Simulating a small monetary union between artificial economies from the bottom up

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Abstract

The proposed paper investigates preliminary simulation results of a multi-agent model with interconnected economies in a small artificial monetary union. We refer to intra-country activities in a good, labour and credit market and inter-country activities with regards to export/import and interbanking. The crucial point of this model is given by its political economy character. We implement three different ruling classes of a modern capitalist economy: firm-, bank and state-owners. Otherwise labour households are employed by capitalist institutions such as firms, banks and states. Expected profit rates and endogenously changing interest rates drive the accumulation process and represent the crucial variables for the evolving system, since risk becomes a systemic issue. In our upcoming simulation experiments we aim for an analysis of political interests and resulting conflicts between industrial and financial capital which destabilize the monetary union over time. The final paper will elaborate on aspects of agent-based macroeconomic models, which still represent niches in the current literature. We derive an interconnected multi-country system representing an artificial monetary union bottom-up, addressing prototypic within and between interbanking as well as export/import relations. We account for current conflicts within three capital ruling classes (firm-owners, bank-owners and state-owners) and between capital and labour. Insofar we highlight the different role models of agents in action in modern globalized political economies. Our model highlights the interactive dimension of a multi-agent macroeconomic system, with respect to social learning within and between rule populations on the meso level of institutional change.

1. Introduction

In this paper we present a mid-range computational agent-based model (currently ~5000 agents) of interconnected economies, where each economy is developed as a bottom-up macro-economic system. In this respect we follow the recently growing literature on heterogeneous and endogenous macroeconomics focussing on the economy as an evolving complex adaptive system. In particular our model shares characteristics similar to Delli Gatti et al. (2005), Delli Gatti et al. (2010), Cincotti et al. (2010) or Raberto et al. (2012); for a recent overview compare Bargigli and Tedeschi (2012). This type of agent-based economic models highlights the incorporation of endogenous money in a full-fledged bottom-up economy, thereby following a Post-Keynesian approach, compare also Seppecher (2012) for instance. The fast growing literature and the increasing attention towards this modelling realm in the economic community speaks for the tremendous success of this approach in emphasizing the notion of systemic risk and vulnerability in credit networks between households, firms and banks. Economic stability reaches a new theoretical level beyond general equilibrium economics by synthesizing Post-Keynesian macroeconomics with bottom-up econophysics. Others such as Dosi et al. (2008) introduce Schumpeterian innovation into multi-agent models and look into the business cycles of artificial macroeconomies. Recently this approach got synthesized by the authors with the Keynesian agent-based interpretation for policy investigations between short- and long-run, compare Dosi et al. (2010). The agent-based approach with regards to macroeconomic modelling experiences a fresh spring and the current agendas are majorly given within the mentioned corridors. Open research questions and problems are still manifold from several aspects of non-general-equilibrium economics. The final paper will elaborate on aspects of agent-based macroeconomic models, which still represent niches in this approach. (1) We derive an interconnected multi-country system from the bottom up representing an artificial monetary union, addressing prototypic within and between interbanking as well as export/import relations. (2) We account for current conflicts within three capital ruling classes (firm-owners, bank-owners and state-owners) and between capital and labour. Insofar we highlight the different role models of agents in action in modern globalized political economies. (3) Our model emphasizes the interactive dimension of agent-based macroeconomic models, in particular the aspect of social learning in local neighbourhoods. Thereby our model is different from models employing micro-simulation techniques, compare Gilbert et al. (2005) or Gilbert (2007) for a disambiguation.. In particular we refer to modelling characteristics presented in Hanappi (2012)[1], as outlined in the following.

