# Financial Frictions, Financial Shocks and Unemployment Volatility

Tito Boeri
Bocconi University and LSE

Pietro Garibaldi
University of Torino, Collegio Carlo Alberto

Espen R. Moen
University of Oslo

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**Abstract**

Financial market shocks and imperfections, alongside productivity shocks, represent both an impulse and a propagation mechanism of aggregate fluctuations. When labor and financial markets are imperfect, firms' funding and leverage respond to productivity changes. Models of business cycle with equilibrium unemployment largely ignore financial imperfections. The paper proposes and solves a tractable equilibrium unemployment model with imperfections in two markets. Labor market frictions are modeled via a traditional Diamond Mortensen Pissarides (DMP) model with wage positing. Financial market imperfections are modeled in terms of limited pledgeability, in line with the work of Holmstrom and Tirole. We show analytically that borrowing constraints increase unemployment volatility in the aftermath of productivity shocks. We calibrate the model to match key labor and financial moments of the US labor markets, and we perform two quantitative exercises. We first ask whether the interaction between productivity shocks and borrowing constraints increase the volatility of unemployment with respect to models that focus only on the labor market imperfections. In the general specification of the model, both leverage and non pledgeable income move with the cycle. Our calibration exercise shows that the volatility of unemployment in response to productivity shock increases by as much as 50 percent with respect to a DMP model with wage posting. The second quantitative exercise explores the role of pure financial shocks on aggregate equilibrium. We define financial distress as a situation in which internal liquidity completely dries up. The second exercise shows that full dry up of internal liquidity implies an increase in unemployment as large as 60 percent. These results throw new light on the aggregate impact of financial recessions.

# 1 Introduction

Following the Great Recession, there is a new interest in the aggregate dynamics of labor market. On the one hand, the surge in US unemployment in 2008 despite moderate productivity fall challenged the view that labor market dynamics can be mainly accounted for by productivity shocks. On the other hand, empirical research has established that unemployment volatility is larger during financial recessions. These facts and regularities forced scholars into investigating the links between financial frictions and unemployment.

There are at least two ways to study the interlinks between labor and finance over the business cycle. The first is to ask whether financial frictions propagate and amplify standard business cycle fluctuations. The second is to study the effects of financial shocks on the labor market. This paper offers a contribution into both dimensions. The key prerequisite for studying the interactions between labor and finance is to develop a tractable general equilibrium model of unemployment with financial frictions. This paper proposes a stochastic dynamic model in which aggregate productivity shocks induce fluctuations in both investment opportunities as well as in financial constraints. We integrate the Diamond Mortensen-Pissarides (DMP) model with the work of Holmstrom and Tirole in a tractable way. Part of a firm's funding come from pledgeable income and firms invest and build capacity within an imperfect labor market. Firms need funds to invest in both physical capital as well as in search capital. The latter is the accumulation of rents within an imperfect labor market. Funds come from external and internal liquidity. Internal liquidity comes from the internal cash flow of the firm, and depends on pledgeable income. External liquidity is an entrepreneur's own cash-flow and it is fully pledgeable. Both types of liquidity are subject to business cycle fluctuations.

The steady state of the model is calibrated to match key moments of the US labor market as well as the average leverage of non-financial non-listed firms in the US in 2006. We also calibrate non-pledgeable income using the parallel between pledgeability and collateral emphasized by Homstrom and Tirole (2011). The paper embarks into two quantitative exercises. We first investigate the amplifications effects of productivity shocks induced by financial market imperfections. In this first exercise, we take productivity shocks as the driving force of business cycle fluctuations, in the spirit of the recent work by Shimer (2005) and (2010), Hall (2005) and Hagedorn and Manovski (2008). Unlike these quantitative versions of the (DMP) model, we study in close details fluctuations to borrowing constraints and firms' funding. In our model, aggregate productivity changes affect investment opportunities, the labor market and- indirectly- firm funding. A natural amplification mechanism of aggregate shocks emerge from the simple theory. The analytical results show that financial frictions increase the responsiveness of the economy to productivity changes along two channels. The first amplification channel of productivity is an external effect. The second channel is a pledgeability effect. The economics of the these two effects is clear, and operate in the same direction. A fall in productivity causes a fall in profit per worker, exactly as in the original Pissarides (1988) model. If borrowing constraints are not endogenously responding to the productivity fall, general equilibrium and free entry of firms is ensured through a fall in the welfare value of unemployment. If funding responds to the fall in productivity, as it does in our theory, a productivity shock reduces leverage and the size of entrant firms along the two channels. Such a response at the entry margin amplifies the response of unemployment. Quantitatively, the increase in the responsiveness of unemployment to productivity changes is as large as 50 percent, particularly when the pledgeability effect is fully operating.

