Financial Instability after Minsky: Heterogeneity, Agent Based Models and Credit Networks

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1 Introduction[1]

Albeit the majority of the profession either ignores Minsky's *Financial Instability Hypothesis* (FIH) or considers it plainly wrong, at least since the mid-80's a few influential economists – who have certainly not embraced any unorthodox credo – have grown more receptive to this idea and eager to incorporate it in their models, even if diluted and sometimes disguised in order to make it more palatable to the conventional "representative" macroeconomist.

Due to the asymmetric information revolution in microeconomics, in fact, and the associated emphasis on capital market imperfections, Minsky's ideas have got renewed attention and a large macroeconomic literature has developed in which financial factors play a major role: Greenwald and Stiglitz (1993,2003), Bernanke and Gertler (1989, 1990), Kiyotaki and Moore (1997). For the sake of simplicity, we will lump together these models under the general heading of the *Financial Accelerator Hypothesis.* Bernanke, Gertler and Gilchrist (1999) cast the Financial Accelerator story in a New Keynesian - Dynamic Stochastic General Equilibrium framework. More recently, in the light of the Global Financial Crisis, a variety of "financial frictions" have been incorporated in NK-DSGE models: A non exhaustive list includes Christiano, Motto and Rostagno (2010), Curdia and Woodford (2009), Gertler and Kiyotaki (2011), Gerali *et al.* (2010), Angeloni and Faia (2009).

Starting from different cultural and methodological premises, this literature yields predictions which are in line with some of the insights one can get from Minsky's conceptual framework. In other words, the Financial Accelerator and the Financial Instability hypotheses share some features. Should we be satisfied with this? I don't think so. *Minsky's legacy goes beyond the emphasis on the role of financial factors and provide important directions for future research.* In my opinion the role of *heterogeneous financial conditions* is the specific piece of Minsky's intellectual heritage that has been so far underresearched and that

[1] The present paper draws heavily on Assenza, Delli Gatti and Gallegati (2010).

may be the cornerstone of a new research agenda. Albeit the FIH can be formulated without making explicit reference to heterogeneity (section 2), at a deeper level Minsky develops his ideas in an heterogeneous agents' setting, characterized by *hedge, speculative* and *Ponzi* units (section 4). On the other hand, the Financial Accelerator literature is still mainly based on the Representative Agent, heterogeneity been confined to an almost innocuous role (section 3).

The increasing availability of computational power has allowed the implementation of *multi-agent (or agent based) models* (ABM) so that we are at present equipped with an adequate (at least in principle) framework for the analysis of the role of heterogeneity in macroeconomics. [2]. I provide a skeletal example of an ABM with heterogeneous financial conditions in section 5. Last but not least, we have to take seriously the notion of *credit interlinkages* which connect financially constrained agents. In order to do so the multi-agent models we need should be based on an explicit *network* structure. This line of research is briefly illustrated in section 6. This conceptual framework allows to deal with the propagation of financial distress, an issue of the utmost importance in the generation of a financial crisis. Section 7 concludes.

2 Financial instability: The aggregate view

The core of Minsky's analysis is a *financial theory of investment* according to which investment is essentially driven by: (i) the volume of internal finance, (ii) the difference between the market price of capital assets (i.e. the Stock price) and the price of current output. The former depends upon long run expectations of profit flows while the latter is based upon expectations of demand conditions in the short run. Minsky's theory of investment determination is illustrated in figure 1.

The "quantity" of capital is measured on the x-axis and the "prices" of capital on the y-axis. Minsky draws a distinction, in fact, between the supply price of investment goods – which we assume for simplicity to be equal to the average price level (P) – and the market price of capital assets (V), which can be thought of as the present value of the stream of expected quasi rent per unit of capital. By assumption, it coincides with the Stock price.

Investment can be financed in part by means of internally generated funds, i.e. net worth (A) and in part by external finance. The maximum volume of investment which can be financed by means of internal funds is $K_0 = A_0$. If the firm chooses a level of investment greater than K_0, it has to raise funds on the credit market. In this case banks have to be remunerated for the risk they assume *(lender's risk)*, so that the actual supply price of investment goods for the borrowing firm is higher than the price of current output P_0. The schedule of the actual price of investment goods *(P schedule)*, therefore, is flat at P_0 until the maximum volume of internally financed investment K_0 is reached and is increasing thereafter.

[2] See Tesfatsion (2006) for a thorough introduction to agent based modelling.