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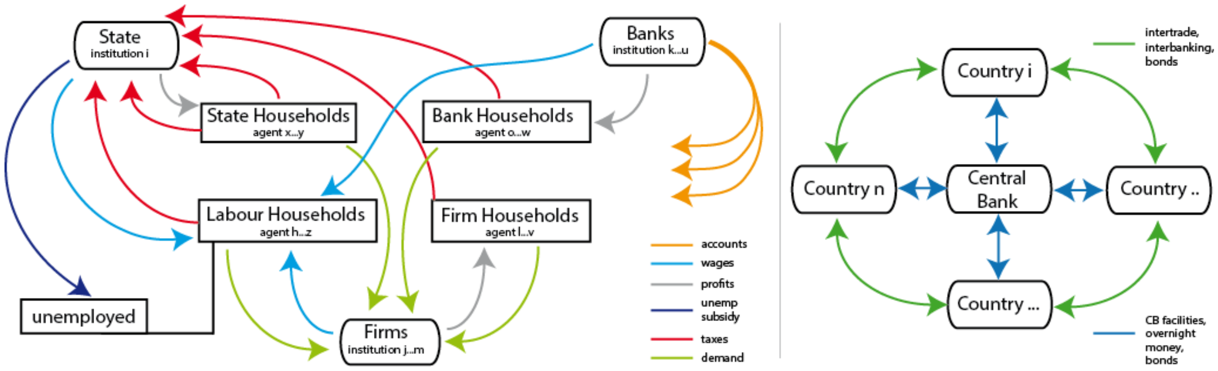
[1] Compare Appendix 1-4 in Hanappi (2012).

2. Topology, Agents and Institutions

The model connects real and monetary sector across a goods, labour and credit market. It exhibits a price and wage system in dependence of micro-founded production. Firms produce one good conditional on labour input and physical capital. They pay wages with respect to their local market situations, meaning in particular that each firm has its own local consumption community. Firms expect prices adaptively to the changing environment (price competition within the whole firm population), which are matched with households' reservations finally. Households currently buy one unit of good if their reservation price is below the firms' selling price in correspondence with their budget constraints. Banks issue loans to firms in order to recapitalize them (physical capital gets depreciated every round) if the firm's expected rate of profit is above a profitability threshold. Households are able to save their remaining income in bank deposits, visible on the liability side of the banks' balance sheets. We focus on the bank as a financial intermediary of endogenous credit-money. Therefore we are able to monitor economic activities in a consistent stock-flow framework, with focus on an integration of balance sheets and the transaction flow matrix, compare Godley and Lavoie (2012, p. 44). The basic monetary flows are given in Figure 1.

Figure 1: Basic Model Architecture – Monetary Flows



Source: flow diagram based on Hanappi (2012, Appendix 1)

Agents and institutions are represented as nodes on the network, where their stock variables (assets and liabilities) are encapsulated. They are connected via links representing the flows of the economy, in particular given by consumption payments (purchasing amount and paid price), wage flows, interest payments, tax and saving flows. Every agent's and institution's account is held by a particular bank. The basic declaration of institutions is given below

States $(\boldsymbol{i} \dots \boldsymbol{n})$

States collect taxes on consumption goods, a corporate tax on firm profits, an income tax on worker/employee wages and a tax on bank profits. Major expenditures are currently assumed by the payment of unemployment subsidies, reflecting a basic public social infrastructure. Every country contains institutions (firms and banks) and households (firm-owner-, bank-owner-, state-owners and labour households).

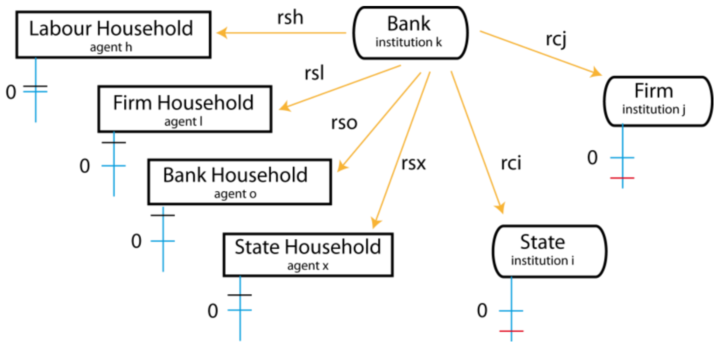
Firms $(\boldsymbol{j} \dots \boldsymbol{m})$

