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Macroeconomic impacts of trade credit: An agent-based modeling exploration☆

Michel Alexandre [a,b,*], Gilberto Tadeu Lima [c]

[a] *Central Bank of Brazil, Brazil*
[b] *Institute of Mathematics and Computer Science, University of São Paulo, Brazil*
[c] *Department of Economics, University of São Paulo, Brazil*

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Abstract

This paper explores the effects of trade credit by assessing its macroeconomic impacts on several dimensions. To that end, we develop an agent-based model (ABM) with two types of firms: downstream firms, which produce a final good for consumption purposes using intermediate goods, and upstream firms, which produce and supply those intermediate goods to the downstream firms. Upstream firms can act as trade credit suppliers, by allowing delayed payment of a share of their sales to downstream firms. Our results suggest a potential trade-off between financial robustness as measured by the proportion of non-performing loans and the average output level. The intuitive reason is that greater availability of trade credit, which however does not necessarily imply proportionately greater actual use of it by downstream firms, allows more financial resources to remain in the real sector, favoring the latter's financial robustness. Yet, given that trade credit is proportionally more beneficial to smaller downstream firms, it enhances market competition. This results in a decrease in markups and thereby in profits and dividends, which contributes negatively to aggregate demand formation.

JEL classification: C63; E27; G32

Keywords: Trade credit; Agent-based modeling; Macroeconomic effects

1. Introduction

Trade credit can be defined as a "credit extended by a seller who allows delayed payment for his products" (Biais and Gollier, 1997, p. 903). At first glance it may seem puzzling to see firms resorting on credit granted by non-financial

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* Corresponding author.
E-mail addresses: michel.alsilva@gmail.com (M. Alexandre), giltadeu@usp.br (G.T. Lima).

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firms rather than by specialized financial intermediaries, such as banks. Nevertheless, trade credit corresponds to a non-negligible source of external finance, although such an importance varies across countries, across regions or sectors of a given country, and across firm sizes of a given sector. According to Norden and van Kampen (2015), for instance, the median accounts payable-to-total assets ratio in Italy is 26%, while it is 9% in Germany. In the United States, for the particular case of small and medium-sized enterprises (SMEs), trade credit accounts for 31.3% of total debt (Carbo-Valverde et al., 2016).

There are a number of theoretical and empirical papers investigating the rationale behind the existence and magnitude of trade credit. On the demand side, the principal argument is that firms resort to trade credit mainly in scenarios of bank credit shortage (Petersen and Rajan, 1997). The model in Burkart and Ellingsen (2004), for instance, suggests that trade credit, at least for some firms which are bank-credit constrained, is countercyclical. Some empirical studies (e.g., Choi and Kim, 2005; Demiroglu et al., 2012) show that the usage of trade credit increases in face of negative monetary policy shocks. Another evidence found in the empirical literature is that trade credit is particularly important to SMEs, given that they are more likely to be bank-credit constrained. For instance, Carbo-Valverde et al. (2016), using firm-level Spanish data for the aftermath of the financial crisis of 2008, show that the relative importance of trade credit increased for financially vulnerable SMEs that were initially less liquid, highly dependent on short-term bank finance, and with greater levels of intangible assets.

On the supply side, most of the motivations for individual firms to act as trade creditors are linked to the intuitive idea that they have better access to unique information not available to other lenders – especially banks – about the creditworthiness of potential customers (Uchida et al., 2013). This informational advantage would allow suppliers to identify firms whose credit risk is potentially lower than that estimated by banks (Biais and Gollier, 1997). In fact, the seller's provision of trade credit can provide a valuable signal to the banker that the buyer is worthy of credit, thus potentially mitigating credit rationing (Biais and Gollier, 1997). According to Burkart and Ellingsen (2004), the credit suppliers' informational advantage comes from the input transaction itself, as in-kind (rather than in-cash) loans are potentially less vulnerable to moral hazard problems. Another way through which credit suppliers can potentially mitigate moral hazard problems is presented by Cunat (2006): in a context of limited enforceability of contracts, credit suppliers are able to restrain the supply of intermediate goods to borrowing firms. We would argue, however, that the positive feature of such interruption (or even reduction) in the supply of intermediate goods should be weighted against the potentially negative impact it will have on the ability of the borrowing firms to serve any still outstanding debt. Meanwhile, the extension of trade credit to large borrowers can be advantageous to small suppliers as it potentially signals product quality (Klapper et al., 2011). Also, Petersen and Rajan (1997) add that credit suppliers can liquidate assets more easily and efficiently and have an implicit equity stake in the customers. Although all these supply-side motivations for a firm to extend trade credit to its customers are arguably important, we would argue that a (probably unjustifiably) less emphasized motivation which combines supply- and demand-side elements is that the extension of trade credit is likely to also operate as a strategic mechanism to induce demand from potential customers. From this perspective, the extension of trade credit can be interpreted as a kind of *conditional credit*, in the sense that the actual access to it is conditional to the use of it to meet (partially or entirely) the payment commitment associated with the purchase of a good and/or service. Note that when such a demand-inducement element associated with the offer of trade credit is also taken into account, the possibility arises that the assessment of the credit risk of the potential borrowing customer may in fact become deliberately more lenient. The intuitive reason is that the *expected* net profitability of a seller firm may rise by its granting of trade credit to a customer who would not realize the purchase (or would purchase a smaller amount of the good or service) otherwise.

While many studies have been devoted to shed light on the reasons leading firms to demand or supply trade credit, the impacts of trade credit on several macroeconomic dimensions remain much less explored. The few studies on this research issue are mostly aimed at understanding the impacts of trade credit at a micro level, generally in niche markets. For instance, the empirical study conducted in Barrot (2016) concluded that a reform restricting the supply of trade credit by French trucking firms leads the corporate default probability to drop by one-fourth in the sector, while Jacobson and Von Schedvin (2015) find that trade creditors that issue more trade credit are more exposed to trade debtor failures. By evaluating the roles of financial constraints and creditor-debtor interrelationships, the authors also detect that the trade credit failure propagation mechanism is driven by both credit losses and demand shrinkage. In fact, the authors show that the evidenced propagation mechanism constitutes a significant part of the overall bankruptcy frequency, which clearly suggests that it has measurable implications at more aggregate levels. Examining data for a sample of Spanish manufacturing SMEs over the 2000–2007 time period, Martínez-Sola et al. (2014) concluded that managers can improve firm profitability by providing financing to customers. Meanwhile, a U-shaped relationship between trade credit and profitability was found in Petersen and Rajan (1997).

The model developed in Barbosa et al. (2017) interestingly shows how competition between informed and uniformed credit suppliers weakens the usual link between trade credit cost and the borrower's creditworthiness, while Yang (2011) explores the relationship between trade credit and bank loans. The latter finds that the use of trade credit and bank credit can be either complements or substitutes. In periods of monetary tightening, trade credit is mainly a substitute for bank borrowing, while in periods of monetary loosening trade credit and bank loans are mostly complements. In this vein, Mateut et al. (2006) explores the channel of monetary policy transmission when trade credit is included among the alternative sources of external finance. Based on the idea that sellers have an information advantage over banks, so that they may have incentives to ameliorate credit conditions for borrowers and at the same time raise their profits, the authors examine the evidence using panel data from a large sample of manufacturing firms in the UK. They find that in a monetary tightening it turns out that bank loans decline in absolute and relative terms and trade credit increases. Besides, when they separate small firms from medium and large firms, and then compare the responses over tight and loose monetary policy, they detect that it is the small (and potentially financially weaker) firms that are excluded from bank loans and these firms resort to trade credit.