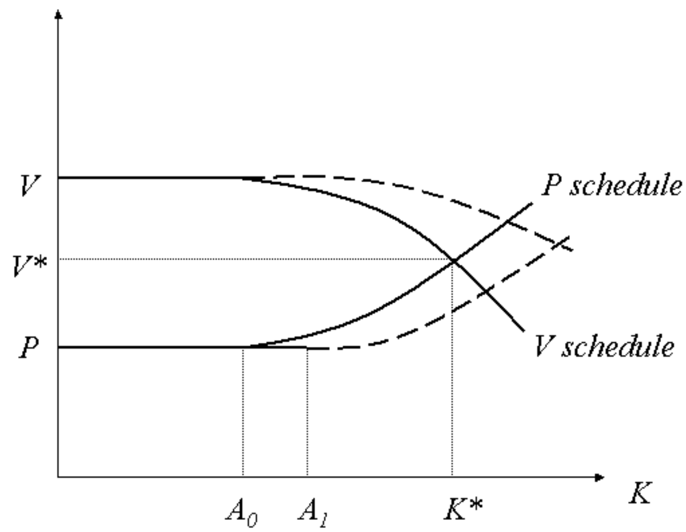

Figure 1: Minsky's theory of investment determination

By assumption, the quasi rent is increasing with the volume of net worth. If the firm chooses a level of investment greater than K_0, therefore, the risk of bankruptcy for the firm *(borrower's risk)* increases and the expected quasi rent decreases so that the actual Stock price is lower than the original one V_0. The schedule of the actual market price of investment goods *(V schedule)*, therefore, is flat at V_0 until the maximum volume of internally financed investment K_0 is reached and is decreasing thereafter.

The equilibrium volume of investment (K^*) and the equilibrium price of investment goods (V^*) are determined at the intersection of the V and P schedules. During booms, an increase in the availability of internal funds (for instance from A_0 to A_1) brings about an outward shift of both schedules as shown in the figure. Net worth, the capital stock, leverage and the Stock price will increase. Once the turning point of the cycle is reached, the schedules will vibrate in the opposite direction. Equilibrium investment depends upon the volume of internal finance, on the interest rate and on the degree of borrower's and lender's risk which affect the slopes of the V and P schedules.

The diagram above applies to the individual firm. In principle, all the determinants of investment can be firm-specific. Let's assume for the moment, however, that the Representative Agent assumption holds true. In this case, aggregate investment is:

$$K = K(A) \tag{1}$$

Equation (1) can be conceived of as the main building block of a skeletal Minskian macroeconomic framework. It is an *investment equation* which links capital accumulation to net worth. This equation can be complemented by, for instance, a profit equation *à la* Kalecki. Aggregate output can be determined by means of Keynes' theory of effective demand. Most of the aggregative Keynesian-Minskyan models developed in the '80s and early '90s following the seminal paper by Taylor and O'Connell (1985) are based on this type of equations (see for example Delli Gatti, Gallegati and Gardini, 1993).

3 Financial accelerator

Minsky's Financial Instability Hypothesis has represented the minority view in the profession until the mid '80s when the asymmetric information revolution in microeconomics has raised doubts about the plausibility of the Modigliani-Miller (MM) *irrelevance* proposition. Once one acknowledges that capital markets are imperfect due to informational asymmetries, the MM construct – according to which internal and external sources of funds are perfect substitutes so that the capital structure of the firm does not affect investment decisions – crumbles. Sources of finance are imperfect substitutes and can be ordered in a financing hierarchy in which internal finance comes first.

In this conceptual context financial factors are indeed crucial for investment and therefore for business fluctuations. The tools to deal with this phenomenon, however, were not available to the average neoclassical macroeconomist who had so far eagerly accepted the MM credo: "How does one go about incorporating financial distress and similar concepts into macroeconomics? While it seems that there has always been an empirical case for including credit-market factors in the mainstream model, early writers found it difficult to bring such apparently diverse and chaotic phenomena into their formal analyses. As a result, advocacy of a role for these factors in aggregate dynamics fell for the most part to economists outside the US academic mainstream, such as Hyman Minsky, and to some forecasters and financial market practitioners." (Bernanke-Gertler-Gilchrist, 1999, p.1344)

Over the last twenty years, a large literature has filled this void, incorporating financial factors in macroeconomic models, a line of research which we can label the *Financial Accelerator Hypothesis*. At least three frameworks have been proposed by Greenwald and Stiglitz (1993,2003) – GS hereafter –, Bernanke and Gertler (1989, 1990) – BG hereafter –, Kiyotaki and Moore (1997).