The second quantitative exercise deals with pure liquidity shocks at given aggregate productivity. Stochastic expected changes to pledgeability do not have any direct effect on profit per worker, but they affect borrowing constraints. Changes in financing possibility affect the firm investment opportunities, its scale of operation and its search capital. The challenge is to calibrate the financial shocks around the steady state level of leverage. We define financial distress as a situation in which firms internal funding for new firms completely dries up, and we calibrate these events to match the (low) frequencies of financial crises, as documented by Reinhart and Rogoff (2009) and by the recent work of Boissay et al. (2013). The exercise shows that a very adverse and unlikely financial shocks has strong aggregate effects. Technically, we show that a one-off full dry up of internal liquidity and the associated fall in leverage implies an increase in the level of unemployment as large as 60 percent. These results shed light on the aggregate impact of financial recessions, and are coherent with the main aggregate dynamics of the US in 2007-09, when vacancies plummeted, unemployment soared while output per hour barely moved. The time-line of the Great Recession is coherent with a realization of financial shocks early in 2007.

The paper proceeds as follows. Section 2 briefly summarizes the growing literature on financial recessions and its links to the labor market, and compares our approach to what has been proposed in the literature. Section 3 introduces the stochastic model focusing on its labor and the finance dimensions. The idea of search capital, leverage and internal liquidity are spelled out in this section. The section derives the equilibrium and the analytical links between business cycle fluctuations and unemployment volatility. Section 4 calibrates the steady state of the economy and performs the first quantitative exercise. Section 5 focuses on pure financial shocks and performs the second exercise. Section 6 summarizes and concludes.

## 2 Existing Literature and Motivating Facts

Labor and finance is a growing and vibrant field and various papers are now contributing to understanding the labor market impact of financial shocks and financial market imperfections on unemployment. In positioning the contribution of our paper in the literature, we review the motivating facts and the various brands of literature.

### 2.1 The early literature

The links between, on the one hand, financial market imperfections and, on the other hand, labour demand and unemployment, have been traditionally investigated along four main channels by the literature.

The first channel is a risk adjustment effect highlighted by Greenwald and Stiglitz (1993), based on a intuition by Hart (1983), when studying optimal labour contracts under asymmetric information and moral hazard. Greenwald and Stiglitz argue that capital market imperfections tend to increase risk aversion of firms, and, consequently, reduce the risk-adjusted marginal product of labour. The reduction in the marginal product of labour, in turn, negatively affects employment and labour demand. Furthermore, imperfections in capital markets can give rise to potentially large fluctuations in the effective marginal product of labour in a way that would not happen if the capital markets were to be perfect. If firms pay efficiency wages, these risk adjustment effects turn out to be amplified, so that there is a complementarity between imperfect capital markets and imperfect labour markets in amplifying cyclical fluctuations. This mechanism operates mainly via the layoff side.

The second channel is a quasi-fixed investment effect of labour demand: insofar as labour involves some ex-ante costs, e.g., training and hiring costs (Oi, 1962), the financing of such investment costs within imperfect capital markets affects the demand for labour. The best indirect rigorous application of this simple mechanism can be found in Farmer (1985) model of optimal contracting under private information, where firms have to finance a machine in order to hire workers. The presence of limited liability induces an equilibrium relationship between interest rate shocks and labour demand. Limited liability implies that a creditor receives a low return if the firm goes bankrupt, and consequently requires a higher return if the firm does not go bankrupt. In Farmer model, an increase in interest rates reduces employment even in a frictionless labour market, since the optimal contract then guarantees a higher interest rate if the lender does not go bankrupt, and, as a result, more firms choose to file for bankruptcy. This drives up unemployment during financial crises, via an increase in job destruction.

A third channel linking finance to employment emphasizes the stickiness of the bank-borrower relationship resulting from asymmetric information. On the one hand, long term bank-borrower relationships can be the result of adverse selection in the market for borrowers that switch lenders (Sharpe, 1990). On the other hand, long term bank-borrower relationships act as signalling mechanism to overcome the moral hazard problem (Holmstrom and Tirole, 1997). The presence of sticky relationships implies that specific shocks to financiers transmit quickly to hiring firms, and thus to labour adjustment.

A fourth channel analyses financial frictions within a New-Keynesian modelling approach. Seminal contributions include Bernanke and Gertler (1989), Carlstrm and Fuerst (1997) and Bernanke, Gertler and Gildchrist (1999). Financial frictions are described as in Townsends (1979) model, in which costly verification in times of distress creates bankruptcy costs so that investors shy away from bankruptcy risk. Persistence and propagation is created through the investors income flows and/or the value of machines used as collateral. Unemployment is not modelled or it is caused by sticky wages and prices.