The purpose of this paper is to contribute to the literature on the considerably less explored issue of the economy-wide effects of trade credit by assessing its macroeconomic impacts on several dimensions. In order to accomplish this purpose, we develop herein an agent-based model (ABM) with two types of firms: downstream firms, which produce a final good for consumption using intermediate goods, and upstream firms, which supply the inputs to the downstream firms. Inputs are produced exclusively on demand, as required and then ordered by downstream firms. Meanwhile, the wage bill paid by upstream firms is used to buy the consumption good produced by downstream firms. Upstream firms can act as trade credit suppliers, by allowing delayed payment of a share of their sales to downstream firms. A "deep-pocketed" banking system supplies the residual credit passively. We choose an ABM framework given that the complex interactions and interrelationships among firms give rise to strong nonlinearities, which are better addressed by this kind of modeling.[1]

Some ABMs (e.g., Battiston et al., 2007; Gatti et al., 2010) contemplate trade credit in their structure. However, in these models, this is mostly done in a simplified fashion. Trade credit corresponds to 100% of the cost of inputs, which are paid at the end of the period. We improve upon the assessment of trade credit relative to these models mainly in two key aspects: (i) trade credit is to be paid back in installments over several periods and (ii) the availability of trade credit is measured by a parameter which defines the maximum proportion of inputs that can be purchased through trade credit; a sensitivity analysis on this parameter is then performed, allowing us to revealingly assess how changes in the supply of trade credit by upstream firms impacts on the macroeconomic variables of the system.

This paper fits well the theme of this Special Issue, "Economics and Complexity for a Smart, Inclusive and Sustainable Growth and Development", at least for two reasons. First, this paper deals with credit (and, specifically, trade credit) which is arguably a key driver of economic growth and development. Second, as intimated earlier, traditional general equilibrium models have serious limitations in tackling the economy when the latter is properly conceived as a complex adaptive system. In this case, ABM, which is the modelling tool we are applying here, is one of the main alternative approaches that can be more promisingly employed.

In addition to this introduction, this paper contains four other well-delimited parts. Section 2 outlines the structure of the model. The results of basic simulations are shown in Section 3. Section 4 then performs a sensitivity analysis of the parameter measuring the supply of trade credit, thus interestingly assessing its impacts on several micro and macroeconomic variables of the model. Concluding remarks are contained in the last section of the paper.

2. Description of the model

The model economy herein is considerably adapted from Alexandre and Lima (2017). It is populated by five groups of agents: (i) downstream (D) firms, which produce and sell the single, homogeneous final good for consumption (we abstract from capital accumulation and hence from investment demand, so such a final good serves consumption

[1] For a critical comparison between ABMs and more traditional equilibrium-oriented (notably, DSGE) models, see, for instance, Fagiolo and Roventini (2012).

purposes only), (ii) upstream (U) firms, which produce and supply the single, homogeneous input to D-firms, (iii) a "deep-pocketed" banking system, which provides banking credit to firms of both types, (iv) households (workers and shareholders), who consume goods produced by D-firms, and (v) the government, which carries out fiscal policy.

Upstream firms use only labor to produce the intermediate good, while D-firms' technology requires only such input supplied by U-firms in order to produce the final good. An individual D-firm's sales are a proportion of aggregate effective demand, which is composed by the aggregate wage bill (paid only by U-firms) and dividends. An individual D-firm's output production can be either equal to or lower (engendering unfulfilled demand) or higher (engendering unsold production) than the respective firm's share in aggregate effective demand. It is supposed that both types of firms nonetheless operate in an imperfect information environment, which then allows them to set different prices. Firms with a net worth below a threshold level are expelled from the model, and any bankrupt firm is replaced by a new one.

The matching mechanism between D- and U-firms works as follow: less risky (less leveraged) D-firms order inputs – which are produced on demand – from the U-firms setting the lowest markups. Given our emphasis in this paper on the implications of trade credit between downstream and upstream firms, a proportion of these inputs will be paid in future periods. The remaining inputs required by a given D-firm will be paid in the current period through the use of either its net worth or banking debt. Downstream and upstream firms have long-run leverage targets, which set an upper limit to the respective ratio of total debt (including trade credit, in the case of D-firms) to net worth.

As it turns out, there is an intricate multidimensional interdependence between the downstream and upstream firms' financial robustness. In effect, if an individual D-firm has its net worth reduced, it will then demand a lower amount of inputs from U-firms. In case of bankruptcy of an individual D-firm, part of any outstanding debt in the form of trade credit will not be paid back to the creditor U-firm(s). Moreover, any revenue problems faced by upstream firms may lead them to reduce their scale of production, which will result in a decrease in aggregate effective demand that will then negatively impact on the downstream firms' sales and profits.

The following subsections detail the behavior of each component of the model.

2.1. The matching process

A large number of downstream firms, indexed by $i = 1, \ldots, N^D$, produce the final consumption good using the input supplied by upstream firms. Meanwhile, several upstream firms, indexed by $j = 1, \ldots, N^U$, produce this input using only labor. For simplicity and to keep the focus on the main issue of the implications of trade credit, we assume that there is only one type of final consumption good, and only one type of input, so that both of them are homogeneous. It is further assumed that both downstream and upstream firms operate as imperfectly-competitive producers and suppliers under conditions of imperfect information on the part of buyers and sellers in order to allow for the logical possibility of price heterogeneity.

It is assumed that D-firms prefer to buy from upstream firms charging the smallest prices (given that inputs are homogeneous), whereas U-firms are prone to negotiate with D-firms that have a smaller target leverage. This is due to the possibility of trade credit, which occurs when part of the inputs is not paid at sight, but it is instead paid back in installments over several consecutive future periods. In effect, less leveraged D-firms have a lower probability of bankruptcy, a financial troublesome situation that will lead U-firms to not recover some part (or even all) of the trade credit granted to a given D-firm.

More precisely, D-firms are sorted in ascending order according to their target leverage and the U-firms, according to their markup. The less leveraged D-firm negotiates and closes a deal with the U-firm charging the smallest markup. If this D-firm is still willing to purchase more inputs, it approaches the next U-firm in the list. This process is repeated until the fulfillment of all demand for inputs placed by D-firms or the utilization of all the available capacity of U-firms to supply it.

An individual U-firm can use either its own resources (net worth) or banking loans to hire labor and produce the amount of inputs demanded by D-firms. A "deep-pocketed" banking system supplies unlimited banking credit to D- and U-firms. Banking loans are to be paid back in full at the end of the production-and-sale period. Meanwhile, firm's leverage (total debt-to-net worth ratio) cannot be greater than a target leverage l^T. The maximum additional banking credit to be granted to a given U-firm j is given by:

$$B_{j,t}^{MAX} = l_{j,t}^{T} NW_{j,t} - D_{j,t}^{S}, \tag{1}$$

where $NW_{j,t}$ is the net worth of a given U-firm j and $D^S_{j,t}$ is such U-firm j's total debt. U-firms produce the input using hired labor according to a linear production technology given by $Q_{j,t} = L_{j,t}$. Therefore, the maximum amount of inputs that a given U-firm j is able to produce is given by:

$$Q^{MAX}_{j,t} = \frac{NW_{j,t} + B^{MAX}_{j,t}}{w}, \tag{2}$$

where w is the nominal wage received by one unit of labor. Similarly to U-firms, D-firms also have a maximum leverage equal to l^T. The maximum amount of inputs that a given U-firm j is willing to sell through trade credit is $mQ^{MAX}_{j,t}$, where $0 < m < 1$ is a measure of the maximum proportional supply of trade credit granted by a given U-firm j. Therefore, the flow of trade credit between a given D-firm i and a given U-firm j at period t is equal to:

$$Q^{TC}_{i,j,t} = \min\left(mQ^{MAX}_{j,t}, \frac{l^T_{i,t}NW_{i,t} - D^S_{i,t}}{w(1+\mu_{j,t})}\right), \tag{3}$$

where $D^S_{i,t}$ is the total stock of debt (trade credit plus banking loans) of a given D-firm i and $\mu_{j,t}$ is the markup charged by a given U-firm j. Hence, a given U-firm j sets the price of its input by applying a markup on the nominal wage (which, given its linear production technology with labor productivity equal to one, is equivalent to applying a markup on the unit labor cost). As a result, $Q^{TC}_{i,j,t}$ is the minimum between the maximum amount of inputs that a given D-firm i can buy through additional debt and $mQ^{MAX}_{j,t}$. If necessary, D-firms can resort to credit granted by the banking system to purchase any amount of inputs which could not be purchased through trade credit. The maximum additional banking credit to be allocated to a given D-firm i is given by:

$$B^{MAX}_{i,t} = l^T_{i,t} - D^S_{i,t}. \tag{4}$$

The amount of inputs paid at sight instead of paid back in installments over several consecutive future periods is then given by:

$$Q^S_{i,j,t} = \min\left(Q^{MAX}_{j,t} - Q^{TC}_{i,j,t}, \frac{NW_{i,t} + B^{MAX}_{i,t}}{w(1+\mu_{j,t})}\right) \tag{5}$$

and the amount of credit granted by the banking system to a given D-firm i is represented by:

$$B^F_{i,t} = \max(0, K^S_{i,j,t} - NW_{i,t} - D^S_{i,t}), \tag{6}$$

where $K^S_{i,j,t} = (1+\mu_{j,t})wQ^S_{i,j,t}$. Similarly, the cost of the inputs purchased through trade credit is given by $K^{TC}_{i,j,t} = (1+\mu_{j,t})wQ^{TC}_{i,j,t}$. Therefore, a given D-firm i will purchase from a given U-firm j an amount of inputs equal to $Q_{i,j,t} = Q^S_{i,j,t} + Q^{TC}_{i,j,t}$ at a cost given by $K_{i,j,t} = K^S_{i,j,t} + K^{TC}_{i,j,t}$.

2.2. Production, profits, and net worth dynamics

The relationship between the output of each individual D-firm, $Y_{i,t}$, and the quantity of inputs purchased from U-firms, which is given by $Q_{i,t} = \sum_j Q_{i,j,t}$, is represented by the following production function:

$$Y_{i,t} = \alpha Q^{\beta}_{i,t}, \tag{7}$$

where $\alpha > 0$ and $0 < \beta < 1$ are exogenously fixed (and uniform across firms) parameters.

The nominal revenue of a given D-firm i at period t corresponds to a share $0 < s_{i,t} < 1$ of the aggregate nominal demand, A_t:

$$A_t = R^H_{t-1} + wL_t + \delta\pi_{t-1} - NWNF_{t-1}. \tag{8}$$

When an individual firm is deciding how much to produce, it does not know either its individual market share $s_{i,t}$ or A_t. Aggregate effective demand is composed of household cash (R^H_{t-1}) plus dividends paid to shareholders of D- and U-firms in the previous period ($\delta\pi_{t-1}$) and the aggregate wage bill paid by U-firms (wL_t), minus any net worth of the new firms ($NWNF_{t-1}$). This feature of the model will be further described later. The parameter δ is the (constant) proportion of distributed profits, which is uniform across firms, whereas π is the aggregate nominal profit of firms. Note that, for the sake of simplicity, we set the propensity to consume of households to 1.

The nominal profit of an individual D-firm is given by:

$$\pi_{i,t} = \min(p_{i,t}Y_{i,t}, s_{i,t}A_t) - K^S_{i,t} - PR_{i,t} - i_{i,t}D^S_{i,t}. \tag{9}$$

The first term in the expression above is the respective firm's revenue. It corresponds to the firm's share, $s_{i,t}$, of aggregate effective demand, which cannot be greater than the firm's nominal production. After production, D-firms calculate their unitary cost of production, considering all inputs paid at sight and purchased through trade credit: $\frac{K_{i,t}}{Y_{i,t}}$. Finally, they determine the price of the final consumption good, $p_{i,t}$, by applying an individual markup, $\mu_{i,t}$, on the unitary cost. Any remaining unfulfilled demand will be converted into household cash, R^H_t, which is then added to aggregate effective demand in the next period. Both goods depreciate completely after one period, thus all firms start any given period with no inventories. The value of the inputs purchased through trade credit is amortized in t_D periods. Therefore, a given proportion equal to $1/t_D$ of the trade credit negotiated at period t is paid back between $t+1$ and $t+t_D$. D-firms' costs include the value of inputs paid at sight, $K^S_{i,t}$, the pro rata payment of trade credit ($PR_{i,t}$), and the interest rate charged on total debt (trade credit and banking loans), $i_{i,t}D^S_{i,t}$. The nominal interest rate charged on each individual D-firm, $i_{i,t}$, equal to $i^B(1 + l^{\gamma}_{i,t})$, where i^B is the base interest rate (which is exogenously set by the monetary authority), $l_{i,t}$ is the degree of leverage of a given D-firm i, and γ is a positive risk premium parameter, $0 < \gamma < 1$. As a result, the interest rate paid by an individual firm is increasing (at a decreasing rate) in its risk level, as measured by the respective leverage.

The nominal profit of an individual U-firm is given by:

$$\pi_{j,t} = K^S_{j,t} + PR_{j,t} + iK^{TC}_{j,t} - wL_{j,t} - i_{j,t}D^S_{j,t} - NPL_{j,t}. \tag{10}$$

The amount of revenues of the U-firms include the value of the inputs paid at sight by D-firms, $K^S_{j,t}$, the pro rata payment associated with any previously granted trade credit, $PR_{j,t}$, and debt commitments associated with the stock of trade credit debt, $iK^{TC}_{j,t} = \sum_i i_{i,t}K^{TC}_{i,j,t}$. The amount of expenses of the U-firms are the respective wage bill, $wL_{j,t}$, the interest paid on banking debt, $i_{j,t}D^S_{j,t}$, and any non-performing loans ($NPL_{j,t}$), which follow the definition of bad debt presented in Gatti et al. (2007): $\sum_{i\in H}\max(\zeta_j NW_i, -Ki^{TC})$, where ζ_j is the trade credit granted by a given U-firm j to a given D-firm i as a proportion of the total trade credit granted to such D-firm i and H denotes the set of eliminated D-firms with negative net worth. The nominal interest rate charged on an individual U-firm, $i_{j,t}$, is set in a similar fashion to $i_{i,t}$.

The markup of an individual D-firm follows a behavioral rule, which is adapted from Dosi et al. (2013) as follows[2]
:

$$\mu_{i,t} = \mu_{i,t-1}(1 + \phi\frac{s_{i,t-1} - s_{i,t-2}}{s_{i,t-2}}), \tag{11}$$

where $0 < \phi < 1$. The expression above can be interpreted in the following way: if an individual D-firm loses market share, it will try to recover it by reducing its markup (as described in Eq. (12)). For upstream firms, we adopt a simpler adaptive rule: when a given U-firm obtains a null market share, it sets its markup equal to 80% of the average markup of the U-firms. A variation in the market share of a given D-firm will also impact on its target leverage according to:

$$l^T_{i,t} = l^T_{i,t-1}(1 + \lambda\frac{s_{i,t-1} - s_{i,t-2}}{s_{i,t-2}}), \tag{12}$$

where $0 < \lambda < 1$. The change in $l^T_{(i,t)}$ is constrained to the interval given by [10%, +10%] per period, which is intended to impose sufficient cautiousness on agents' willingness to adjust their desired leverage. A rise in the demand for their output production will lead D-firms to revise upwards their desired leverage: they will ask for more loans in order to produce more and realize higher sales. This rule can also be intuitively thought of as being driven by the very rationale of the banking system and the U-firms, as they are both willing to lend to the more profitable D-firms.