Firms are implemented as nodes on an institutional layer of the network. They produce and sell one single homogenous capital good with regards to their heterogeneous labour input and homogenous physical capital. Since labour households are randomly distributed, firms are also equipped with different initial labour input. Firms are able to hire and fire workers with regards to their production processes. Residuals stemming from the production and sales activities represent the profit of a firm which is fully transferred to the firm-owner at the end of each period.

Banks $(\boldsymbol{k} \dots \boldsymbol{u})$

Banks are implemented in a similar way as firms, but produce financial capital respectively. We initialize banks in small and tightly connected oligopolistic interbank markets. Banks hold the accounts of all involved agents and institutions, accordingly they transform savings of one group into credit for another (Hanappi 2012). In our model banks charge different interest rates to the different heterogeneous groups of households of our model, as well as different rates for saving and investment, explained in section 3. Otherwise the central bank is implemented to lend facilities to banks and to buy bonds already in exchange. Bank relations are monitored within a consistent accounting system, as illustrated in Figure 2.

Figure 2: Bank Accounts and Interest Rates



Source: flow diagram based on Hanappi (2012, Appendix 1)

Households

We distinguish between four types of households: Labour households $(\boldsymbol{h} \dots \boldsymbol{z})$ are engaged in a capitalist-worker relation, where the capitalist can either own a firm, bank or state. We allow for inter- and intra-class conflicts respectively. Bank $(\boldsymbol{o} \dots \boldsymbol{w})$ and firm owners $(\boldsymbol{l} \dots \boldsymbol{v})$ govern the processes of industrial and financial capital production and collect the full profits of firms and banks each period. State-owners $(\boldsymbol{x} \dots \boldsymbol{y})$ respond to these two modes of capitalist production with corresponding endogenous policies. Labour households are randomly distributed across the firm population by initialization. Insofar we distinguish also between workers (producing an industrial good) employed in firms and employees (producing a financial capital good) employed in banks. Firms and banks may fire and hire workers/employees as explained in section 3. In consequence labour households may also be unemployed and involved in a state relation only thereafter. However all households are free to choose their trading firm independent from their wage relation.

3. Activities and Dynamics

In our agent-based model time advances in discrete steps (round-based) and agents are updated semi-asynchronously in different phases. In general we assume one time step in the model to be roughly equivalent to one month of real economic production and consumption. Thus 100 time periods in the model represent approximately 8 years of economic time respectively; reflecting the statistical time period of a Juglar cycle, compare Hagemann (2008, p. 234). Each turn agents are asked to do the following activities – the timing of events:

- produce (major firm activity)
- invest (firm-bank interaction)
- hire and fire (firm-labour household interaction)
- consume (household-firm interaction)
- save (household-bank interaction)
- pay interest (household-bank + firm-bank interaction)
- collect taxes (household-state + firm-state + bank-state interaction)
- pay unemployment subsidies (unemployed labour household-state interaction)

Production

Firms perform one whole production phase per simulated time step. The production process exhibits the core of this agent-based interconnected artificial monetary union. Although it refers to a fictional and highly simplified mechanism, it entails the basic decision problems for entrepreneurs. Every firm's output is constrained by a Cobb-Douglas production function of the following form:

$$Y_j = A_i * {L_j}^{\beta} * {K_j}^{\alpha} \tag{1}$$

The planned output (Y_j) of a firm (j) in a country (i) depends on labour input (L_j) and physical capital (K_j). In the current version of the model we have not yet incorporated any endogenous technical progress and keep the technological coefficient (A_i) constant and exogenously given. This will of course be a crucial parameter for a further empirical calibration and endogenization of Schumpeterian innovation. Labour input refers to the number of workers per firm in this simplified picture. Since the firm is not confronted with fixed costs, wages represent the only costs in this context. Physical capital is heterogeneously distributed over the population of firms. To start with a roughly meaningful value physical capital, K_j is chosen to be optimal for the average firm size, i.e. depending on the number of employees (L_i) for country (i)) and the number of firms (n_i) in country (i)), following from (1).