Consider for instance investment determination in BG. If the firm chooses a level of investment greater than the available internal funds, it has to raise funds on the credit market. In this case banks have to be remunerated for the risk they assume *(lender's risk)* so that the cost of funds for the borrowing firm – i.e. the return on lending for the bank – is higher than the risk free interest rate, the difference being the *external finance premium.* [3] An increase of net worth makes the external finance premium go down so that the rate of interest on loans goes down.

Investment determination in a GS framework is shown in figure 2.[4] If the firm chooses a level of investment greater than the available internal funds (i.e. greater than A_0) it has to raise funds on the credit market, running the risk of bankruptcy *(borrower's risk).* Since bankruptcy is costly, the cost of funds for the indebted firm goes up. The schedule of the actual *marginal cost* of funds, therefore, is flat until the maximum volume of internally financed investment $K_0 = A_0$ is reached and is increasing thereafter. The upward sloping portion of the marginal cost schedule incorporates the probability of bankruptcy. GS show that this probability is decreasing with net worth.

In an uncertain context, the relative price (i.e. the ratio of the individual price to the average price level) is unknown. GS assume that it is oscillating randomly in a certain interval (see the grey area). The horizontal line is the mathematical expectation of this random variable (i.e the expected relative price, equal to one).

The equilibrium volume of investment (K^*) is determined at the intersection of the marginal cost schedule and the expected relative price. An increase of net worth makes the marginal bankruptcy cost go down so that investment goes up as shown in the figure. Hence, equilibrium investment depends upon the volume of internal finance $K = K(A)$.

It is clear therefore that both in GS and in BG one can reach qualitatively the same conclusion that Minsky already put forward on the importance of financial factors – namely internal finance or net worth – on investment determination (see equation (1)). The context, however, is different. The financial accelerator theories are generally derived from the solution of an optimization problem of a rational representantive agent, often in a context of rational expectations, while Minsky casts the Financial Instability Hypothesis in a context of true Knightian uncertainty. This is clearly a major methodological divide. In our opinion, however, Minsky's ideas have indeed penetrated the protective belt of mainstream macroeconomics. *He got a point*, which is now at the centre of the debate in macroeconomics, expecially in the light of the Global Financial Crisis.

[3] As a matter of precision, in the original framework, BG assume that, due to ex post asymmetric information, the lender has to incur a monitoring cost to assess the return on the investment project he/she has financed (costly state verification). They show that in the optimal financial arrangement, the probability of monitoring – which is the is main determinant of the external finance premium – is decreasing with the borrower's net worth.

[4] As a matter of fact, GS (1988, 1993) have developed a framework in which there is no role for physical capital since the technology considered employs only labour. "Capital" in their framework is meant to be a wage fund and the need for finance is due to a production lag so that wages must be anticipated by the employers to the employees. For the sake of comparison we discuss in this section a simplified model in which physical capital is the only input. For simplicity, we can assume a one to one technology: $Y = K$.

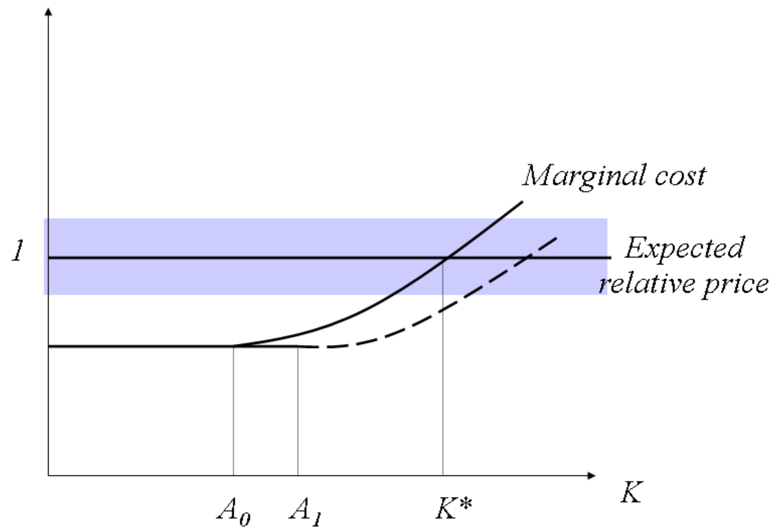

Figure 2: Investment determination in GS

4 Heterogeneous financial conditions: Minsky's taxonomy

Minsky's theory of investment determination can be formulated without explicit reference to heterogeneity as shown above. At a deeper and more significant level, however, *Minsky's ideas can be properly expressed only in an heterogeneous agents' setting.* The Financial Instability Hypothesis, in fact, is based on the distinction among *hedge, speculative* and *Ponzi* units.