[2] As in Gatti et al. (2010), D-firms are key drivers of the dynamics of the system, as U-firms produce inputs as demanded by D-firms and the banking system grants credit passively. For this reason, we choose to set more complex behavioral rules solely for variables referring to downstream firms (markup, market share and target leverage).

The market share of an individual D-firm is initially set as proportional to its net worth and evolves according to the following rule inspired in Dosi et al. (2013):

$$s_{i,t} = s_{i,t-1}(1 + \frac{\mu_t^M - \mu_{i,t-1}}{\mu_t^M}), \tag{13}$$

where μ_t^M is the average markup at period t. Consequently, more price-competitive firms increase their market share.

Meanwhile, the dynamics of the net worth of an individual D-firm is given either by $NW_{i,t} = NW_{i,t-1} + (1 - \delta - \tau)\pi_{i,t}$, if $\pi_{i,t} > 0$, or $NW_{i,t} = NW_{i,t-1} + \pi_{i,t}$, otherwise. The parameter τ is strictly in the interval between 0 and 1 and represents the tax rate. At any period, firms with a net worth below a threshold level κ are expelled from the model. For simplicity, the number of firms is kept constant through the operation of a one-to-one replacement rule to be described shortly.

The sum of the market shares of bankrupt D-firms is randomly distributed among entrant firms. The relevant attributes of the entrant firms (net worth, leverage target, and markup) are established according to the normal distribution represented by $N(M^I, 0.2M^I)$, where M^I is the average value of the respective attribute of incumbent firms. These values take into account the minimum levels specified in the Appendix.

2.3. The government

The government has a budget surplus that evolves according to:

$$\Gamma_t = \Gamma_{t-1} + \tau \sum_{\pi>0} \pi_{i,t} - E_t. \tag{14}$$

Thus, the government revenues are composed of taxes collected from downstream and upstream firms with positive profits. Following Riccetti et al. (2015), the government has a role in financing the new entrants. The government' expenditures, E_t, will be any net worth of the new firms, but keeping a surplus of at least 90% of the initial surplus:

$$E_t = \min(\Gamma_t - 0.9\Gamma_1, NWNF_t). \tag{15}$$

The residual net worth of new firms, if any, will be subtracted from households' funds, as set in Eq. (8), up to the limit of 99% of their resources. If money to finance the new entrants is still needed, the government intervenes, incurring in a surplus smaller than its benchmark level (which can even be negative). It should be stressed that, as there is no injection of new resources in the model when new firms replace the defaulted ones, we guarantee the stock–flow consistency of the model.

3. Results of simulations: basic statistics

This section describes some basic statistics generated by the model. We run 50 simulations of 1000 periods each. They are then ranked in decreasing order according to their variance and the top 10 in the list are excluded. Finally, we calculate the average considering the remaining 40 simulations. The value of the parameters and the initial conditions are displayed in the Appendix.

Fig. 1 displays the real output and price level of the consumption good for some representative values of m. Recall that m represents the maximum proportion of inputs that U-firms are willing to sell through trade credit, so that m is a measure of the maximum proportional supply of trade credit. We assume that m is uniform across U-firms. Note that the system more or less stabilizes after a reasonable transient period, with the variables oscillating around a stationary value. There is no long-run positive growth tendency, which is expected given the lack of any source of economic growth. A nonlinear relationship between m and the real output, as well as the price level of the consumption good, seems to hold. These variables reach their maximum value with $m = 5\%$ and then decrease for larger values of m. We will explore this nonlinearity in more detail in the next subsection.

Regarding the nominal credit-to-output ratio (Fig. 2), which encompasses both trade and bank credit, it can be detected a positive correlation between this variable and m. Nevertheless, the system goes through a process of deleveraging after the transient period. The relationship between non-performing loans, also shown in Fig. 2, and m is apparently nonlinear, although this variable seems to be less volatile for higher values of m.

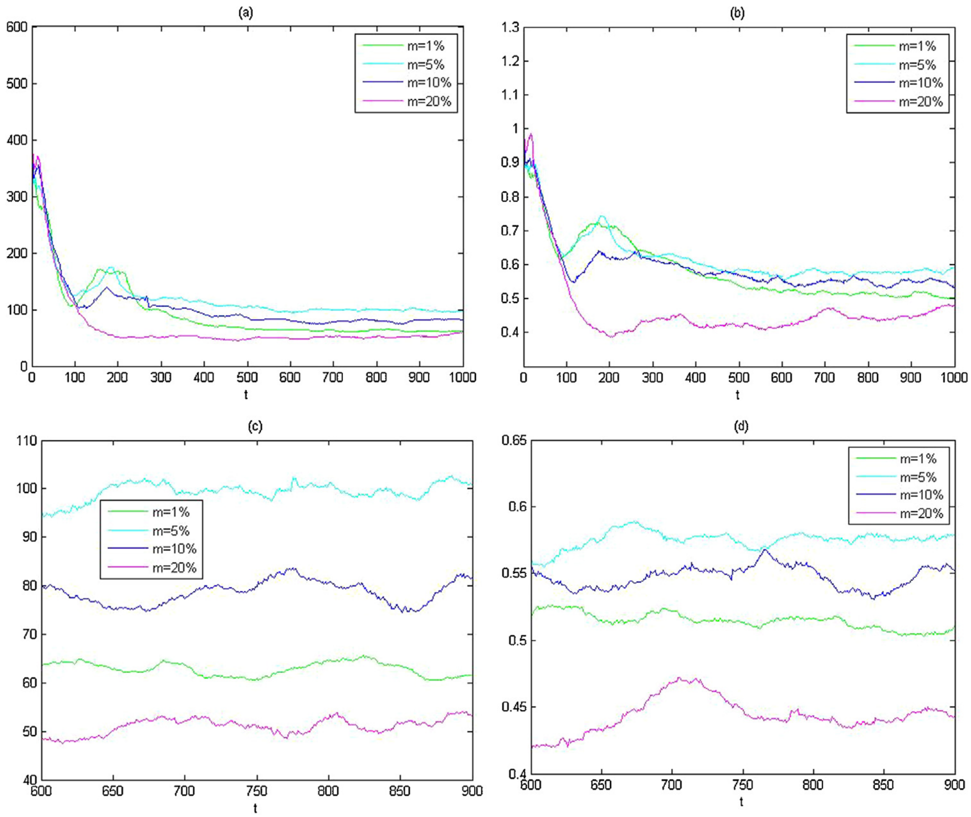

Fig. 1. Output and price for different levels of m. Figures (a) and (b): real output and price level of the consumption good. Figures (c) and (d): the same variables displayed in a narrower time window.

Fig. 3 displays the cumulative distribution function of the net worth of the firms for some representative values of m. It can be seen that, for values of net worth greater than 1, the distribution is well represented by a power law[3] in the form of the following equation:

$$P(x > X) = X^{-\theta}. \tag{16}$$

Our results go in hand with empirical findings. In fact, Fujiwara et al. (2004), for instance, assessed the size of firms as measured by total assets, sales and number of employees in four European countries (Italy, Spain, France and UK) from 1993 and 2001. They concluded that the upper-tail of the distribution can be fitted with a power law. They also estimated a value for the Pareto index (θ) around 1, a value arguably close to the 1.2 that we have found in our simulations for both downstream and upstream firms, as reported in Fig. 3.