$$K_j = \frac{L_i}{n_i}\frac{\beta}{\alpha} \tag{2}$$

We plan to use the production coefficients as reasonable variations for the different political economies. Physical capital is depreciated every turn by δ (e.g. $\delta = 4\%$), meaning that every firm needs to constantly reinvest in their machines and equipment. It is assumed that firms do not have perfect information about consumer demand. They try to optimize their profits by firstly determining the expected sales in their consumption neighbourhood in the next time step. Expected sales quantity is derived by a simple mechanism, which leads to an individual price expectation for the following period.

$$p_{t_j}^e = p_{(t-1)_j}^e + \gamma(p_{(t-1)_i} - p_{t-1}^e) \tag{3}$$

The crucial point related to this adaptive expectation mechanism is given by the computed country price $(p_{(t-1)_i})$ of the last period. This price represents the average price within a country i computed as the share of revenues and sold quantities. It is understood as a public ex-post price information available for each country in every time step. Firms use this as a reference point to calculate the expectation error from the last period; which is weighted by (γ) as an exogenous parameter for price anticipation. Lower values of (γ) refer to firms resistant to short-term price changes in the whole market and follow just the trend. Firms with a higher value of (γ) take account of price changes to a high degree and expect the price for the next period more realistically. Future implementations may elaborate on endogenous anticipation weights, changing from within the evolving economy. Furthermore, it is assumed that firm (j) will not produce below its marginal costs, i.e. the wage per worker. For the sake of simplicity we currently assume that the firm has a rough expectation about the demand structure and adjusts its production to be a share of the projected sales:

$$q_{t_j}^e = \left(q_{top_i} - p_{t_j}^e * \left(\frac{q_{top_i}}{p_{top}}\right)\right) * \frac{L_j}{m_i} \tag{4}$$

Every firm sets its expected production stock with regards to the market size (q_{top_i}) of country (i), which is given by the highest possible quantity of sale in the market (i.e. which is the result of every consumer buying the good).Firms currently a priori assume that the consumers behave very simplistic and thus calculate a fictitious demand curve $q_{top_i} - p_{t_j}^e * \left(\frac{q_{top_i}}{p_{top}}\right)$for their home market. This expectation gets weighted with regards to the relative firm size in country (i); the share between the size of firm (j), i.e. the firm's labour input (L_j), and the amount of firms (m_i) in country (i). Quantities not sold to the market remain as inventories in the stock of the firm. That means in particular that firms may not need to produce with full capital utilization each round, since they may sell their stock from former periods in the given period. We compare the inventories with the above calculated expected stock every round to adapt production during the period. Since firms optimize their production process they may fire workers in this step if they can rely on a sufficient stock for further selling. Of course this becomes an apparent adaptation issue in the first periods of production (because of the naïve initial expectations which tend to overshoot), in the medium-run firms adopt an adequate production process by hiring and firing on behalf of their expected output. If their stocks can't cover the expected stocks fully, the production process needs to be adapted for the difference between available physical capital and additional physical capital, purchased to sustain production.