"For hedge financing units, the cash flows from participation in income production are expected to exceed the contractual payments on outstanding debts in every period. For speculative financing units, the total expected cash flows from participation in income production when totaled over the foreseeable future exceed the total cash payments on outstanding debt, but the near term payment commitments exceed the near term cash flow from participation in income production, even though the net income portion of the near term cash flows ... exceeds the near term interest payments on debt. A Ponzi financing unit is a speculative financing unit for which the income component of the near term cash flow falls short of the near term interest payments on debt so that for some time in the future the outstanding debt will grow due to interest on existing debt. Both speculative and Ponzi units can fulfill their payment commitments on debts only by borrowing (or disposing of assets)" (Minsky, 1982:22-3).

In a "tranquil era" ("prosperous times"), both borrowers and lenders expect future cash flows to be more than enough to validate debt. Asset prices, which incorporate these expectations, increase relative to the price of current output, stimulating investments which in turn drive up output, profits and employment. Banks are less cautious in extending credit and firms are less cautious in borrowing. As a consequence hedge units, that is borrowers who are able to service debt in each and every period of the time horizon of their financial contracts, become speculative units. Borrowers who were speculative units, in turn, become Ponzi units, i.e. they have to borrow in order to service outstanding debt. As the proportion of hedge units in the population of borrowers decreases, *financial fragility* increases:

"over a period in which the economy does well, views about acceptable debt structure change. In the deal-making that goes on between banks, investment bankers, and businessmen, the acceptable amount of debt to use in financing various types of activity and positions increases. This increase in the weight of debt financing raises the market price of capital assets and increases investment. As this continues the economy is transformed into a boom economy." (Minsky, 1982:65-66).

In other words, in Minsky's heterogeneous agents setting, the increase of aggregate financial fragility during the expansion is due to the change of the *structure of the economy*, the weight of hedge units shrinking over time. When the perception spreads that in the aggregate cash flows do not validate debt any more – for instance because a stream of overextended borrowers goes bankrupt – the network of financial relations collapses and a *financial crisis* sets in.

Albeit very different, all of the Financial Accelerator theories consider economies characterized by imperfect and asymmetric information on financial markets. Implicitly or explicitly, therefore, they *should* be based upon the assumption of agents' *heterogeneity*. In the end, however, very few heterogeneous agents are dealt with in these models, basically one "representative" for each group of agents (firms, households, banks, etc.). This shortcut allows to resume the Representative Agent assumption, which is still the cornerstone of most of contemporary macroeconomics. [5] The awareness of its limitations, however, is spreading well beyond the circle of more or less dissenting economists.

5 Heterogeneous financial conditions: The agent based framework

The Financial Accelerator/Financial Instability story can be cast in a context of truly heterogeneous agents by means of *multi-agent (or agent based) models.*

[5] See Hartley (1997) for a detailed historical account of the development of the representative agent assumption and a thorough critique of its use and misuse.

I have been working on this line of research, together with Mauro Gallegati and a number of junior co-authors, for a few years. We have adopted the Greenwald-Stiglitz variant of the Financial Accelerator story to model individual behavior, so that, in a nutshell, the scale of activity at the firm level turns out to be a function of its net worth.[6] Here is the simplest example I can think of.[7]

Suppose the "financial robustness" of a firm is captured by the *equity ratio*: $a_i := A_i/K_i$ i.e. the ratio of net worth (or the equity base) to the capital stock.[8] As shown in Assenza and Delli Gatti (2012), in a GS framework, the (optimal) investment ratio k_{it} at time t (i.e. the ratio of individual investment to the average capital stock) is a non linear concave function of the equity ratio at time t-1 and of the interest rate: $k_{it} = k\left(a_{it-1}, r_t\right)$ (figure 3). For the sake of discussion, consider the simplest case of a corporate sector consisting of just two firms, indexed 1 and 2, whose equity ratios at time 0 are $a_{1,0}$ and $a_{2,0}$. The average equity ratio is a_0 so that the average investment ratio (growth rate of aggregate capital) is k_1. An increase of the average equity ratio would bring about also an increase of the average investment ratio (not shown). On the other hand, a mean preserving increase in dispersion (due to an increase of robustness of firm 2 and a decrease of robustness of firm1) would bring about a decrease of the average investment ratio as shown in the figure.

Hence the average investment ratio is function of the cross-sectional mean and variance of the equity ratio, given the interest rate: $k_t = g\left(a_{t-1}, V_{t-1}, r_t\right)$. *Heterogeneity (here captured by the variance) plays a macroeconomic role.* [9] This is the first building block of a skeletal post Minskian macroeconomic framework. It is an *investment equation* which links capital accumulation to the moments of the distribution of financial conditions.