4. Sensitivity analysis: a varying *m*

4.1. Sensitivity analysis

The previous section provided us some revealing insights on the relationship between the parameter m, which is a measure of the maximum proportional supply of trade credit by U-firms, and some variables of main interest. In this section, we intend to go further and deeper in this analysis. We will change m between 0% and 25% in increments of

[3] Power laws are pervasive in economics, being observed in distributions of city and firm sizes, stock market returns, and other variables. They help to understand many economic phenomena, such as aggregate economic fluctuations. The existence of power laws suggests that size distribution is more affected by random shocks with small frictions than by economic underpinnings. In firm size distribution, for instance, power laws defy static theories of firm, grounded on elements such as economies of scope, fixed costs, and elasticity of demand Gabaix (2016).

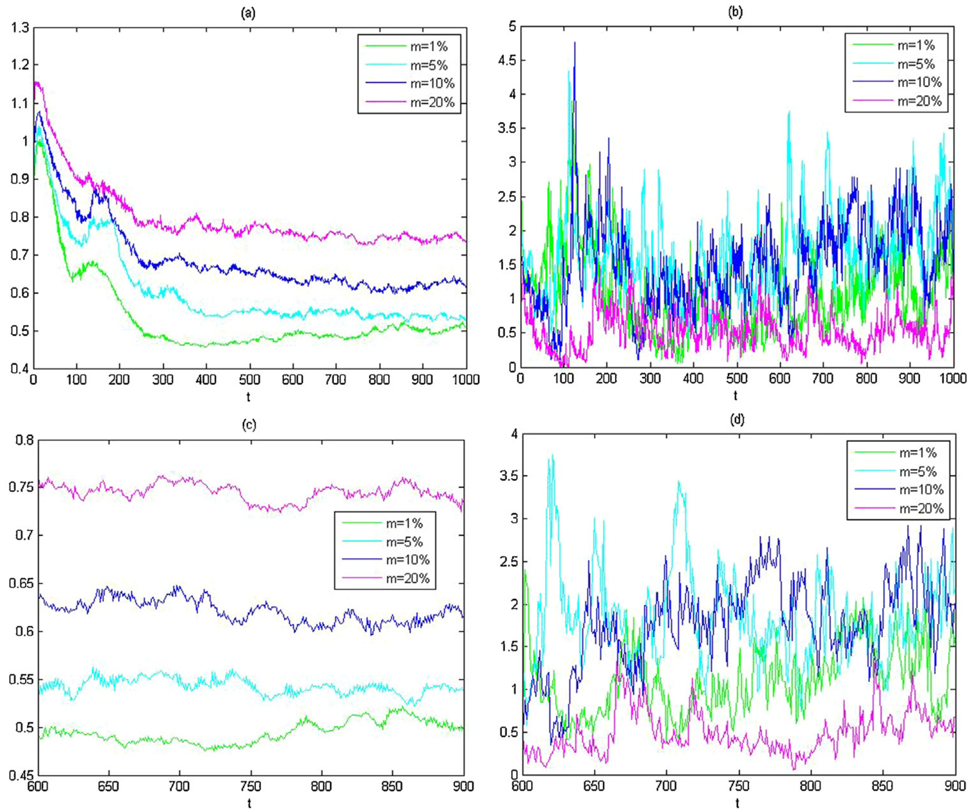

Fig. 2. Credit and non-performing loans for different levels of m. Figures (a) and (b): nominal credit-to-output ratio and non-performing loans as a percentage of total credit. Figures (c) and (d): the same variables displayed in a narrower time window.

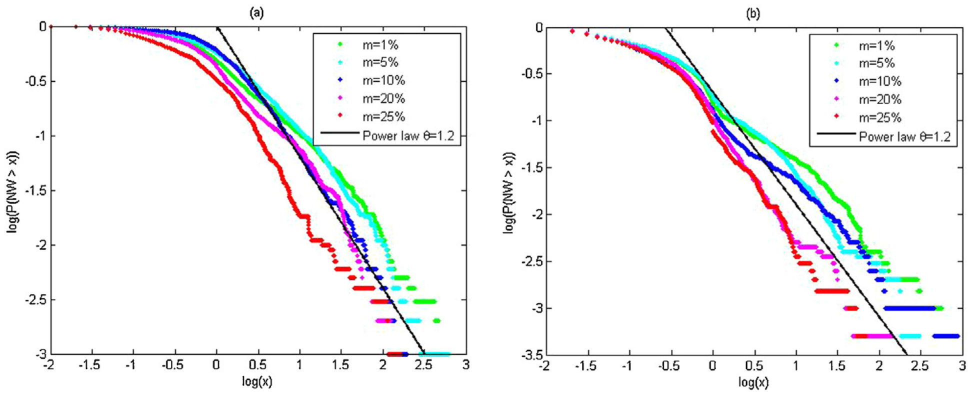

Fig. 3. Distribution of firms' net worth for different levels of m. Cumulative distribution function of the net worth of downstream (a) and upstream (b) firms. Logs are at base 10. We have considered the values of firms' net worth at period $t = 1000$ of 50 simulations.

0.5% and assess, in more detail, how this change impacts on the average behavior of real and financial variables of main interest. For each value of m, which is still assumed to be uniform across U-firms, we run 50 simulations of 1000 periods each, excluding those with the highest volatility as measured by their variance, as we did in Section 3.

As expected, the proportion of inputs negotiated by U-firms through trade credit actually increases with m (Fig. 4). However, this relationship is concave. In fact, as m increases, so does the negative gap between the actual proportion of trade credit granted and the maximum proportion of production that U-firms are willing to sell through trade credit.

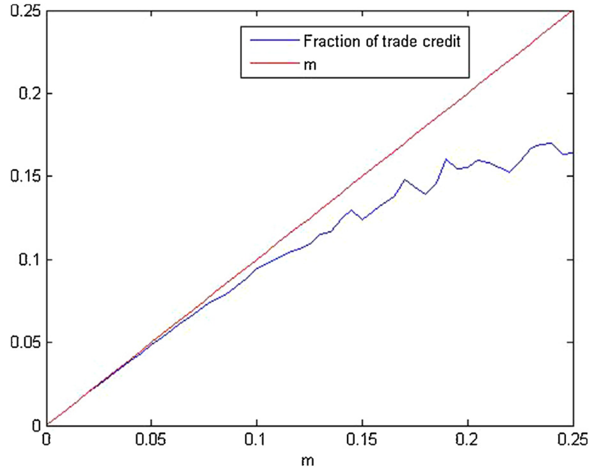

Fig. 4. Relationship between m and the fraction of trade credit. Proportion of inputs negotiated by U-firms through trade credit.

