as pure strategies in a perturbed game

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Firms

- observe own costs
- slight uncertainty on the costs of rival

Alternative interpretations

- Osborne and Rubinstein (1994, p. 39)
  - mixed-strategy equilibria are stochastic steady states
  - each occurrence of the game takes place after n players are randomly chosen from different populations
- interpretation consistent w/ assumptions of our model
  - interacting firms in the market are *not* the same in each occurrence of the game (we have entry and exit)
  - existing firms chosen stochastically (both entry and exit are determined by stochastic shocks)

Assumptions

- firms simultaneously choose both prices and quantities
- proportional rationing applies
- profit (payoff) function of firm is continuous in prices
- amount of work hired by each firm:
  - constitutes a capacity constraint
  - is based on labour contracts set for time t, until time $t + 1$
- quantities decided by the firms are "contracts" (not commodities)
- i.e. "commitments" to sell commodities
- might be subject to stochastic shocks

Assumptions (cont.d)

- *ex ante* expectations
- *ex ante* amount of labour
- *ex ante* individual firm's output

Determined on the basis of

- *ex ante* demand curve at time t
- which is the *ex post* demand for time $t-1$, i.e. the empirically observable demand curve that emerges after the realization of all the stochastic shocks of the model

The ex post price at time t (i.e. the *ex post* distribution of prices) is determined by the oligopolistic firms, who pick up a specific part of the aggregate demand

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Summarizing the model

Ex ante amount of workers hired by all the firms

$$L_{j,t} = \left(\frac{E_{t-1}(\varphi_{j,t})}{\Lambda} \right)^{1/\alpha} \tag{1}$$

Total amount of employed workers

$$L_t^* = \sum_{i=1}^{H_t} L_{j,t} = \sum_{j=1}^{H_t} \left(\frac{E_{t-1}(\varphi_{j,t})}{\Lambda} \right)^{1/\alpha} \tag{2}$$

Total amount of employed individuals

$$L_t^* + H_t = L_t^* + H_t^e + H_t^{in} \tag{3}$$

Aggregate demand equation

$$
\begin{aligned}
D_t(\cdot) &= [\Omega(r_t)/P_t] \cdot \\
&\cdot \{A_t + [1/(1+r_t)] \sum_{i=0}^{\infty} [(1+E(r_{t+i}))(1+E(\iota_{t+i}))]^{-i} \cdot \\
&\cdot n_{t+i}(W_{t+i} + h^{e}_{t+i} E(\Pi^{e}_{t+i}) + h^{in}_{t+i} E(\Pi^{in}_{t+i}))\}
\end{aligned}
$$

Aggregate demand equation, alternate version

Past stocahstic shocks included

$$
\begin{aligned}
D(\cdot)_t \quad = \quad & (\Omega(r_t)/P_t) \cdot \\
& \cdot[A_t + [1/(1+r_t)] \sum_{i=0}^{\infty} [(1+E(r_{t+i})) \cdot \\
& (1+E(\iota_{t+i}))]^{-i} \cdot E\{(n_{t+i} w_{t+i}) + \\
& +[(n_{t+i-1} - H_{t+i-1})\beta(var(\Psi_{t+i}))]\Pi^{e}_{t+i} + \\
& +[H_{t-1} \cdot \Pr(\Pi^{in} \geq 0) - (1+r_{t-2})\xi F \cdot \\
& \cdot(n_{t-2} - H_{t-2})\beta(var(\Psi_{t-1}))]\Pi^{in}_{t+i}]\}
\end{aligned}
$$

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The making of the simulation model

The equations introduced in the analytical sections are now transformed, via a sequence of steps, into instructions to individual agents for the simulation.

The making of the simulation model

We use 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 documentation of the construction and calibration of the agent-based model is at `https://github.com/terna/oligopoly`, together with all the calculation routines.

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Action sequence

The steps:

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

Highlighting the main steps of the sequence

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 an action.

