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**Working Paper**

## Multi-country decentralized agent based model: Macroeconomic dynamics and vulnerability in a simplified currency union

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# FinMaP-Working Paper No.50



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FINMAP –

FINANCIAL DISTORTIONS AND MACROECONOMIC  
PERFORMANCE: EXPECTATIONS, CONSTRAINTS AND  
INTERACTION OF AGENTS

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TITLE

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We observe that credit dynamics are strictly associated to business cycle: phases of credit growth are associated with increasing leverage and connectivity that creates the conditions for crisis.

Moreover, we tested the effects of different fiscal regimes on output dynamics, showing that in a common currency area restrictive fiscal regimes may increase country inequality and systemic vulnerability. Inequality between countries derives from differences in technological progress patterns which open competitiveness gaps. Conversely, in fiscal regimes where public deficits are excessively high the public debt burden tends to increase transferring risk from the private sector to the public one.

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# Multi-Country Decentralized Agent Based Model: Macroeconomic Dynamics and Vulnerability in a Simplified Currency Union

Ermanno Catullo and Mauro Gallegati \*

December 14, 2015

## Abstract

We developed a multi country agent based simulation model with endogenous incremental technological change. Macroeconomic dynamics derive from simple behavioral and interacting rules defining the actions of adaptive firms, banks and households (Delli Gatti et al., 2008; Riccetti et al., 2014; Caiani et al., 2015). Countries join a currency union with a perfectly integrated good market, while labor and capital are not exchanged across countries.

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## 1 Introduction

We modeled a multi-country agent based model with endogenous productivity growth, where macroeconomic dynamics are the emerging results of the interactions of decentralized agents, which follow simplified adaptive behavioral rules and matching mechanisms operating in good, credit and labor markets (Delli Gatti et al., 2008; Riccetti et al., 2014; Caiani et al., 2015).

Countries belong to a monetary union with a common currency. Goods are exchanged in a perfectly integrated good market, while capital and labor are immobile between countries. The model endogenizes incremental technological change in the form of firm productivity growth as the consequence of individual imitative and innovative efforts, assuming the presence of country-based technological spillovers.

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We observe that credit dynamics is strictly connected with business cycle. Credit growth anticipated output growth, but at the same time increasing leverage and connectivity credit increase may lead to crisis. Thus, in the simulated data, we follow the methodology developed by Schularick and Taylor (2012) to isolate aggregate variable which may represent effective early warning indicators for crises.

Moreover, we tested the effects of different fiscal regimes on income dynamics through their impact on technological progress. Simulations shows that income inequality between countries derives from different technological innovation patterns. Indeed, productivity growth leads to higher output which, in turn, may provide more resources to foster imitation and innovation. Therefore, technological gaps are translated in different competitiveness levels that may foster inequality between countries.

Restrictive fiscal regimes tend to increase income differences. Indeed public spending may reduce the effects of negative local shocks, sustaining demand and, indirectly, the innovative effort. Moreover, restrictive policies increase systemic vulnerability augmenting output volatility, firm failures and crisis occurrence. However, in fiscal regimes where the allowed deficit levels are too high, the debt burden increases consistently shifting the risk from private agents to the government.

The paper is structured as follows. The following section describes the model, The third shows simulation results. The last concludes.

## 2 The Model

The artificial economy is a currency union made by  $K$  countries. Each country is populated by:  $H$  households and an endogenously variable number of firms  $I$  and banks  $Z$ . Firms employ workers which produce final goods that are sold to households.

Countries are linked only by good flows and the associated payment movements. Indeed, there is not international factor mobility. Firms use internal resources and credit lent by domestic banks for hiring workers. Government collects taxes, provides public expenditure, while central bank sustains the monetary flows of the economy.

Technological change is endogenous: the innovative efforts of firms lead to productivity growth through imitation and innovation; we assume the presence of technological spillovers among firms of the same country. Agents choices and interactions follow a decentralized adaptive approach similar to the one modeled in Riccetti et al. (2014) and Caiani et al. (2015). The following two sections will describe agents behaviors and interactions.

### 2.1 Agents

#### 2.1.1 Households

Each household plays three roles: worker, shareholder and consumer.

As worker, each household supplies a given quantity of labor ( $l^S$ ), they may be employed in different firms ( $l_{hit}$  with  $l_{ht} = \sum_i^n l_{hit}$ ), thus receiving different wages from each firm ( $w_{hit}$ ); we assume that wages can not be lower than a

minimum level ( $w^M$ ). However, the effective labor provided ( $l_{ht}$ ) may be lower than quantity supplied ( $l^S$ ).

Moreover, households receive interest ( $r_d$ ) paid by banks on deposits ( $D_{ht}$ ) and government transfers ( $TF_t$ ).

Thus, family income ( $y_{ht}$ ) and disposable income ( $y_{ht}^D$ ) after taxation are:

$$y_{ht} = \sum_i^n w_{hit} l_{hit} + r_d D_{ht} \quad (1)$$

$$y_{ht}^D = (1 - \tau) y_{ht} + TF_t \quad (2)$$

where  $\tau$  is the income tax rate.

Consumption desired ( $C_{it}^D$ ) and, thus, savings desired ( $S_{ht}^D$ ) are a constant proportion of disposable income ( $y_{ht}^D$ ) and of the wealth accumulated by households in the form of deposits ( $c_D D_{ht}$ ).

$$C_{it}^D = c_y y_{ht}^D + c_D D_{ht} \quad (3)$$

$$S_{ht}^D = y_{ht}^D - C_{it}^D \quad (4)$$

with  $0 < c_y < 1$ .

Desired saving are distributed according to a given constant between deposits ( $D_{it}^D$ ) and firm participations ( $A_{it}^D$ ) through the preference for liquidity  $\lambda$ :

$$D_{it}^D = \lambda S_{ht}^D \quad (5)$$

$$A_{it}^D = (1 - \lambda) S_{ht}^D \quad (6)$$

thus, if firm participations owned are lower than the ones desired ( $A_{h,t-1} < A_{ht}^D$ ) consumer  $h$  will try to invest in the creation of a new firm, that will be funded jointly with other households.

According to a circular Hotelling's locational specification of preferences, we assume that good varieties produced by firms and consumer variety preferences are randomly located on a circle (Figure 1). The smaller the minimum distance between a firm and a consumer ( $\omega_{ih}$ ) the higher the utility ( $u_{hit}$ ) that the consumer extracts from that good. In the good market, each consumer ordines the goods offered according to good prices ( $p_{it}$ ) and variety ( $\omega_{ih}$ ).

$$u_{hit} = \frac{1}{p_{it} \omega_{ih}} \quad (7)$$

Because of supply scarcity, desired consumption ( $C_{ht}^D$ ) may not be completely transformed in effective consumption ( $C_{ht}$ ), thus part of the desired consumption may become forced savings in the form of deposits. Each period, each household deposits its saving in a random chosen banks from which it receives interests at a constant interest rate ( $r_d$ ) which is the same for all the banks.