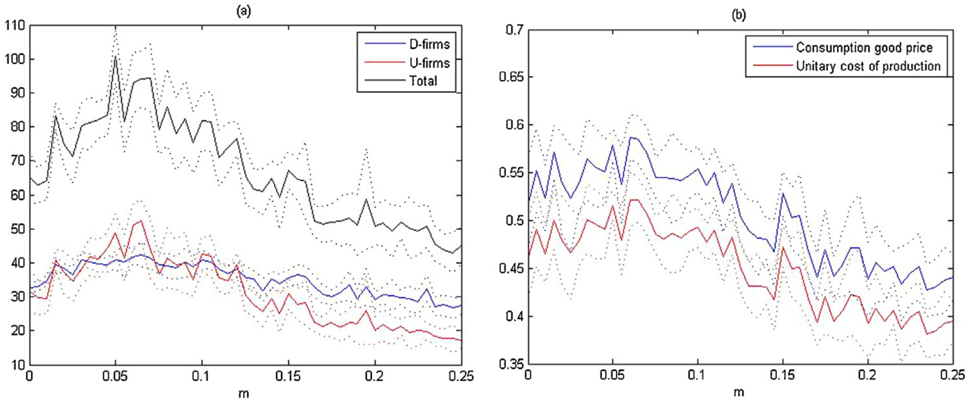

Fig. 5. Response of output and price to changes in m. Average real output (a) and average price level (b). Dashed lines correspond to the confidence interval, computed by adding (subtracting) 2 standard deviations to (from) the average.

There is also a nonlinear relationship between the real output and the parameter m (Fig. 5). This nonlinearity is also observed when the proportion of inputs negotiated through trade credit instead of m is considered, as seen in Fig. 6. These variables reach their peak at m around 5% and then starts to fall as m increases. This decline is stronger for the upstream firms. When m surpasses a value close to 12%, there is a consistent gap between the output of downstream firms and that of upstream firms. The same relationship with m is observed regarding the price of the consumption good and the unitary production cost. While there is not a clear relationship between the volatility of the price, as measured by the respective coefficient of variation, and m, the real output tends to become more volatile as the availability of trade credit increases (Fig. 7).

As expected, an increase in m results in a rise in the trade credit as a proportion of the total credit (Fig. 8). In fact, it reaches almost 60% for $m = 25\%$. The proportion of the total bank credit granted to upstream firms is not significantly affected, while the bank credit granted to downstream firms loses participation in the total credit. The overall effect is an increase in the nominal credit-to-output ratio.

Meanwhile, Fig. 9 pictures the degree of market concentration of production, as measured by the Hirschman-Herfindahl Index (HHI), corresponding to different values of m. Although the HHI in the consumption goods sector is not clearly and discernibly affected by changes in m, there is a nonlinear relationship between the market concentration in the input-producing sector and this parameter. The HHI of the input-producing sector reaches its maximum at m around 7% and then declines until reaching a level similar to that of the consumption good sector.

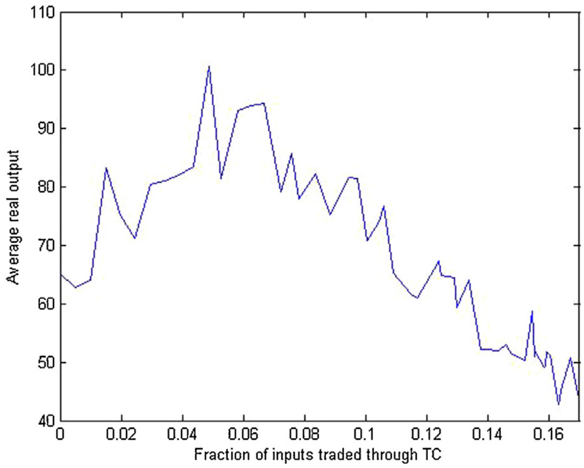

Fig. 6. Response of output to changes in the trade credit fraction. Average real output as function of the proportion of inputs negotiated through trade credit.

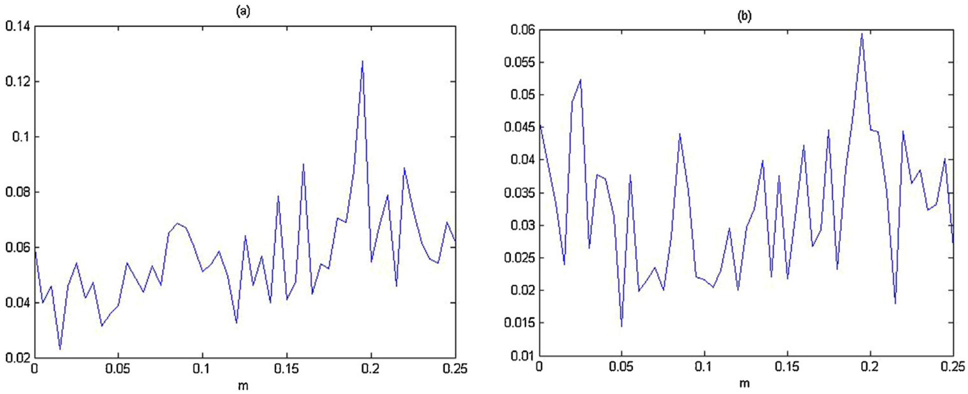

Fig. 7. Response of output and price volatility to changes in m. Coefficient of variation of the real output (a) and the consumption good price (b).

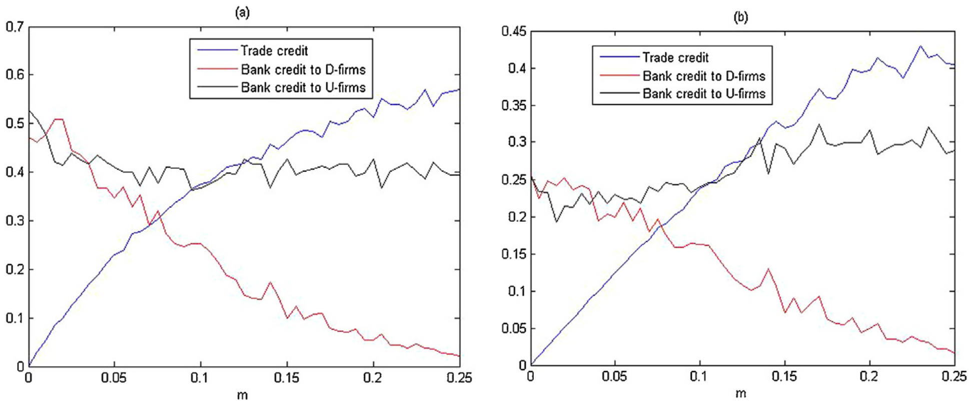

Fig. 8. Response of credit to changes in m, by type of credit. Composition of total credit (a) and nominal credit-to-output ratio (b).

The non-performing loans-to-credit ratio is higher in the case of the banking credit for values of m smaller than around 10%. For higher values of m, an increase in this parameter causes a decline in the NPL of both types of credit, with this reduction being more intense for the banking credit, as shown in Fig. 10.

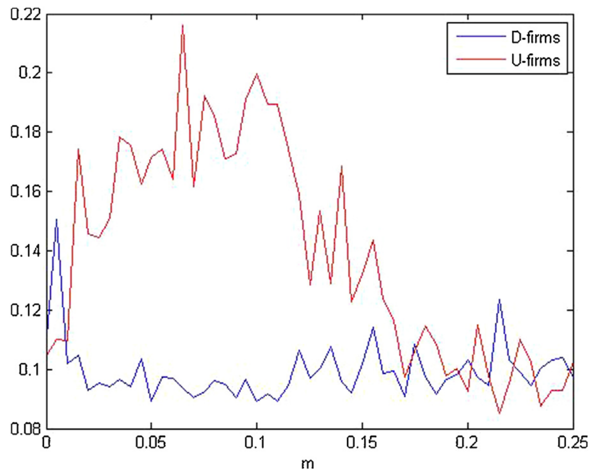

Fig. 9. Response of market concentration to changes in m, by type of firm. HHI of production of downstream and upstream firms.