`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 $time = 0$, all of them are unemployed)

Highlighting the main steps of the sequence

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.

$$\widehat{\varphi}_t^i \sim \ Pois(\nu) \tag{4}$$

with

$$\nu = \rho \frac{(N_{workers} + N_{entrepreneurs})}{N_{entrepreneurs}} \tag{5}$$

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

Highlighting the main steps of the sequence

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, 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 $u_t^i \geq 0$

$$\widehat{\varphi}_t^i = \frac{\frac{D_{t-1}}{P_{t-2}}}{N_{entrepreneurs}}(1 + u_t^i) \tag{6}$$

- if $u_t^i < 0$

$$\widehat{\varphi}_t^i = \frac{\frac{D_{t-1}}{P_{t-2}}}{N_{entrepreneurs}}/(1 + |u_t^i|) \tag{7}$$

Highlighting the main steps of the sequence

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):

$$\widehat{L}_t^i = \widehat{\varphi}_t^i / \pi \tag{8}$$

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.

Highlighting the main steps of the sequence

workTroubles

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:

$$\varphi_{c}{}_t^i = \varphi_t^i(1 - \Psi_{i,t}) \tag{9}$$

where φ_c means *corrected production*.

Highlighting the main steps of the sequence

produce

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 $L_t^i + 1$ (+1 to account for the entrepreneur), obtaining the profit Π_t^i, where i identifies the firm and t the time.

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

$$\varphi_t^i = \pi(L_t^i + 1) \tag{10}$$

With eq. (9) above, the production is finally corrected for work troubles, calculating the value ${\varphi_c}_t^i$.

Highlighting the main steps of the sequence

planConsumptionInValue

sent to entrepreneurs or to workers

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

$$C_i = a_j + b_j Y_i + u \tag{11}$$

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

Highlighting the main steps of the sequence

setMarketPrice

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.

Highlighting the main steps of the sequence

setMarketPrice

If the shock Ξ is (≥ 0):

$$P_t = \frac{D_t(1+\Xi)}{O_t} \tag{12}$$

if the shock Ξ is (< 0):

$$P_t = \frac{D_t/(1+|\Xi|)}{O_t} \tag{13}$$

Highlighting the main steps of the sequence

evaluateProfit

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:

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

γ are extra costs for new entrant firms.

Highlighting the main steps of the sequence

toEntrepreneur

Workers decide to become an entrepreneur at time t, if their employer had a relative profit $\geq$ a given *threshold* at time $t-1$, considering also a max number of new entrepreneurs at each time.

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*.

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Two tales of fifty cycles (1/2)

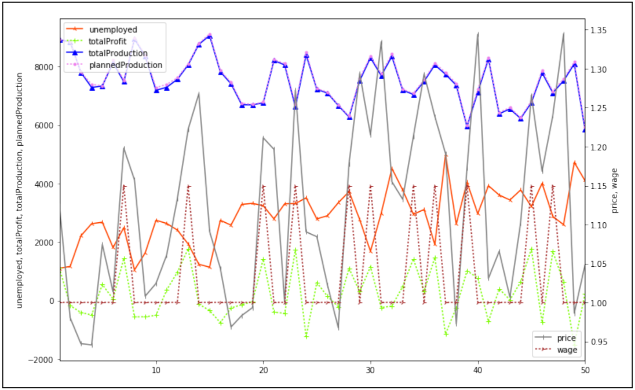

Figure: 50 cycles with entry/exit

Two tales of fifty cycles (2/2)

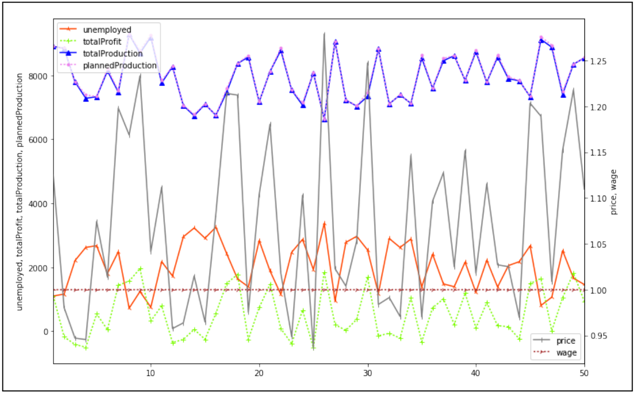

Figure: 50 cycles, without new entrant firms

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 entry/exit

Correlation matrix (2/2)

	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)

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- 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 the informational shocks.
- The simulations also show that the model provides an explanation for the countercyclical mark up phenomenon.

- Is this a path also for DSGE models?