Investment

In this case firms may purchase credit-money from banks to recapitalize their physical capital; we assume a full monetarization of physical capital. In order to compute the expected firm profit rate for every firm j as a measure for credit evaluation and potential investment, we need to calculate expected firm profits in advance:

$$\rho_{t_j}^e = p_{t_j}^e * q_{t_j}^e - \sum_{a=1}^{L_{t_j}} w_{t_{j_a}} - (DB_{t-1_j} + DB_{t_j}^e) * (r_{c_j} + rep_c) \tag{5}$$

Expected profits for firm j are given by expected revenue $(p_{t_j} * q_{t_j}^e)$ minus current wages for all currently employed workers. In addition firms need to pay interest (r_{c_j}) on previously accumulated credit debt $(DB_{(t-1)_j})$ as well as credit repayments with a given repayment rate (rep_c) for the previously accumulated credit debt (currently a simplistic mechanism). $(DB_{t_j}^e)$ represents the expected purchase of additional credit for the following round, depending on the difference between available and additionally demanded physical capital to sustain production in our case. Endogenizations of the interest rates are of particular importance for further simulation experiments. Furthermore if profits are positive, then every firm profit (ρ_{t_j}) is transferred to the firm owner at the end of the period. We refer to profits respectively (ρ_{t_l}) for each firm household l. With computed firm profit expectations we may focus on the expected profit rate now.

$$\pi_{t_j}^e = \frac{\rho_{t_j}^e}{K_{t_j}} \tag{6}$$

With reference to Hanappi (2012) we define the expected profit rate as the ratio between expected profits $(\rho_{t_j}^e)$ and physical capital stock (K_{t_j}) of firm (j). Credit-money for re-investment in physical capital is purchased if the expected profit rate is above the interest rate on firm credits.

$$if\ \pi_{t_j}^e > r_{c_k}\ then\ invest \tag{7}$$

In case of (6) the firm's physical capital receives a reinvestment of (DB_{t_j}), reflecting the current credit debt supplied by bank (k), which is added to the asset side of the bank and to the liability side of the firm in correspondence. We assume that every firm maintains credit relations with just a single bank at the moment. If (6) is not fulfilled, the firm cannot afford further reinvestment (credit-driven production) and needs to cool down production to a new output level. If there are still more than one worker employed in the firm, it is able to fire workers. In that case it firstly reduces the level of output (Y_j) with regards to given physical input and secondly labour input (L_j) aiming for the new output target. If this newly calculated labour input is above the actual amount of workers, we need to cool down production to the lowest level in this case, producing inefficiently thereafter. Otherwise the firm may still fire more workers, then the type of the labour household switches to unemployed.

Consumption

All households consume either one or no good per period depending on their reservation prices. Currently reservations are equally distributed across each household population with regards to a country-dependent maximum price. The labour household population represents the greatest share within households and is initialized with a fine granularity of reservation prices therefore. Firm, bank and state owners (still households) have higher reservation prices respectively with regards to the median. In the basic version of the model every consumer randomly chooses firm for trade and maintains this connection, thereby consumers do not vary between producing firms. If the reservation price is higher than the proposed price and firms still have quantities in stock then one unit is traded.. After all trades have been completed, average price for the whole market in country (i) is computed with respect to actualized revenues and traded quantities. This average country price represents the reference price for the new expectations in the following period. Then, realized assets and liabilities are computed for each firm. Afterwards we calculate the real profits made by firms and transfer them to the firm owners if they are positive.

Firm bankruptcy

With regards to the evaluations at the end of a consumption period, a firm may also end up with a negative account. Respectively the firm may go bankrupt if it exceeds a certain debt risk threshold determined by its bank. For that very reason we compute the debt ratio of every firm and compare the debt and the account with the remaining physical capital. Then it depends on the bank's heterogeneous risk aversion to either drop the firm or to keep it alive. Risk aversion becomes a key parameter for further developments with regards to systemic risk in firm-bank networks and interbanking across the economies. In case of firm insolvency all customer relations are dissolved initializing search for a new selling firm randomly. In consequence the firm-owner gets unemployed.