### 2.1.2 Firms

Firms produce final goods. Labor is the only production factor and its used in both production and innovation processes.

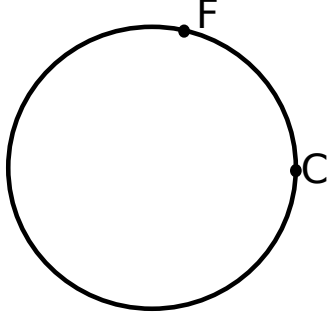


Figure 1: Hotelling cycle example. C expresses consumer variety preferences. F is the variety produced by firm F.

At time  $t$ , for firm  $i$  production depends on labor employed ( $l_{it}$ ) and productivity ( $\phi_{it}$ ):

$$q_{it} = \phi_{it} l_{it} \quad (8)$$

The desired production ( $q_{it}^D$ ) derives from previous sales ( $\hat{q}_{i,t-1}$ ) and previous effective production ( $\bar{q}_{i,t-1}$ ). In fact, effective production may be lower than the desired one ( $q_{i,t-1}^D$ ), for instance firms may not receive enough credit from banks or there is scarcity of labor.

If sales ( $\hat{q}_{i,t-1}$ ) were lower than production ( $\bar{q}_{i,t-1}$ ), the desired production ( $q_{i,t}^D$ ) declines otherwise it augments according to a random value extracted from a uniform distribution between 0 and the adjustment parameter  $\delta$ .

$$q_{it}^D = \begin{cases} q_{i,t-1}^D(1 + U[0, \delta]), & \text{if } \bar{q}_{i,t-1} - \hat{q}_{i,t-1} = 0 \\ q_{i,t-1}^D(1 - U[0, \delta]), & \text{if } \bar{q}_{i,t-1} - \hat{q}_{i,t-1} < 0 \end{cases} \quad (9)$$

Similarly, selling price ( $p_{it}$ ) changes according to previous period sales:

$$p_{it} = \begin{cases} p_{i,t-1}(1 + U[0, \delta]), & \text{if } \bar{q}_{i,t-1} - \hat{q}_{i,t-1} = 0 \\ p_{i,t-1}(1 - U[0, \delta]), & \text{if } \bar{q}_{i,t-1} - \hat{q}_{i,t-1} < 0 \end{cases} \quad (10)$$

The innovation process depends on the quantity of labor employed for innovating, which is a given proportion ( $\gamma$ ) of the labor demanded for production, thus labor demand is given by:

$$l_{it}^D = \frac{q_{it}^D}{\phi_{it}}(1 + \gamma) \quad (11)$$

The effective quantity of labor employed ( $l_{it}$ ) may be lower than the demanded one ( $l_{it}^D$ ) and labor dedicated to innovation is a given proportion of the effective labor employed ( $\gamma l_{it}$ ).

The wage offered changes according to the difference between labor demanded ( $l_{i,t-1}^D$ ) and labor effectively employed in the previous period ( $l_{i,t-1}$ ) and the probability of reducing the wage offered depends on the unemployment rate  $p(u_t) = 1 - u_t^v$ .

$$w_{it} = \begin{cases} w_{i,t-1}(1 + U[0, \delta]), & \text{if } l_{i,t-1}^D - l_{i,t-1} = 0 \\ w_{i,t-1}(1 - U[0, \delta]), & \text{if } l_{i,t-1}^D - l_{i,t-1} < 0 \text{ with } p(u_t) \end{cases} \quad (12)$$

Wages can not be lower than a minimum level ( $w^M$ ).

Firms may increase their productivity through both imitation and innovation. In both cases, the higher the amount of labor employed in innovation the higher the possibility of increasing productivity. Through imitation firms reduce their distance from the domestic firm with higher productivity ( $\phi_m$ ). Imitating probability ( $p_{it}^I$ ) and the productivity after imitation ( $\phi_{i,t+1}^I$ ) are given by:

$$p_{it}^I = 1 - e^{-l_{it}} \quad (13)$$

$$\phi_{i,t+1}^I = \min(\phi_{i,t}(1 + U[0, \delta]), \phi_m) \quad (14)$$

Moreover, a firm may innovate directly. Similarly to imitation, direct innovation probability ( $p_{it}^D$ ) and the new level of productivity ( $\phi_{i,t+1}$ ) are given by:

$$p_{it}^D = 1 - e^{-l_{it}} \quad (15)$$

$$\phi_{i,t+1} = \phi_{i,t+1}^I(1 + U[0, \delta]) \quad (16)$$

Firm labor demand is financed through firm net-worth ( $A_{it}$ ) and loans ( $L_{it}$ ). Loan demand is given by the desired labor expenditure that is not covered by internal resources:

$$L_{it}^D = \begin{cases} w_{it}l_{it}^D - A_{it}, & \text{if } w_{it}l_{it}^D > A_{it} \\ 0, & \text{if } w_{it}l_{it}^D \leq A_{it} \end{cases} \quad (17)$$

For simplicity if the net-worth  $A_{it}$  is greater than the desired labor expenditure ( $w_{it}l_{it}^D$ ), the difference is given back proportionally to firm owners as a form of capital revenue.

Firms may not receive all the loan demanded, thus loan effectively received ( $L_{it}$ ) is lower or equal than the one demanded ( $L_{it} \leq L_{it}^D$ ).

Thus profits depend on sales minus labor and interest rate costs:

$$\pi_{it} = p_{it}q_{it} - w_{it}l_{it} - r_{it}L_{it} \quad (18)$$

$$A_{i,t+1} = A_{it} + \pi_{it} \quad (19)$$

### 2.1.3 Banks

Banks collect deposits from consumers, paying a given interest on deposits ( $r_d$ ). At the same tie, banks provide loans to firms creating deposits. The probability of receiving credit ( $p_{it}^L$ ) and the interest rate charged on loans ( $r_{it}$ ) depends on firm leverage.

$$p_{it}^L = 1 - L_{it}^D/A_{it} \quad (20)$$

$$r_{it} = \chi L_{it}^D/A_{it} + r_t \quad (21)$$



where  $r_t$  is the discount rate fixed by central bank.

The desired supply of loans depends on bank net worth ( $L_{zt}^{DS} = \mu A_{zt}$ ) The maximum amount that a bank may provide to each single firm is a maximum share of its supply ( $\zeta L_{zt}^{DS}$ ).

Banks have to deposit in the central bank a minimum amount of reserves ( $R_{zt}^M$ ) as a proportion of deposits:

$$R_{zt}^M = r_{ec} D_{zt} \quad (22)$$

the remaining amount of bank liquidity is used for acquiring public bonds ( $B_{zt}^D$ ).