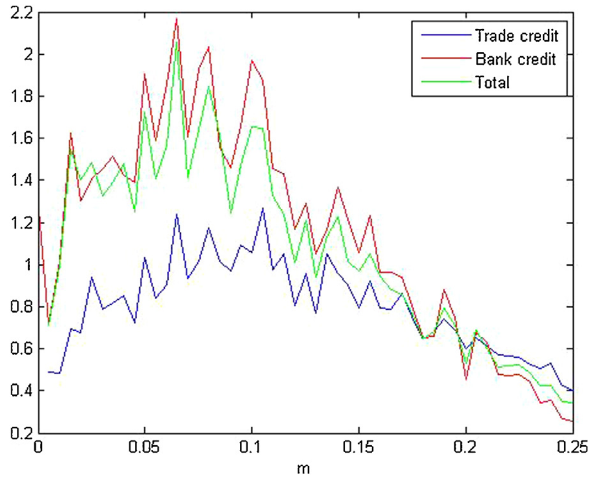

Fig. 10. Response of NPL to changes in m, by type of credit. NPL-to-credit ratio.

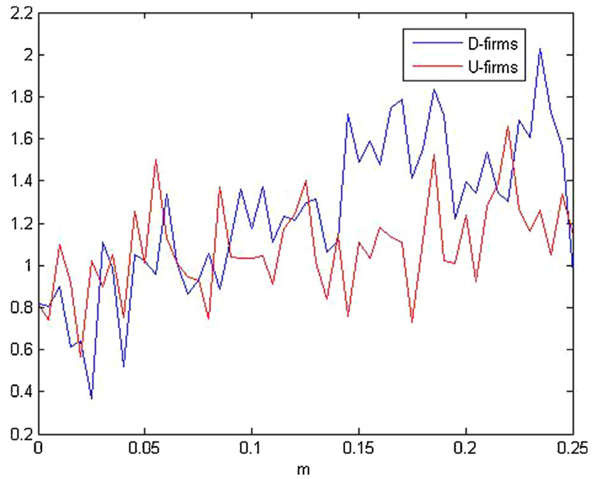

Fig. 11. Pareto index for the firms' net worth distribution as function of m, by type of firm. Pareto index for the firms' net worth distribution. Eq. (16) was estimated varying X between 1 and 100. We have considered data of period $t = 1000$ of 50 simulations. R^2 ranges between 0.8835 and 0.9948.

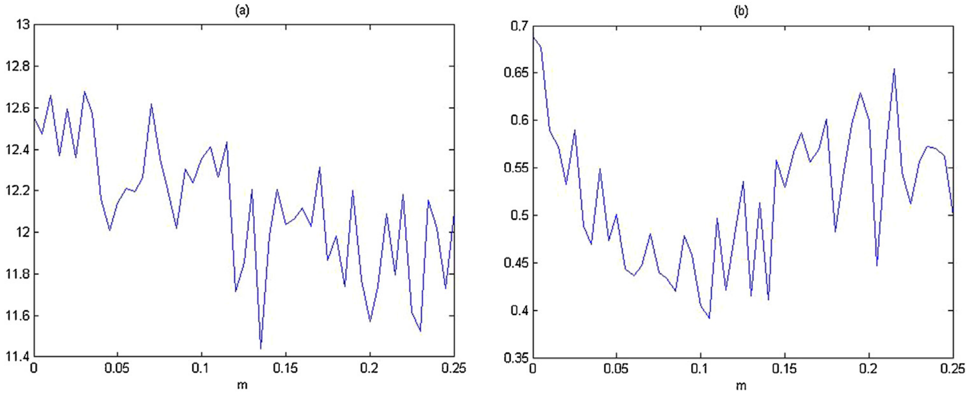

Fig. 12. Response of markup to changes in m, by type of firm. Average markup (in %) for downstream (a) and upstream (b) firms.

Fig. 11 shows the Pareto index for the distribution of firms' net worth estimated for each value of the parameter m. It can be seen that there is a positive correlation between m and the Pareto index in both sectors. The intuition for this result seems to be that, for higher values of m, the probability of appearance of larger firms is smaller.

The average markup is depicted in Fig. 12. The average markup of downstream firms is considerably larger than that of upstream firms. There is a negative correlation between D-firms' average markup and m. As for the U-firms, this relationship is nonlinear, taking a U-shaped form.

4.2. Discussion

In ABMs, the large quantity of variables interacting in a nonlinear way makes inference of causality a very hard analytical task. For this reason, the analysis of the results generated by these computational models is usually carried out through a qualitative discussion based on correlations and regularities.

Our results suggest the existence of a trade-off between the level of output and financial stability as far as the supply of trade credit is concerned. For a sufficiently large value of m, increases in this parameter provides greater financial stability (in the form of a decline in the non-performing loans-to-credit ratio), but causes a decrease in the average output level.

Regarding the relationship between financial stability and the availability of trade credit, there seems to exist two mechanisms, with opposite effects, through which trade credit affects U-firms. With a greater proportion of inputs negotiated through trade credit, U-firms are negatively affected by the maturity mismatch between revenues and expenses, as all wage bill is paid at sight while part of the payments for the inputs will be (potentially) received in future periods. On the other hand, a sort of "internalization" of interest payments into the real sector seems to occur: a larger amount of interest service that would be paid on loans granted to firms by the banking sector is now paid to downstream firms, which keeps these financial resources in the productive sector.[4] After a threshold level of m, the positive effects engendered by the internalization of interest services seem to more than offset the negative effects stemming from the maturity mismatch between revenues and wage expenses. Due to the positive feedback featured in the interaction between the two types of firms (D-firms demand inputs from U-firms, while U-firms pay the wage bill that will be used to buy the consumption goods produced by D-firms), a greater availability of trade credit potentially increases the financial robustness of both downstream and upstream firms, which enhances their capacity to service their financial commitments.

Meanwhile, as documented in the empirical literature, trade credit is especially beneficial to smaller firms. This is corroborated, in our results, by the decline in the HHI of the production of the upstream firms (Fig. 9) and the increase in the Pareto index (Fig. 11) brought about by higher levels of m. The consequent greater competition contributes to

[4] Recall that trade and bank credit have the same cost in our framework so that they are perfectly interchangeable. More trade credit also creates an internalization of losses, though: any default of final consumption good firms spreads throughout the real sector with more intensity. However, our results (the decrease of non-performing loans for higher values of m) suggest that this does not seem to be a major concern.

the fall in the markups (mainly for downstream firms), as Fig. 12 shows, which in turn reduces profits and dividends and reduces aggregate demand formation. Therefore, it is possible that a greater availability of trade credit, through the channel just described, contributes to decline in the average output level.

5. Concluding remarks

We set forth an ABM featuring intermediate goods firms that operate as credit suppliers, by allowing a delayed payment of part of their sales to consumption goods firms. Although this feature is already present in other ABMs, we went beyond the way trade credit is addressed in previous models mainly in two key dimensions: trade credit is to be paid in installments over several consecutive future periods, rather than at the end of the production-and-sales period, and a varying parameter (for simulation purposes) specifies the availability of trade credit (in other ABMs, trade credit simply corresponds to the totality of inputs costs).