Overall, the early literature has clearly many insights, but it is not concerned with equilibrium unemployment. In addition, its finance to labor effects operate mainly along the layoff- job destruction- side of the labor market.

## 2.2 Post Great Recession Research and Facts about Financial Recessions

After the Great Recession, involving a very large financial shock at least judging from financial market spreads or asset prices, various papers contributed to the understanding of the interplay between labour and finance. The field is indeed very vibrant, and it is not simple to make full justice to all the contributions

The financial crisis of 2008 led to a surge in interest in the macroeconomics of financial recessions, over and beyond its labor market dimension. Reinhart and Rogoff (2009) documented a large body of stylized facts on banking crises and financial recessions. To put things in perspective, we begin with some definitions. A 'financial and banking crisis' is an event during which the financial sector experiences bank runs, increase in default rates, capital losses, bankruptcy, etc. A recession is defined as a 'financial' when it takes place in concomitant with a banking crisis.

While the interest of this paper is on the labor market consequences of these event, we simply recall the key findings of financial recessions, following the recent empirical work by Boissay et al. (2013) and Siemer (2014)

1. Financial recessions are deeper and last longer than ordinary recessions. Boissay et al. (2013) argue that the drop in real GDP per capita from peak to trough is 40% bigger during financial recessions than during normal recessions. Financial recessions are longer and last one extra year, on average.

2. Financial recessions, or banking crises during recessions, are rare events. Boissay et al. (2013) find that banking crises have a yearly frequency of less than 5%, which means that a country experiences a banking crisis every 22 years. Only half of those are financial recessions, so that they happen once every 40 years.

3. The 2007-2009, arguably a financial recession, features an un-precedent decline in firm entry. The number of entering firms during the great recessions dropped by more than 25 percent, an un-precedent drop over the last 30 years (Siemer, 2014). In addition, Siemer (2014) estimates a differential impact of financial constraints on employment growth and finds that in the 2007-2009 recession employment growth in (small) firms with larger financial constraints was 5 percent lower than employment growth in less constrained firms.

We will use these background facts to motivate our theory. Fact 1 is the basic starting point of our research into the amplification effects of financial imperfections. Fact 3 suggests that firm entry

Table 1: Unemployment and GDP during financial recessions

| Country | Type of recession | du | du/u | dy/y | $\epsilon^a$ |
|---|---|---|---|---|---|
| US | Financial rec | 2.65 | 50% | -3.0% | 16.66 |
| | Other rec | 1.93 | 33% | -2.6% | 12.69 |
| | *Difference* | *0.72* | *17%* | *-0.4%* | *3.97* |
| UK | Financial rec | 2.10 | 36% | -3.2% | 11.25 |
| | Other rec | 0.50 | 7% | -3.1% | 2.25 |
| | *Difference* | *1.60* | *28%* | *0.0%* | *9.00* |

[a] Apparent elasticity of unemployment with respect to GDP.

Notes: Episodes of recessions with financial crises: UK 1975, 1990, 2008; US 1990, 2008.

UK: Unemployment data starting from Q1-1983; Employment Q2-1992; GDP and data starting from 1970;

US: Unemployment rate and Employment data starting from Q1-1970; GDP data from 1970.

Sources: OECD, US Bureau of Labor Statistics.

played a key role over the great recession, a feature that will be prominent in our theory. Fact 2 will help us calibrating the frequency of financial shocks. In terms of the labor market, our earlier work showed showed that recessions involving in their early stages a financial crisis feature a stronger employment and unemployment response than non-financial recessions (Boeri et al., 2013) .

Table 1 displays changes in unemployment during financial recessions. The Table shows that financial recessions are characterized by a larger unemployment response (in terms of both changes in the unemployment rate and percentage variations) than 'ordinary' recessions. The apparent elasticity of unemployment changes to GDP is as high as 16 during financial recessions in the US. While GDP contracts by some 3 percent, unemployment increase by as much as 50 percent. In normal recessions the same elasticity has a value of 12.69. Similar results hold for the United Kingdom, even though the absolute value of the elasticity is substantially lower. The same phenomenon is not observed in all other G7 economies. This is also not surprising, since labor market institutions clearly interact with the volatility of unemployment over the recessions. These findings are consistent with those of the IMF (2010).