If a bank has low reserves it will ask for loans to the central bank ( $L_{zCt}$ ).

Therefore bank profit ( $\pi_{zt}$ ) and net-worth ( $A_{zt}$ ) is equal to:

$$\pi_{zt} = \sum_i^n r_{it} L_{izt} + r_{bt} B_{zt} + r_{re} R_{zt} - BD_{izt} - r_d D_{zt} - r_t L_{zCt} \quad (23)$$

$$A_{z,t+1} = A_{zt} + \pi_{zt} \quad (24)$$

$$(25)$$

where interest  $r_{bt}$  and  $r_{re}$  are respectively the interest rate on bonds and on reserves. Bad debts ( $BD_{izt}$ ) are those loans that are not entirely paid back because of firm failures.

#### 2.1.4 Central Bank

Central banks collect reserves ( $R_{Ct}$ ) and offer loans to cover the liquidity necessity of banks ( $L_{Ct}$ ). Moreover central banks buy bonds emitted by government ( $B_t$ ) that are not absorbed by banks. If in the system there are not banks, as in the initial periods of the simulation, central banks collect household deposits but can not offer credit to firms. Central banks profit ( $\pi_{Ct}$ ) derives from interests on bonds and loans minus interests on compulsory reserves.

$$\pi_{Ct} = r_{bt} B_{Ct} + r L_{Ct} - r_{re} R_{Ct} \quad (26)$$

Central bank profits are appropriated by the government.

The discount interest rate is common to all country and is fixed following a Taylor rule on average levels of inflation.

$$r_t = \bar{r}(1 - \xi) + \xi * r_{t-1} + (1 - \xi) * \xi^{IN} (IN_{t-1} - \overline{IN}) \quad (27)$$

where  $\xi$  is an adjustment parameter,  $\bar{r}$  is the long run interest rate,  $\xi^{IN}$  is the inflation sensibility,  $IN_{t-1}$  is the level of inflation and  $\overline{IN}$  the inflation target level.

#### 2.1.5 Government

Government collects income taxes from households. Indeed the total amount of taxes collected ( $T_t$ ) is:

$$T_t = \sum_h^H \tau y_{ht} \quad (28)$$

Government public primary expenditure  $G_t$  is shared equally among household as transfers ( $TF_t$ ).

Public expenditure derives from a constant amount ( $G$ ) that is gradually adjusted to the country price level ( $P_t$ ). However, public expenditure is constrained, it is limited by a maximum level of primary deficit over output ( $d$ ), which lead to a maximum level of expenditure desirable ( $G_t^M$ ). The expenditure desirable ( $G_t^M$ ), target expenditure ( $G_t^T$ ) and the effective one ( $G_t$ ) are respectively:

$$G_t^M = dY_t + T_t - r_{bt}B_t \quad (29)$$

$$G_t^T = \min(P_t G, G_t^M) \quad (30)$$

$$G_t = (1 - \delta)G_{t-1} + \delta G_t^T \quad (31)$$

The basic level of primary expenditure  $G$  is given by the product between the tax ratio and the number of consumer ( $G = \tau H$ ) in order to balance public expenditure with revenues. In the first period of the simulation, to activate economy activity with a monetary injection the primary deficit rule is not respected.

Moreover, government has to repay bonds and interest of bonds on the previous period. Bonds interest depends on the level of debt over output ( $B_t/Y_t$ ) and on central bank discount rate ( $r_t$ ):

$$r_{bt} = \chi_B B_t/Y_t + r_t \quad (32)$$

In effect, if taxes are not enough to cover primary expenditure ( $G_t$ ) and the service of the public debt new bonds are issued. Besides, government has to cover deposits in case of bank failure issuing bonds.

## 2.2 Interaction Structure

### 2.2.1 Asset ownership

Part of household savings are collected to provide funds for the formation of new firms. In each country, when an amount of savings of at least  $A_t^m$  is disposable a new firm or bank is created and the households that provide these funds become shareholders, thus the initial firm or bank net-worth is  $A_{it} = A_t^m$ . Therefore, the larger the amount of savings invested for creating new firms or banks the higher the number of firms and banks that enter into the market. Entry initial net worth evolves according to wage level  $W_t$ :

$$A_t^m = W_t A^m \quad (33)$$

We try to preserve a constant proportion of firms and banks in terms of their cumulative net-worth. Thus if the sum of the net-worth of banks is lower than a certain percent ( $\theta$ ) of that of firms, there is a given probability that a new bank enter (the probability has for simplicity the same value  $\theta$ ).

Firms and banks with a net-worth level lower than  $F_t = W_t F$  exit from the market, with  $F = 1$  firms that are not able to employ at least a worker exit from the market.

### 2.2.2 Good market

Each firm offers its goods domestically and abroad (subsection 2.1.2). In a random order each consumer expresses its preferences considering a maximum number ( $\psi$ ) of goods offered. Each consumer orders the selected goods according to their preferences, thus, consumers try to buy the larger quantity of the more satisfactory good. If the quantity disposable of the first best good is not enough to cover the desired consumption expenditure (subsection 2.1.1), the consumer will buy the second best and so on, until the resources allocated to consumption are exhausted or until there are no more goods left to buy on the market. After another consumer expresses its demand. The matching process ends when no more matching possibilities are left.

### 2.2.3 Labor market

Labor is the only production factor in the economy (subsection 2.1.2). Each period, each firm  $i$  demands a certain amount of labor ( $l_{it}^D$ ) at a determined level of wage ( $w_{it}$ ). Household express a given supply of work ( $l_h$ ) and they may work at the same time in more than one firm. Each period households look for job, because of limited information and search costs they may compare the job demand of a given number of firms ( $\psi$ ), they choose firms that offer the higher wages (subsection 2.1.1).

### 2.2.4 Credit Market

Banks collect deposits and provide loans to demanding firm. Firms may receive loans from different banks. Loans are lent with a certain probability and with a given interest rate that depends on firm target leverage, conceived as a risk measure, thus firms with lower target leverage pay lower loan interests and have higher probability of receiving loans. Moreover banks may maintain a certain amount of reserves in the central bank and if they incur in liquidity problem they may ask for loans to the central bank (subsection 2.1.3).

### 2.2.5 Bond Market

Government collects taxes and issues bonds to cover its expenditure (subsection 2.1.4) that are bought by demanding banks. Banks access to bond market in a random order with a given individual bond demand (subsection 2.1.3). If the government is not able to allocate all the bonds to banks, the central bank will buy the remaining bonds.