We performed a sensitivity analysis on the parameter specifying the supply of trade credit. This allowed us to assess how changes in the availability of trade credit affect some macroeconomic variables of interest in our artificial economy. Our results suggest that there is a trade-off between financial stability and the average output level. For values of the parameter measuring the availability of trade credit above a given level, further increases in it bring about a decline in the non-performing loans-to-credit ratio, but also on the average output level. A plausible explanation for these results is the following: a greater availability of trade credit allows more financial resources to remain circulating in the real sector of the economy. A larger proportion of the interest service on loans that would be paid back to the banking system by downstream firms is now paid back to upstream firms. Given the positive feedback existing in the interaction between the two types of firms that arises from their reciprocal demand relationships, a greater availability of trade credit potentially contributes to improve the financial robustness of the real sector as a whole. However, trade credit is relatively more beneficial to smaller firms, thereby enhancing competition and reducing markups, profits, and dividends. Thus, trade credit potentially contributes to a decline in aggregate demand formation and consequently in the average output level.

Needless to mention, the results coming from ABMs should always be taken and interpreted with caution. Identifying causality between variables is a cumbersome exercise in ABMs owing to the several feedback loops and severe nonlinearities that they typically feature. Furthermore, these models suffer from over-parametrization and high sensitivity to parameters and initial conditions. Nevertheless, they provide quite useful analytical insights that should be taken into consideration. In the specific model we set forth in this paper, its stock-flow consistency and the logical coherence and empirical and theoretical plausibility of its key assumptions lend greater credibility to qualitative and quantitative results. Moreover, some specific predictions generated by the model (e.g., a nonlinear relationship between the availability of trade credit and non-performing loans) can be further logically evaluated and refined in analytical models and empirically tested in econometric models.

Finally, as a topic for future research, it would be interesting to assess how the monetary policy would or should work in the presence of this alternative type of credit. Suppose, for instance, that a monetary policy tightening is adopted, leading to an increase in the cost of the traditional (banking) credit. If trade credit remains available (which may not be the case if the potential suppliers of trade credit are also negatively affected by such monetary tightening), credit-seeking firms could possibly resort to trade credit as an alternative to the more expensive (and/or less available) banking credit. Of course, even if the supply of trade credit is not negatively affected, credit-seeking firms may not demand more trade credit precisely because their sales expectations are worsened by the given monetary tightening. In any case, a relevant issue that requires investigation is whether the lack of regulatory restrictions to trade credit arrangements can eventually negatively impact on the effectiveness of monetary policy.

Appendix: Parameters and initial conditions

Symbol	Meaning	Value
N^D	Number of downstream firms	20
N^U	Number of upstream firms	40
α	Production parameter (see Eq. (7))	3
β	Production parameter (see Eq. (7))	0.7

δ	Proportion of profits distributed as dividends	0.25
τ	Tax rate	0.25
t_D	Duration of trade credit (in periods)	3
i^B	Base interest rate	0.02
γ	Risk premium parameter	0.02
ϕ	D-firms' markup sensitivity to a change in market share (Eq. (11))	0.2
λ	D-firms' leverage sensitivity to a change in demand (Eq. (12))	1
κ	Minimum net worth	0.01
w	Nominal wage	1
$NW_{i,0}$	D- and U-firms' initial net worth[a]	$NW_{i,0} \sim \mathcal{N}(10, 2)$
$\mu_{i,0}$	D- and U-firms' initial markup[b]	$\mu_{i,0} \sim \mathcal{N}(0.15, 0.03)$
$l^T_{i,0}$	D- and U-firms' initial target leverage	$l^T_{i,0} \sim \mathcal{U}(0.01, 3)$
Γ_0	Government initial surplus	10,000

References

Alexandre, M., Lima, G.T., 2017. Combining monetary policy and prudential regulation: an agent-based modeling approach. J. Econ. Interact. Coord., 1–27, http://dx.doi.org/10.1007/s11403-017-0209-0.

Barbosa, K., Moreira, H., Novaes, W., 2017. Interest rates in trade credit markets. J. Money Credit Bank. 49 (1), 75–113.

Barrot, J.-N., 2016. Trade credit and industry dynamics: evidence from trucking firms. J. Finance 71 (5), 1975–2016.

Battiston, S., Gatti, D.D., Gallegati, M., Greenwald, B., Stiglitz, J.E., 2007. Credit chains and bankruptcy propagation in production networks. J. Econ. Dyn. Control 31 (6), 2061–2084.

Biais, B., Gollier, C., 1997. Trade credit and credit rationing. Rev. Financ. Stud. 10 (4), 903–937.

Burkart, M., Ellingsen, T., 2004. In-kind finance: a theory of trade credit. Am. Econ. Rev. 94 (3), 569–590.

Carbo-Valverde, S., Rodriguez-Fernandez, F., Udell, G.F., 2016. Trade credit, the financial crisis, and SME access to finance. J. Money Credit Bank. 48 (1), 113–143.

Choi, W.G., Kim, Y., 2005. Trade credit and the effect of macro-financial shocks: evidence from US panel data. J. Financ. Quant. Anal. 40 (4), 897–925.

Cunat, V., 2006. Trade credit: suppliers as debt collectors and insurance providers. Rev. Financ. Stud. 20 (2), 491–527.

Demiroglu, C., James, C., Kizilaslan, A., 2012. Bank lending standards and access to lines of credit. J. Money Credit Bank. 44 (6), 1063–1089.

Dosi, G., Fagiolo, G., Napoletano, M., Roventini, A., 2013. Income distribution, credit and fiscal policies in an agent-based Keynesian model. J. Econ. Dyn. Control 37 (8), 1598–1625.

Fagiolo, G., Roventini, A., 2012. Macroeconomic policy in DSGE and agent-based models. Rev. OFCE (5), 67–116.

Fujiwara, Y., Di Guilmi, C., Aoyama, H., Gallegati, M., Souma, W., 2004. Do Pareto-Zipf and Gibrat laws hold true? An analysis with European firms. Phys. A: Stat. Mech. Appl. 335 (1–2), 197–216.

Gabaix, X., 2016. Power laws in economics: an introduction. J. Econ. Perspect. 30 (1), 185–206.

Gatti, D.D., Di Guilmi, C., Gallegati, M., Giulioni, G., 2007. Financial fragility, industrial dynamics, and business fluctuations in an agent-based model. Macroecon. Dyn. 11 (S1), 62–79.

Gatti, D.D., Gallegati, M., Greenwald, B., Russo, A., Stiglitz, J.E., 2010. The financial accelerator in an evolving credit network. J. Econ. Dyn. Control 34 (9), 1627–1650.

Jacobson, T., Von Schedvin, E., 2015. Trade credit and the propagation of corporate failure: an empirical analysis. Econometrica 83 (4), 1315–1371.

Klapper, L., Laeven, L., Rajan, R., 2011. Trade credit contracts. Rev. Financ. Stud. 25 (3), 838–867.

Martínez-Sola, C., García-Teruel, P.J., Martínez-Solano, P., 2014. Trade credit and SME profitability. Small Bus. Econ. 42 (3), 561–577.

Mateut, S., Bougheas, S., Mizen, P., 2006. Trade credit, bank lending and monetary policy transmission. Eur. Econ. Rev. 50 (3), 603–629.

Norden, L., van Kampen, S., 2015. The dynamics of trade credit and bank debt in SME finance: international evidence. RBA Annual Conference Volume.

Petersen, M.A., Rajan, R.G., 1997. Trade credit: theories and evidence. Rev. Financ. Stud. 10 (3), 661–691.

Riccetti, L., Russo, A., Gallegati, M., 2015. An agent based decentralized matching macroeconomic model. J. Econ. Interact. Coord. 10 (2), 305–332.

Uchida, H., Udell, G.F., Watanabe, W., 2013. Are trade creditors relationship lenders? Jpn. World Econ. 25, 24–38.

Yang, X., 2011. Trade credit versus bank credit: evidence from corporate inventory financing. Q. Rev. Econ. Finance 51 (4), 419–434.