Starting from the investment equation, the aggregate output gap can be determined by means of Keynes' theory of effective demand. We obtain an IS curve. *The moments of the distribution of the equity ratio are shift parameters of the IS curve.* The macroeconomic model can be closed by means of an LM curve.

In figure 4 we represent the macroeconomic equilibrium.

Suppose the mean and the variance of the distribution at time 0 are a_0 and V_0. In this case the macroeconomic equilibrium in time 1 is E_1. The moments of the distribution of financial conditions, however, change over time. They are the driving force of the model dynamics. Consider for example the case in which the

[6] See for instance Delli Gatti et al. (2003, 2005, 2008, 2011). Financial conditions play a relevant role also in agent based models which draw inspiration from other sources such as the EURACE model (Cincotti et al. 2010) or the "Keynes meeting Schumpeter" model (Dosi et al. 2010).

[7] The following draws heavily on Assenza and Delli Gatti (2012).

[8] The equity ratio is the reciprocal of leverage, which in turn is a measure of financial fragility.

[9] If only the first moment of the distribution (in our case: the average equity ratio) were important from a macroeconomic point of view, heterogeneity would be irrelevant and the modeller could confidently rely upon the representative agent as a convenient and realistic approximation. This is in a nutshell the argument put forward by Krusell and Smith (1998). In our framework, heterogeneity would be irrelevant if the k(.) function were linear.

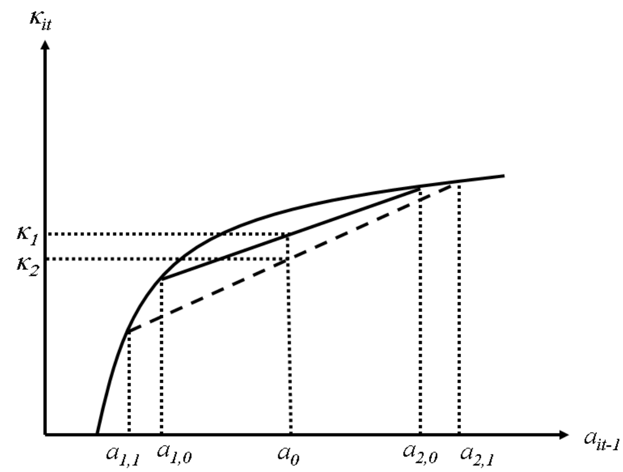

Figure 3: Investment and financial robustness

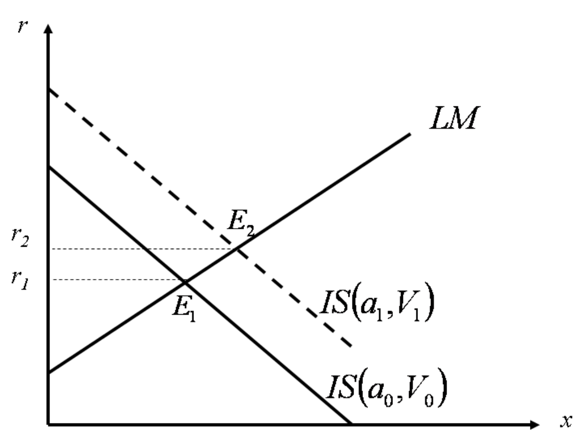

Figure 4: The macroeconomic equilibrium

mean of the distribution is increasing while the variance is decreasing ($a_0 < a_1$ and $V_0 > V_1$): the IS curve shifts up and the macroeconomic equilibrium moves from E_1 to E_2 characterized by a higher level of output and the real interest rate. Therefore, in equilibrium:

$$r_t = r\left(a_{t-1}, V_{t-1}\right) \tag{2}$$

In order to determine the law of motion of the moments, first of all we have to establish the law of motion of the individual equity ratio. As shown in Assenza and Delli Gatti (2012), the law of motion of the individual equity ratio is a non linear difference equation whose generic form can be represented as follows:

$$a_{it} = f\left(a_{it-1}, r_t\right) \tag{3}$$

In a multi-agent setting, the dynamics of the model are described by a myriad of laws of motion of the individual equity ratios, i.e. a multi-dimensional system of non-linear difference equations (subject to stochastic shocks). Since it is impossible to compute closed form solutions for such a system, we have to resort to computer simulations. From the output of these simulations it is immediate to compute the moments of the distribution of financial conditions (i.e. the cross-sectional mean and variance) for each time period.