## 2.3 Simulation scheduling

Each period of the simulation follows these time steps:

1. Deposit and Credit markets matching
2. Firm production and innovation choices
3. Labor market matching
4. Firm production and innovation implementation

5. Government taxation and public expenditure
6. Household consumption and saving choices
7. Good and Bonds markets matching
8. Exit and enter of firms and banks

### 3 Simulation results

Following the simple model presented in chapter three of Godley and Lavoie (2008), at the beginning of the simulation money is created through public deficit covered with the emission of bonds bought by central bank. Thus, in the first period of the simulation income is zero. Public spending, in the form of transfers to the household, is partially used to fund the formation of firms and banks. Thanks to public funds emissions the artificial economy gradually starts to reproduce simple economic processes: firms employ workers, pay wages, produce goods and try to increase their productivity. Banks funds private and public debt. Workers pay income taxes, save part of their disposable income and consume goods produced both domestically and abroad.

Figure 2 shows the dynamics of some crucial aggregate variable in the different countries. In first instance, both real and nominal aggregate income increase during simulation, nominal income increases faster thanks to price dynamics. Real wage on productivity decreases sharply at the beginning of the simulation, in reason of the initial rapid increase of prices, and after follow a slow decline caused by incremental productivity innovations. Government funds the starting economy, thus at the beginning debt is high. Gradually debt is reduced thanks to increasing tax revenues and because of the expenditure limits deriving from public deficit targets.

In fig 3 we observe a reduced section of the time series generated by the simulation. Focusing on the country associated with the red color, we see that this country has a huge reduction in output that is associated with an high level of unemployment. The reduction of the level of activity implies lower tax collection for the government, thus public deficit increases. Moreover, also the trade balance is strongly negative, thus deteriorating international competition is connected with the bad country performance.

Indeed, output dynamics are strictly related with the variables associated to country competitiveness. As expected, real output is positively correlated with productivity (Figure 4). Wages anticipate negatively output: wage growth may lead to output reduction, increasing firms costs and, thus, reducing their international competitiveness. Moreover, high level of wages are correlated with previous high levels of output, which allowed relatively high wage levels. The ratio between wage and productivity is a competitiveness measure representing unit labor costs, indeed high level of output are negatively correlated with the wage on productivity ratio. While prices are positively correlated with income.

Output dynamics is strictly associated to the dynamics of other macroeconomic variables. Figure 5 gives some insight into the relative dynamics of macro variables with respect to output. Aggregate credit, leverage and connectivity in the credit market are positively correlated to income. Indeed, sustaining production, credit anticipates output growth, but at the same time growth phases

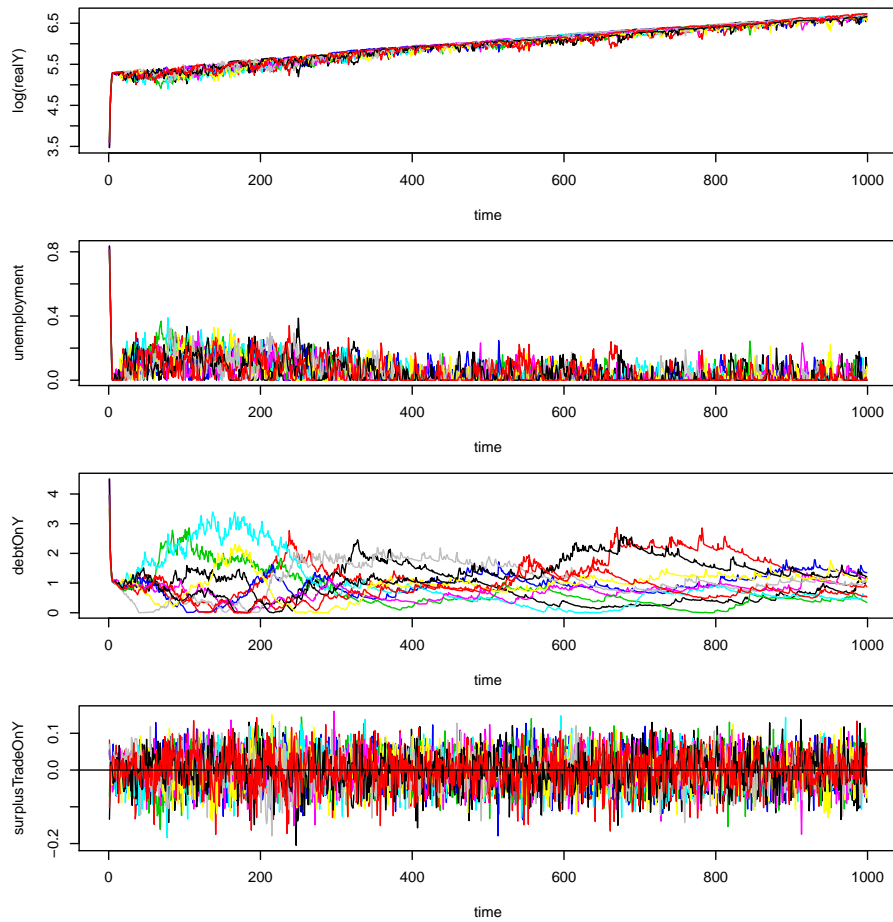


Figure 2: Simulation dynamics of aggregate variables. In the first panel, the nominal aggregate output in logarithms of each country. In the second panel, real output. In the third panel, the ratio between average real wages and average productivity. In the fourth panel, debt over output.