Saving/Overdraft

Households save remaining money after trade. Banks assign interest rates on savings for labour households (r_{s_h}), for firm- (r_{s_l}) state owners (r_{s_x}) and for bank owners (r_{s_o}). Every period banks update their assets and liabilities with regards to these interest payments. Households hold their saving account at their connected bank. We address interest on overdraft (r_o) in the same manner. With regards to interest payments and savings we assume that the ruling class receives a discount, since greater values of accumulated wealth are involved. In dependence on the bank's in- and outgoing interest payments we are able to calculate the bank's profit. The revenues (R_{t_k}) of the bank contain all interest income on outstanding credit and current overdraft by its debtors. The costs (C_{t_k}) of the bank refer correspondingly to the bank's interest payments on household savings and positive institutional accounts. Revenues are given by their difference conclusively:

$$R_{t_k} = Liab_{t_x} * r_{o_x} + Liab_{t_i} * r_{o_i} + Liab_{t_o} * r_{o_o} + \sum_{l=1}^{d_k}(Liab_{t_l} * r_{o_l}) + \sum_{h=1}^{e_k}(Liab_{t_h} * r_{o_h}) + \sum_{j=1}^{f_k}(Liab_{t_j} * r_{o_j}) + \sum_{j=1}^{f_k}(DB_{t_j} * r_{c_k}) \quad (8)$$

...where (d_k) relates to the number of firm-owners connected to bank (k), i.e. their industrial capitalist customers; (e_k) relates to the number of labour households connected to bank (k); (f_k) relates to the number of firms connected to bank (k). The revenues of bank (k) depend on the sum of overdraft payments on liabilities of connected customers plus the accumulated debt of purchased credits of firms. At the moment there is just one or none state and state household connected to the bank, in consequence we don't need to accumulate in this case $(Liab_{t_x} * r_{o_x} + Liab_{t_i} * r_{o_i} +)$.
Bank costs are described correspondingly with regards to interest payments on savings.

$$C_{t_k} = Asset_{t_x} * r_{s_x} + Asset_{t_i} * r_{s_i} + Asset_{t_o} * r_{s_o} + \sum_{l=1}^{d_k}(Asset_{t_l} * r_{s_l}) + \sum_{h=1}^{e_k}(Asset_{t_h} * r_{s_h}) + \sum_{j=1}^{f_k}(Asset_{t_j} * r_{s_j}) \quad (9)$$

Assets refer to the current savings of involved agents. In sum profits (ρ_{t_k}) of bank (k) are given by revenues minus costs, as stated in (10).

$$\rho_{t_k} = R_{t_k} - C_{t_k} \quad (10)$$

The profits of bank (k) are then transferred to the bank owner (o) if there are any, following the same logic as explained previously in context of firm profits.

Taxing and unemployment
Basically we implement taxes on value-added (t_{vat_i}), income (t_{inc_i}) and firm- $(t_{\rho_{i_j}})$ bank- $(t_{\rho_{i_k}})$ profits. Collected taxes equip the state with purchasing power for infrastructure investments and periodical payments. At the moment the state maintains just one social infrastructure, i.e. unemployment subsidies. In the simulation we initialize unemployment at 10% of all labour households for state (i). States currently compensate 50% of the initial wage level for unemployed agents.

4. Outlook and Experiments

We are looking forward to discuss preliminary simulation results with regards to the endogenous dynamics in the basicversion of the model. Beyond this basic version's intra-country closed economy actions we are currently implementing inter-country actions for empirically calibrated country profiles for 3-5 economies. The latter refer to export/import transactions between firms and customers of two different countries, firm-bank interactions in multiple countries and in the future also firm-firm interactions with intermediate goods.. In particular banks will be equipped with different generic credit-rules for bank lending on a cognitive, behavioural and social level in a prototypic way, as proposed in Wäckerle (2013) in the long run.
In future versions of the model we plan to use the simulation as a test bed for different sets of unconventional monetary policy by the central bank, e.g. lending facilities and quantitative easing.
Further simulation experiments of this agent-based artificial monetary union will focus on the political conflicts between the stated three different ruling classes. In this respect we are looking forward to discuss systemic vulnerability within an artificial monetary union as an emergent property of political processes involving different ruling classes in the evolution of capitalism.

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