Notice now that in equilibrium the interest rate is affected by the cross-sectional mean and variance of the equity ratios. Substituting equation (2) into (3) one gets:

$$a_{it} = f\left(a_{it-1}, r\left(a_{t-1}, V_{t-1}\right)\right) \tag{4}$$

so that the individual equity ratio turns out to be a function (through the interest rate) of the moments of the distribution. This is a *macroeconomic externality* whereby the economy-wide financial condition indirectly affects the individual financial condition.

This macroeconomic externality is the source of the financial accelerator, which is therefore affected by *heterogeneity.* In order to illustrate this point, suppose that over time the mean and the variance of the equity ratio tend to a long run value (which are the first and second moments of the long run distribution). In the long run, therefore, also the interest rate and the output gap tend to a stable value. Suppose, for instance, that the mean and the variance of the "long run" distribution are a_0^* and V_0^* (see figure 5). In this case the macroeconomic equilibrium is S_0^*. Suppose now that there is a monetary shock, i.e a downward shift of the LM curve. The impact effect of the monetary expansion is a reduction of the interest rate which boosts investment and makes the output gap increase (see point E_1). This is the end of the story in the textbook IS-LM model but not in the present framework. In fact, the reduction of the interest rate provides a boost to the equity ratio for each and every firm (it is indeed an aggregate shock), the cross sectional mean of the equity ratio therefore goes up. There is an effect also on the dispersion of the individual equity ratios around the cross sectional mean: The variance goes down. Therefore, due to the distributional effects of the monetary shock, the IS curve shifts up. The new long

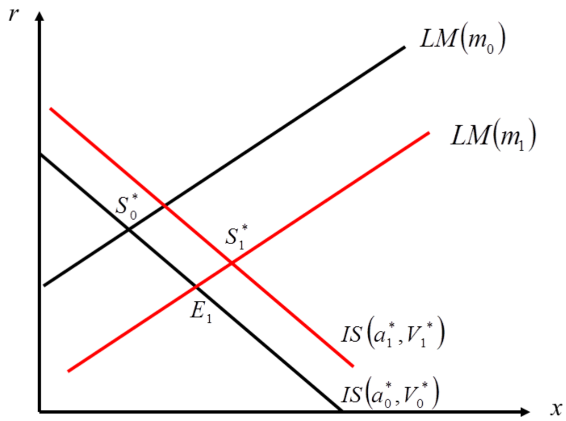

Figure 5: The effects of a monetary shock

run distribution of the firms' equity ratio will be characterized by $a_1^* > a_0^*$ and $V_1^* < V_0^*$. The effect on the output gap is clearly expansionary. The effect on the interest rate is in principle uncertain. From simulations, however, it turns out that also the interest rate goes down. The new long run macroeconomic equilibrium is S_1^*.[10]

6 Credit networks

Let us make another step forward. Building upon recent developments in the science of complexity, we can consider the economy as a *network* of relationships among heterogeneous interacting agents. Relationships may be "real" – i.e. pertaining to production, employment, consumption, investment, technology – or "financial", i.e. concerning borrowing/lending.

The economic activity of lending (and borrowing) can take the form of extending a loan (when the lender is a bank) or purchasing a financial asset – such as a share or a corporate bond – when the lender is a private investor. Financial relationships are pervasive and closely related to real economic activity. They

[10] It is interesting to note that a monetary expansion, in this setting, brings about a shift not only of the LM curve (down) but also of the IS curve (up). This result is reminiscent of a similar outcome in Bernanke and Blinder's CC-LM model (Bernanke and Blinder, 1988): a monetary shock makes the LM curve shift down and the CC curve shift up. There is therefore an amplification of the shock – due to increased credit availability – on output, while the effect on the interest rate is somehow mitigated.

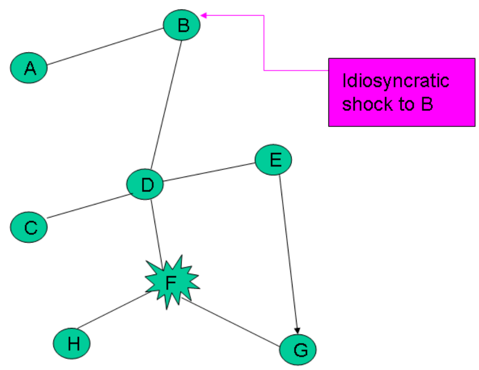

Figure 6: A credit network

establish connections (i) among households and banks on the market for deposits, (ii) among households and firms on financial markets, (iii) among banks on the interbank market, (iv) among firms and banks on the market for loans, (iii) among downstream firms (producing final goods) and suppliers (upstream firms, producing intermediate goods) on the market for trade credit.