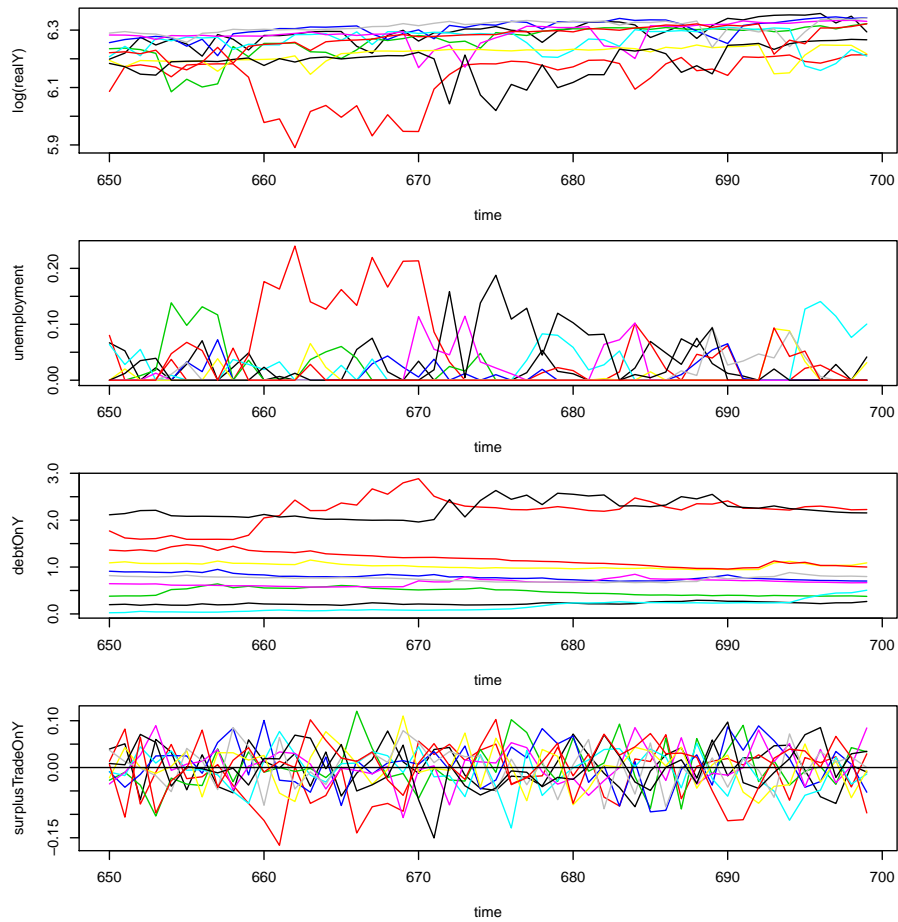


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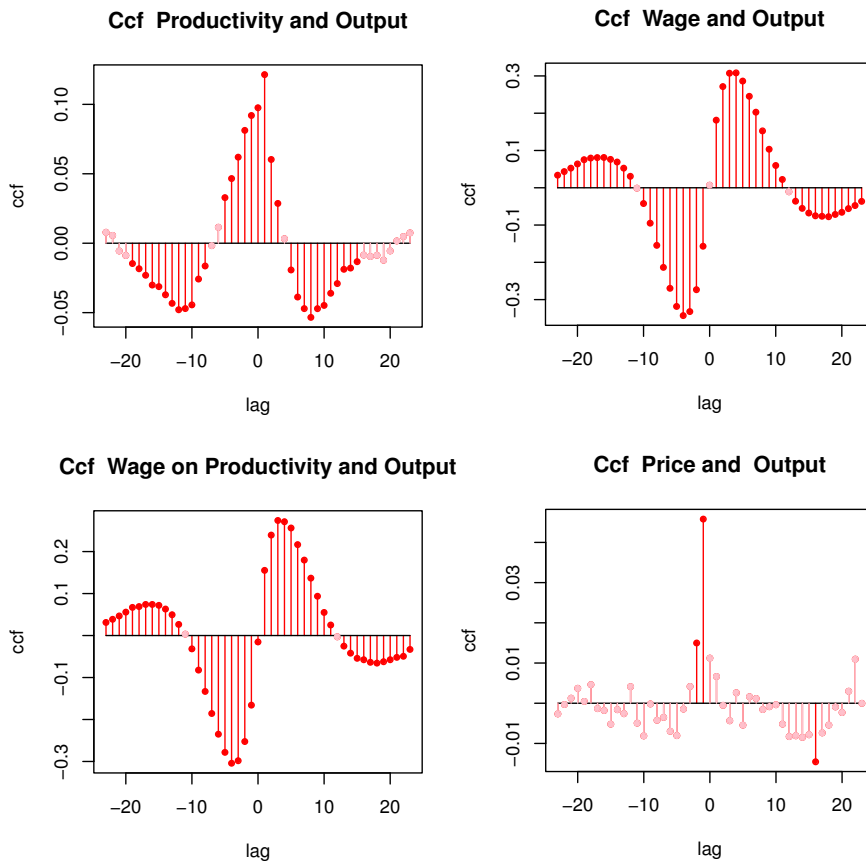


Figure 4: Correlations between Output and Productivity, Wage and Prices. In the upper-left panel, correlation between average productivity and output. In the upper-right panel, correlation between average wages and output. In the bottom-left panel, correlation between average wages over average productivity and output. In the bottom-right panel correlation between average level of prices and output.

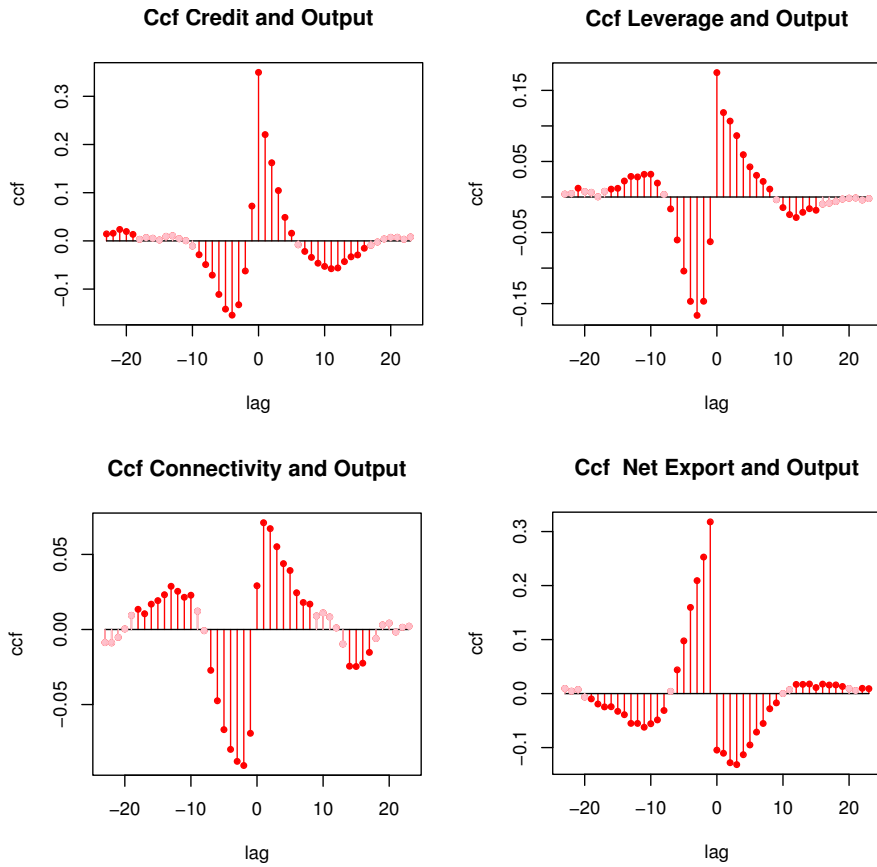


Figure 5: Macroeconomic variables correlations with Output. In the upper-left panel, correlation between aggregate credit and aggregate output. In the upper-right panel, correlation between aggregate firm leverage, as total loans over aggregate firm net-worth, and output. In the bottom-left panel, correlation between public deficit and output. In the bottom-right panel, correlation between net exports and output.



follow phases of leverage and connectivity increase, which may increase systemic risk. Net-exports are negatively correlated with output in reason of the growth of import due to higher income. While net-exports anticipate positively output: when net-exports increase in following period output tend to raise.

