



Emergent dynamics of a macroeconomic agent based model with capital and credit



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ABSTRACT

In this paper we present and discuss a Macroeconomic Agent-Based Model with Capital and Credit (CC-MABM) which builds upon the framework put forward by Delli Gatti et al. (2011). The novelty of this model with respect to the previous framework consists in the introduction of a stylized supply chain where upstream firms – i.e. producers of capital goods (K-firms) – supply a *durable and sticky input* (capital) to the downstream firms, who produce consumption goods (C-firms) to be sold to households. Both C-firms and K-firms resort to bank loans to satisfy their financing needs. There are two-way feedbacks between firms and markets which yield interesting emerging properties at the macro level. We show that the interaction of upstream and downstream firms and the evolution of their financial conditions – in a nutshell: *Capital and Credit* – are essential ingredients of a “crisis” i.e. a sizable slump followed by a long recovery.

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1. Introduction

In macroeconomic model building, very often researchers start from simple models where capital goods are absent. This is the case, for instance, of the simplest New Keynesian DSGE model presented in Clarida et al. (1999) (hereafter CGG) where firms produce only consumption goods using only labor as an input. This is also the case, in the agent based literature, of the Macro Agent Based Model (MABM) developed in Delli Gatti et al. (2011).¹

Toy models in which the only final use of goods is consumption and the only input is labor are easier to interpret and sometimes sufficient to answer deep research questions but they are surely inadequate when one wants to replicate empirical business cycle facts. As it is well known, in fact, changes in capital and in inventories play a major role in shaping the dynamic pattern of GDP. The first reason why we want to move up the ladder of complexity in macroeconomic model building, therefore, is simply *realism*, i.e. the need to reproduce macroeconomic reality as closely as possible.

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¹ In CGG, macroeconomic equilibrium yields the equality of consumption expenditure and aggregate output (so that involuntary inventories and saving are absent). In Delli Gatti et al. (2011) the macroeconomic equilibrium condition is not imposed ex ante (i.e. there is no *top down coordinating device*, as often assumed in agent based models) so that aggregate output may be absorbed by consumption expenditure or end up in involuntary inventories. Hence, by construction, aggregate saving is equal to inventories.

A second and no less important reason is that the financing decisions of firms enter into the picture in a significant way only when investment is considered. The balance sheet of the firm is, in this case, properly defined: capital and liquidity show up in the assets' side, external finance (debt) on the liabilities side, equity or net worth being defined by the difference between the two. Decisions concerning investment and decisions concerning *financial structure* of the investing firm, in fact, are deeply interrelated. Capital should be incorporated into a macroeconomic model if we want to take into account financial factors in an appropriate conceptual setting.²

The NK literature has rapidly gone beyond the simple CGG framework. Starting from the pioneering work of Bernanke et al. (1999) (hereafter BGG), a large literature has developed which takes investment and financing decisions into account in the presence of *financial frictions*. The architecture of these models is rather sophisticated (even if they retain the representative agent assumption), in some cases so complicated that the overall picture becomes blurred and the interpretation of results difficult.

In the agent based literature, too, macroeconomic models have incorporated capital and investment. For instance, in the EURACE framework (Cincotti et al., 2010; Dawid et al., 2012) firms need heterogeneous capital goods and heterogeneous labor services to produce consumption goods. The use of high quality capital goods requires the employment of skilled workers, hence qualities of capital goods and skills of workers are complements in production. In the *Keynes meeting Schumpeter* (K&S) framework, Dosi et al. (2010) assume that firms use machine tools of different vintages and with different productivities to produce consumption goods. Also in the computational literature, therefore, the architecture of macroeconomic models is sometimes so complicated that the resulting emerging properties become difficult to explore.

In this paper we present a MABM with *Capital and Credit* (CC-MABM) which builds upon the MABM developed in Delli Gatti et al. (2011). In the CC-MABM there are four categories of agents: households, firms producing consumption goods (C-firms), firms producing capital goods (K-firms) and banks. The corporate sector describes a stylized supply chain: the *upstream sector*, consisting of K-firms that supply a *durable and sticky input* (capital) to the *downstream sector* consisting of C-firms. Both C-firms and K-firms resort to bank loans to satisfy their financing needs.

The CC-MABM may be considered as a simpler and shorter route (with respect to EURACE or K&S) to introduce capital and investment in a MABM. In our model capital goods (and labor) are not differentiated: the productivity of labor and of capital is uniform across firms and workers. This relatively simple architecture, however, generates two-way feedbacks between markets and sectors which yield interesting emerging properties at the macro level.

The time series of GDP computed on artificial data fluctuates around a “long run mean” for an extended time window which we characterize as *normal times*. Occasionally, however, GDP falls dramatically bottoming out only after many periods of contraction. At the trough, GDP and employment are at least 15% lower than the pre-recession level. The recovery, then, is slow and painful; it takes a long time for GDP and employment to go back to normal. A dramatic slump followed by a long recovery is a *crisis* in our terminology.

Where does a crisis come from? We show that the interaction of upstream and downstream firms and the evolution of their financial conditions – in a nutshell: *Capital and Credit* – are essential ingredients of a “crisis”. If they were absent the volatility of GDP would be limited and no sizable slump would occur.

The paper is organized as follows. Section 2 briefly surveys the literature. In Section 3 we sketch the basic features of the model. In Sections 4, 5, 6 and 8 we present the assumptions concerning the behavior of households, C-firms, K-firms and banks respectively. In Section 7 we define the financing gap and the demand for loans. Section 9 is devoted to a discussion of the accounting framework and the interrelated balance sheets of the main categories of agents. Section 10 is devoted to a discussion of the results of the simulations. Section 11 concludes.

2. Related literature

The need to move up in the ladder of increasing complexity by incorporating capital and credit in macroeconomic models is evident both in NK and in AB literatures.³

In the NK-DSGE literature, the canonical model popularized by CGG in which there are only consumption goods, the only input is labor and financing decisions are absent has been superseded by more sophisticated models with *capital* and *financial frictions* starting from BGG. A large literature has developed from this pioneering paper. A couple of recent and remarkable additions to this literature are Christiano et al. (2010) (hereafter CMR), Gertler and Kiyotaki (2010) (hereafter GK).

In BGG (i) “entrepreneurs” (or wholesale goods producers) use capital and labor to produce and sell a homogeneous good to “retailers”, (ii) retailers differentiate the good and sell final goods to households (in the form of consumption goods) or to capital producing firms (K-firms) (in the form of investment goods), (iii) K-firms use investment goods and undepreciated capital (sold by entrepreneurs to K-firms) to produce and sell new capital to the entrepreneurs.

² In Delli Gatti et al. (2011), in the absence of investment, the firm's financing decision consists in funding the wage bill (a setting which recalls the classical wages-fund theory). The firm seeks external finance (bank loans) to complement internal funds (net worth) in order to anticipate wages to employees. In this simplified setting, by construction, only liquidity shows up in the assets side of the firm's balance sheet, which is then used to pay wages.

³ The remark does not apply to Real Business Cycle models in which capital is playing a key role by construction. Financing decisions, however, are generally overlooked in relatively simple RBC models.

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