We label the web of financial relationship a *credit network* in which nodes represent agents and links represent credit relationships. In this view, *externalities pervasive,* being the unavoidable outcome of agents' direct interaction.

Credit networks are continuously hit by shocks generated within the network – such as a random change in the behavior of one or more agents – or coming from outside – such as rumors of insolvency of one or more banks, maybe due to the onset of a recession. Finally, an agent can go bankrupt and bankruptcy can spread in shockwaves (see figure 6).

I have been working on this line of research, together with M. Gallegati, B. Greenwald, J. Stiglitz, S. Battiston and A. Russo for a few years. We have adopted the Greenwald-Stiglitz model of individual behavior (as in the agent based models discussed in the previous section). In a credit network, however, the scale of activity of an agent is a function not only of the agent's financial robustness (captured, for instance, by the equity ratio) but also of the financial robustness of her partners, i.e. the agents she is interacting with, represented by nodes of the network linked to the agent in question. [11]

[11] See Battiston et al. (2007, 2012a, 2012b) and Delli Gatti *et al.* (2009, 2010) for models of

In Battiston et al. (2012a) we assume that the law of motion of robustness of agent i is represented by

$$da_i = \sum_{j=1}^{k} W_{ij} a_j - a_i + \frac{\sigma}{\sqrt{k}} \sum_{j=1}^{k} W_{ij} d\xi_j - \alpha q(k) \tag{5}$$

where da_i is the change of robustness of agent i (in a small interval of time beginning in t), W_{ij} is the "weight" of partner/neighbor j in the portfolio of agent i while k is the degree of node i, i.e. the number of partners she is linked to (or the "size" of i's neighborhood). $\sum_{j=1}^{k} W_{ij} a_j$ is a weighted average of the neighbors' robustness in t: the financial condition of the neighborhood impacts upon the financial condition of agent i.The term $d\xi_j$ is an idiosyncratic shock which hits neighbor j's robustness at t, σ is the s.d. of the shock. $\sum_{j=1}^{k_i} W_{ij} d\xi_j$is a weighted average of the neighbors' shocks (average shock for short).

The establishment of links *(connectivity)* allows for the *diffusion* of an idiosyncratic shock in the network. A negative shock hitting neighbor j makes agent i more financially fragile but the neighbor has been able to discharge (a fraction of) the shock: distress propagation allows for *risk sharing (captured by t*he term $\sum_{j=1}^{k} W_{ij} a_j + \frac{\sigma}{\sqrt{k}} \sum_{j=1}^{k} W_{ij} d\xi_j$*)*. In their pioneering contribution Allen and Gale (2001) reach the conclusion that as the number of partners of each agent increases the risk of a collapse of the agent hit by the shock goes asymptotically to zero, thanks to risk sharing. The larger the pool of connected neighbours whom the agent can share the shock with, the smaller the risk of a collapse of the agent and therefore of the network, i.e. the higher *network resilience*. *Systemic risk* is at a minimum when the credit network is *complete*, i.e. when each agent is connected with all the other agents. In this case agents fully diversify individual risk. In other words, there is a monotonically decreasing relationship between the probability of individual failure/systemic risk and the degree of connectivity of the credit network.

The term $-\alpha q(k)$ captures a *positive feedback* of individual robustness on itself, i.e. *trend reinforcement.* Suppose agent i (as a borrower) is experiencing a period of decreasing financial robustness. Suppose the lender cannot discriminate but applies an interest rate which reflects the average financial fragility of all the k borrowers she has lent to. The interest rate charged to each and every borrower will increase because of the impact on average financial fragility of the increase in leverage of the borrower i. This is clearly a negative *pecuniary externality* of a financial relationship, i.e. an external effect which works its way from the borrower to the rest of the economy through the interest rate. The partners react ("punish") borrower i by making credit condition harder for the agent, i.e. by raising the interest rate. As a consequence, the financial robustness of agent i drops even further. Hence, in terms of financial fragility, "when things go bad, they can go worse". In a sense, trend reinforcement is the effect of a *network based financial accelerator.*

credit networks. For an overview of the most important issues in modelling credit networks, see Gallegati and Stiglitz (2011).