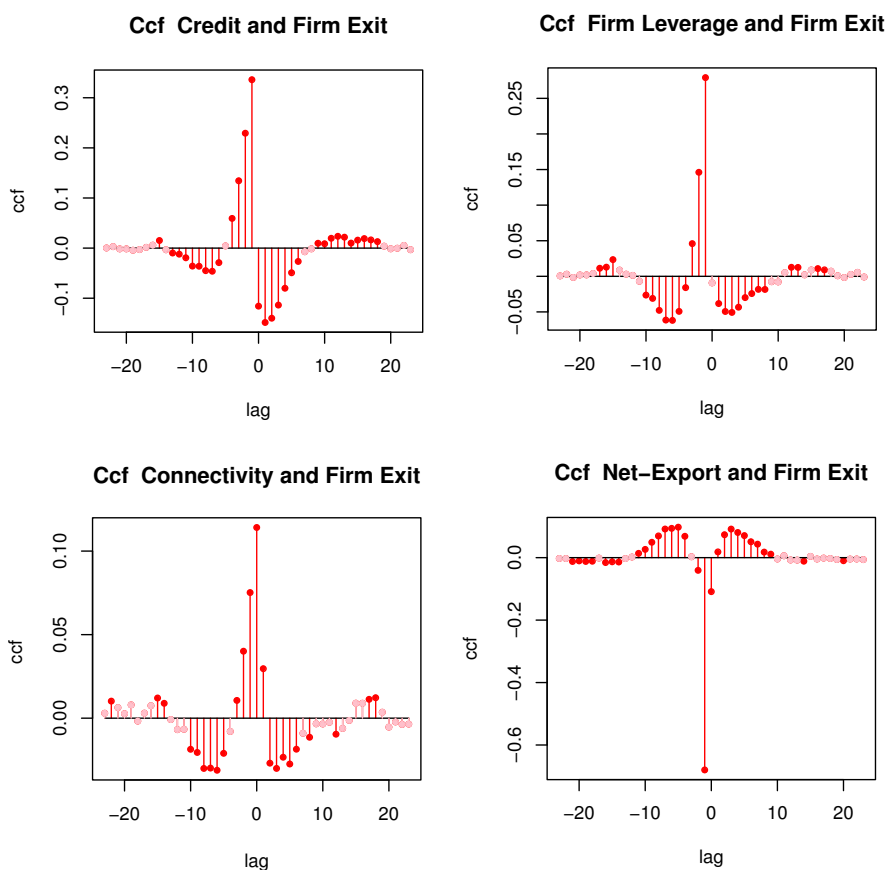


Figure 6: Macroeconomic variables correlations with Failures. In the upper-left panel, correlation between aggregate credit and the failures, as the number of firm failures. In the upper-right panel, correlation between firm leverage, and firm failures. In the bottom-left panel, correlation between public deficit and firm failures. In the bottom-right panel, correlation between net exports and failures.

In the model crisis may be triggered by firm failures which may lead to bank failures or, more in general, to the deterioration of bank balance sheet, which may reduce bank lending capabilities and, thus, the aggregate credit supply. Credit, leverage and connectivity are negatively correlated with the number of firm failures (Figure 6). However credit, leverage and connectivity anticipate failures, indeed high levels of credit, which lead to high leverage, increase firm riskiness. Net-exports anticipate negatively failures, high levels of

net-exports provide in following period higher demand and, at the same time, are an indicator of the competitiveness of domestic firms in international markets.

We follow the methodology developed by Schularick and Taylor (2012) to test the relation between credit dynamics and crisis. We apply the same Logit model implemented by Schularick and Taylor (2012) on simulated data referring to several Monte Carlo runs (10):

$$\text{logit}(p_{it}) = \beta_{0i} + \beta_1(L)\Delta\log\text{CREDIT}_{it} + \beta_2(L)\mathbf{X}_{it} + \epsilon_{it} \quad (34)$$

Where  $(p_{it})$  is the crisis probability,  $(L)\Delta\log\text{CREDIT}_{it}$  are lagged credit logarithmic variations and  $\mathbf{X}_{it}$  are control variables. The predicted probabilities of the Logit regressions are used as early warning indicators: the higher the predicted values the higher the probability of a crisis. A basic measure of the effectiveness of the regressors to isolate early warning measures is the Auroc, which represents the capacity to reduce false alarm without increasing missed crisis.

Table 1 reports the results of the multi-logit panel regression on our simulated data. In line with Schularick and Taylor (2012), credit variations are correlated with crisis probability (column 1). In particular, associating to credit variation past output changes (column 2), leverage measures (column 3) and connectivity (column 4), measured as the average normalized degree of banks, improve the capacity of effectively predicting crises as shown in the Auroc value.

	credit	credit+ y	credit + credit/out	credit + deg	all
L1 $\Delta \log(\text{credit})$	0.195** (0.066)	0.042 (0.072)	-0.645** (0.102)	0.233** (0.062)	-0.956** (0.118)
L2 $\Delta \log(\text{credit})$	0.184** (0.069)	0.344** (0.075)	-0.490** (0.097)	0.176** (0.068)	-0.448** (0.110)
L3 $\Delta \log(\text{credit})$	0.217** (0.068)	0.448** (0.072)	-0.299** (0.090)	0.192** (0.069)	-0.157 (0.100)
L4 $\Delta \log(\text{credit})$	0.359** (0.063)	0.488** (0.067)	0.022 (0.079)	0.339** (0.066)	0.078 (0.089)
L5 $\Delta \log(\text{credit})$	0.121** (0.060)	0.235** (0.063)	-0.134* (0.073)	0.069 (0.064)	-0.100 (0.082)
L1 $\Delta \log(y)$		4.873** (0.6119)			6.916** (0.655)
L2 $\Delta \log(y)$		-1.320** (0.605)			0.236 (0.645)
L3 $\Delta \log(y)$		-3.730** (0.613)			-2.565** (0.651)
L4 $\Delta \log(y)$		-2.248** (0.615)			-1.400** (0.651)
L5 $\Delta \log(y)$		-2.478** (0.591)			-1.967** (0.622)
L1 $\Delta \log(\text{credit}/y)$			1.286** (0.106)		0.023 (0.193)
L1 $\Delta \log(\text{deg})$				0.641** (0.087)	0.634** (0.101)
L2 $\Delta \log(\text{deg})$				0.456** (0.095)	0.468** (0.106)
L3 $\Delta \log(\text{deg})$				0.427** (0.095)	0.442** (0.105)
L4 $\Delta \log(\text{deg})$				0.508** (0.093)	0.453** (0.103)
L5 $\Delta \log(\text{deg})$				0.442** (0.092)	0.427** (0.101)
Observation	500,000	500,000	500,000	500,000	500,000
Groups	50	50	50	50	50
Pseudo $R^2$	0.007	0.014	0.014	0.011	0.025
AUROC	0.569**	0.587**	0.599**	0.584**	0.622**
Standard error	(0.019)	(0.019)	(0.020)	(0.020)	(0.019)