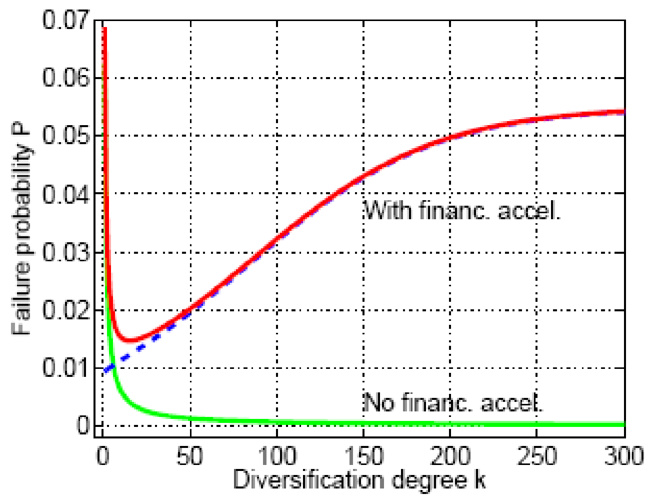

Figure 7: The probability of bankruptcy and the degree of the network

We can conceive of trend reinforcement as the expected value of a random variable equal to $-\alpha$ with probability q, zero otherwise.α measures the *amplitude* of the financial acceleration (further drop of robustness) which may occur when an agent becomes financially fragile; q is the probability of this further drop. In Battiston et al. (2012a) it is shown that q depends on the degree k.Hence $h = -\alpha q(k)$.

Why q depends on k and how? If the "environment" is relatively "noisy" (low k and therefore high $\sigma/\sqrt{k}$), a given decrease of robustness of agent i is considered "normal" and is not punished by the partners. Hence trend reinforcement is not activated. If, on the other hand, the environment is relatively "stable" (high k and low $\sigma/\sqrt{k}$), the same decrease of robustness is considered "abnormal" and is punished: trend reinforcement is activated. An increase of the degree k makes the environment more stable because allows for a better diversification of risk (it leads to a reduction of $\sigma/\sqrt{k}$) but in this case the probability of a punishment goes up: Trend re-inforcement is affected by the density of the credit network.

In the absence of trend reinforcement – i.e. if only risk sharing occurs – the average probability of bankruptcy P_f is monotonically decreasing with k.Moreover, when the number of agents (nodes) n is very large, P_f tends to 0 as k tends to $(n-1)$ *(completeness)*. With trend reinforcement P_f is **not** decreasing monotonically with k (see figure 7).

As k increases one can detect the emergence of a trade off between decreasing individual risk – due to risk sharing – and increasing systemic risk – due to trend reinforcement. The larger the number of connected neighbors, the smaller the risk of an individual collapse but the higher systemic risk and therefore the lower network resilience. In other words, the relationship between connectivity and systemic risk is not monotonically decreasing as in Allen and Gale, but hump shaped, i.e. decreasing for relatively low degree of connectivity and increasing afterwards. Hence, a regulator who aims at minimising the probability of default should not favour unbridled financial integration. On the contrary, she should keep the connectivity of the system at a reasonably low level. Joe Stiglitz has forcefully emphasized this point (Stiglitz, 2010).

In a credit network, shocks and their propagation can lead to bankruptcy. The bankruptcy of one agent is likely to generate the bankruptcy of a set of connected agents (avalanche of bankruptcies or bankruptcy cascade) so that the topology of the network is constantly changing over time. Suppose, for instance, that a firm goes bust. The net worth of the banks which extended loans to the bankrupt firm will bear the brunt of the default. The deterioration of the bank's financial condition may be absorbed if the size of the loan is small and/or the bank's net worth is high. If this is not the case, also the bank goes bankrupt. If the bank survives, however, it will restrain credit supply and/or make credit conditions harsher – raising the interest rate on loans across the board – for all its borrowers. Therefore, the default of one agent can bring about an avalanche of bankruptcies. While the proximate cause of the bankruptcy of a certain firm in the middle of the avalanche is the interest rate hike, the remote cause is the bankruptcy of a firm at the beginning of the avalanche that forced the banks to push interest rates up. The interest rate hike leads to more bankruptcies and eventually to a bankruptcy chain: "the high rate of bankruptcy is a cause of the high interest rate as much as a consequence of it" (Greenwald and Stiglitz, 2003: 145).

7 Conclusions

This paper provides an overview of issues that, in my view, should rank high in a research agenda on Financial Instability in the light of the Global Financial Crisis. The role of *heterogeneous financial conditions* in business fluctuations and in the generation of a financial crisis is the part of Minsky's legacy that may be the cornerstone of this new research agenda. I have sketched the conceptual blocks of two complementary modelling strategies: Agent based modelling and Network analysis. In both cases one can get important policy insights on the transmission mechanisms of policy moves and on the main issues facing regulators.

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