Table 1: Relation between crisis and macro-variables variations in simulated data, crisis defined as -5% output variation

In our artificial economic system, public expenditure is limited by a target maximum level of deficit on aggregate income. We test the effect of different levels of deficit on income targets on output and debt, in particular considering inequality between countries. We considered five regimes, characterized by different levels of maximum target leverage over income, of respectively 0.0 (0%), 0.03 (3%), 0.06 (6%), 0.09 (9%) and 0.12 (12%). While, in the standard simulation analyzed in the previous chapter, the maximum level of target deficit was 0.06 (6%).

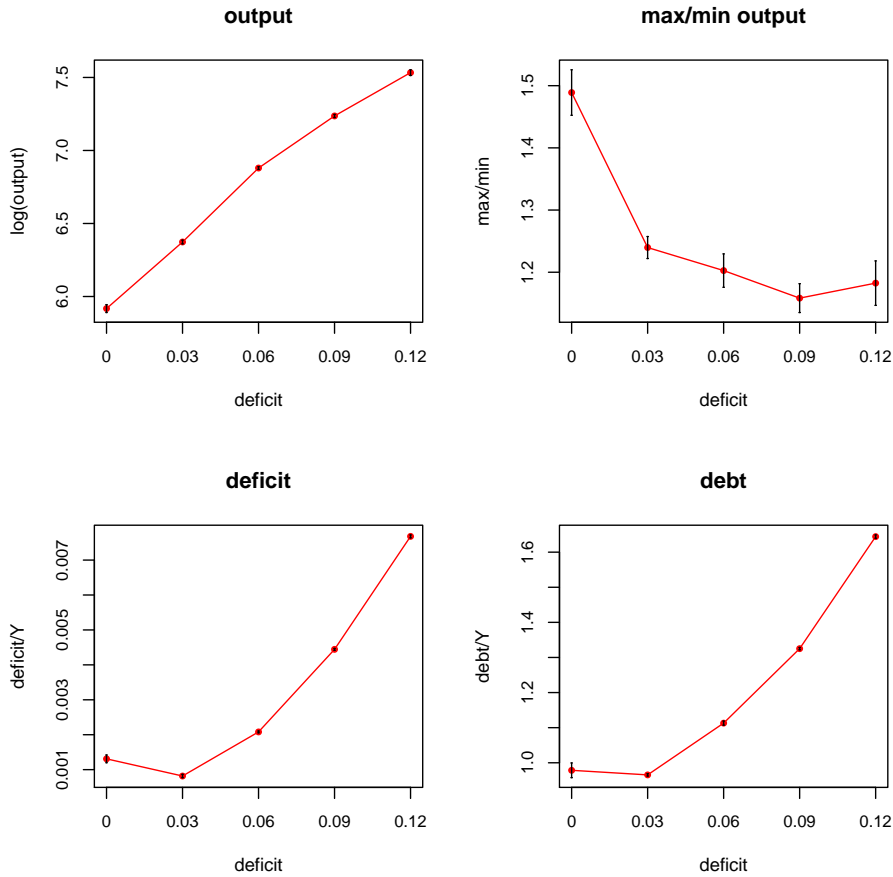


Figure 7: Macroeconomic results of different technological regimes. In the upper-left panel, average output levels in logarithms with respect to fiscal policy regimes. In the upper-right panel, average ratio between country with the highest output level with respect the country with the lower output level in the different fiscal regimes. In the bottom-left panel, average public deficit over income in the different fiscal regimes. In the bottom-right panel, average public debt over income in the different fiscal regimes.

Increasing the level of target deficit on income raises the average level of output while it augments the relative level of debt (Figure 9). Under a cer-

tain deficit target level, increasing public deficit decreases the ratio between the output level of the highest income country on the lowest one. Indeed, a larger possibility of recurring to deficit spending may sustain countries suffering temporary economic difficulties, reducing failures and, thus, protecting the accumulated technological capabilities.

Indeed, in our simulations (Figure 8), income gaps among countries derives essentially from productivity differences. Different technological dynamics are lead by cumulative causal mechanisms amplifying the effect of firm innovations which are diffused at country level by technological spillovers. In effect, higher level of productivity generate higher levels of income that give firms more resources to foster innovation and imitation processes. Therefore, technological change in the form of productivity level variations is a determinant of competitiveness at both firm and country level and, in turn, competitiveness differences may foster output inequality between countries.

Contrasting output slow downs (figure 9), higher level of deficit limits reduce output volatility and firm failures. These leads to a lower crisis probability. However, after a certain level, increasing deficit limit leads to a growing debt burden which may shift the systemic risk to the government.

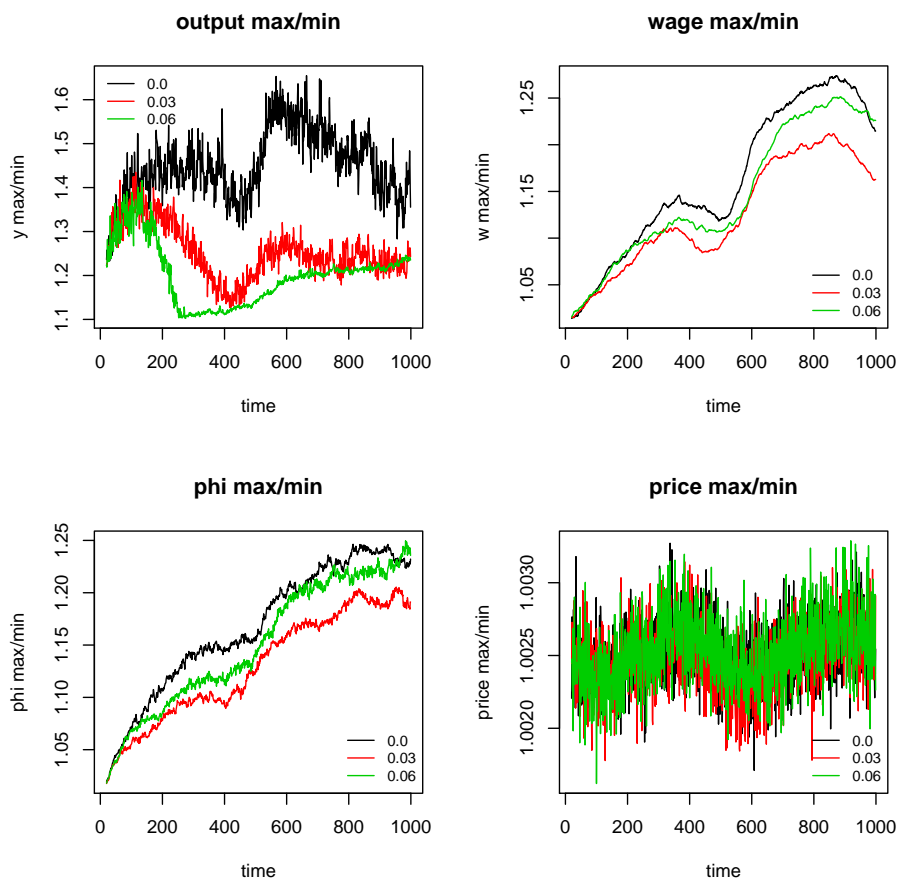


Figure 8: Output inequality dynamics between countries three fiscal regimes. Fiscal regimes correspond to a maximum level of target deficit over income of respectively 0.03 (3%), 0.06 (6%) and 0.09 (9%). In the upper-left panel, ratio between the country with the maximum level of output and the country with the minimum level through time in the three fiscal regimes. In the upper-right panel, the ratio between the country with the maximum average level of wage and the country with the minimum one in the three regimes. In the bottom-left panel, the ratio between the country with the maximum average level of productivity and the country with the minimum one in the three regimes. In the bottom-right panel, the ratio between the country with the maximum average level of price and the country with the minimum one in the three regimes.

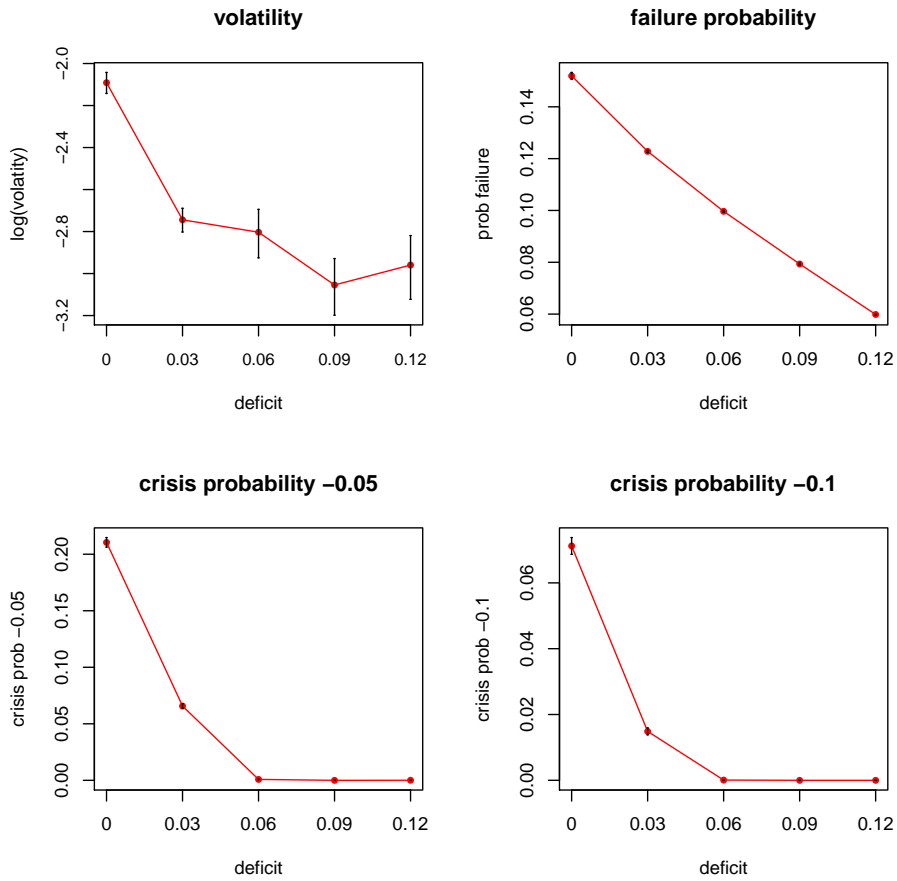


Figure 9: Systemic vulnerability on different fiscal regimes. In the upper-left panel, average volatility expressed as the logarithm of the average output standard deviations with respect to fiscal policy regimes. In the upper-right panel, firm failure probability in the different fiscal regimes. In the bottom-left panel, the probability of a crisis, defined as an output reduction lower than 5%, in the different fiscal regimes. In the bottom-right panel, the probability of a crisis, defined as an output reduction lower than 10%, in the different fiscal regimes.

## 4 Conclusions

We modeled a multi-country economy with a commune currency, perfectly integrated good market, while capital and labor markets do not move across countries. In this simple economic system aggregate dynamics derives from the individual choices of household, firms and banks. Technological change in the form of productivity growth is endogenous and derives from imitation and innovation efforts of firms.

Simulations show the emergence of income inequality between countries due to different technological dynamics, which, in turn, derive from cumulative reinforcing mechanism, indeed productivity growth increases output and augments the amount of disposable resources for innovation.

Following the analysis of Schularick and Taylor (2012), we show that in simulated data it is possible to isolate aggregate variables that may be used to value the level of systemic risk. Indeed, credit, leverage and connectivity variations are an effective early warning indicator of crisis: crises are endogenously created in expansive phases where credit growth is associated with leverage and connectivity increase.

We test the effect of different public expenditure regimes on output and inequality: increasing the deficit target augments output, reduces inequality between countries and output volatility. However, in loose fiscal regimes that allow high deficits, country debt burden increases consistently augmenting sovereign debt risk. Indeed, the model could be extended to introduce capital flows among countries, more in general the model has simple behavioral and interaction structures, thus may be adapted and modified in different directions.

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## Simulation Parameters

Simulations last for 1000 periods. Only the last 500 periods are used for computing statistics and correlations among macro variables. We run ten Monte Carlo for each simulation specification.

system		learning	
$K$	10	$\phi_{t=0}$	1.0
$H$	200	$\delta$	0.01
$l^S$	1.0	$\gamma$	0.03
$w^M$	1.0	$\chi$	0.001
$r_d$	0.0	$\zeta$	0.1
$\tau$	0.4	$\mu$	10.0
$c_y$	0.9	$r_{re}$	0.0
$c_D$	0.2	$re_c$	0.01
$\lambda$	0.1	$\bar{r}$	0.005
$F$	1.0	$\xi$	0.2
$\xi^{IN}$	2	$\overline{IN}$	0.0075
$\psi$	10	$d$	0.06
$A^m$	10.0	$v$	1.0
$\chi_B$	0.0001		