There is also evidence of stronger falls in job creation in countries where firms faced a significant hardening of credit constraint, notably in terms of refinancing operations. In partoicular, evidence from a new European System of Central Banks survey (Wage Dynamics Network, WDN), covering 25 European countries, was addressed at measuring firms perceptions on the nature of shocks driving the Great Recession, suggest that the countries in which a highest proportion of firms stated to be facing serious problems of refinancing experienced the largest falls in monthly hiring as a proportion of employment

The empirical literature behind these facts is vast. Boeri, Garibaldi and Moen (BGM, 2013) review the empirical literature and provide new evidence using macro, sectoral and firm-level data. Chodorow-Reich (2014) and Bentolila et al. (2014) use loan level data for the US and Spain during the 2007/09 financial crisis to identify the effects of banks health on employment changes; Pagano and Piga (2010) use sectoral data to identify the impact of leverage and employment changes, using the methodology proposed by Rajan and Zingales (1998) to study the relationship between finance and growth. Boeri, Garibaldi and Moen (2013) as well as Giroud and Mueller (2015) find that it is highly leveraged firms to have experienced the largest employment losses in the aftermath of the financial recession of 2008-9. Pratap and Quintin (2011) consider the effects of financial crises on emerging markets, documenting that they involved large productivity and earning losses fror workers moving across industries.

### 2.3 Search, Financial Imperfections and Volatility

Within a more DMP labor finance literature, the pioneer work was Wasmer and Weil (2004) investigation of the interplay between matching frictions in both the labor and the financial markets. In such work, the matching function applies also to the meeting of entrepreneus and financiers. Wasmer and Weil show that a financial multiplier emerge in equilibrium. Merz and Yashiv (2007) discuss the relationship between adjustment costs of labor and the value of the firm. Michelacci and Quadrini (2009) analysed the effects of financial market imperfections on employment adjustment and the size distribution of firms. Kueh et al. (2012) integrated search theory with asset pricing. Boeri Garibaldi and Moen (2015) investigate the issue of firm refinincing, job destruction and the emergence of liquid asset within a Holmstrom and Tirole type of imperfection.

Finally, there is a growing set of papers that study the links between labor market volatility and the DMP framework. The baseline work is Shimer calibration of the Pissarides (1988) model without any financial friction. Eckstein et al. (2014) look at the real effects of borrowing spreads, so as to consider a different type of shocks with respect to a pure productivity shock. Petrosky-Nadaeu and Wassmer, (2013) study the dynamic effects and volatility effects of the double frictions á la Wassmer and Weil. Petrosky-Nadaeu (2014) looks at the financial frictions in the vacancy costs. Garin (2015) and Iliopolus et. al. (2015) investigate the effects of shocks to collateral in a Kiotaky and Moore (1997) fashion. These papers show that in an environment in which borrowing limits are linked to the firms physical capital stock can quantitatively account for the sluggish response of labor market variables to productivity shocks

In spite of this flourishing literature, the underlying mechanisms and a careful comparison with respect to a baseline Pissarides model are still far from being fully characterized. On the theory side, the interlink between the limited pledgeability of Holmstrom and Tirole, has not yet been studied within dynamic stochastic setting. Moreover, evidence on a number of other dimensions is still not clear. In addition, most models can not be solved analytically.

Another problem with the literature reviewed above is that in most cases it considers only adjustment of employment/unemployment stocks and does not focus on the role of firm entry and firm size. When this literature yields predictions on gross job flows, finance affects employment almost uniquely via the job destruction margin. A partial exception is the model by Monacelli, Quadrini and Trigari (2011) for which there is, however, limited empirical support: Simintzi, Vikrant and Volpin (2010) in particular show that firms reduce debt when facing an increase in the barganing power of workers. Empirical work, however, point to significant effects on the job creation margin as well, with financial markets deeply affecting firms' entry and post-entry growth (Arellano, Bai and Zhang, 2012). Our aim is to have a model that can generate large effects on employment, by operating along the job creation margin, allowing for entry and growth of firms, and where retained earnings are endogenous.

## 3 The Model

In presenting and solving the model we proceed in the following way. We first spell out the basic characteristics of the environment. Next, we present basic value functions, firms' profit and labor market search at given financing. Funding is then discuss in details, and we derive the endogenous borrowing constraints. Next we define general equilibrium and characterizes the steady state. Finally, we derive the analytical result on the amplification effect played by financial imperfections.

## The basic environment

**Preferences and Discounting**. Time is discrete and all agents discount the future at rate $\beta$; $\beta$ represents both the time preferences as well as the discounted factor of budget constraints. The utility function is linear in the time $t$ income $y_t$, and workers behave so as to maximize the net present value of their future income flow.

**Entry Cost and Firm Size**. Entrepreneurs set up a firm at effort cost $K$. This cost is the only part of investment that does not need financing and it is best thought of as pure effort or entrepreneur equity. Entrepreneurs decide the size or capacity $A$ of the firm, and invest $A$ in *physical* capital. The price of each unit of capital is exogenously fixed at $\phi$. Labor and capital are perfect complements and the technology is Leontief. With a given probability rate $\lambda$, the project ends and the firm simply 'dies'. The workers survive in the unemployment pool and receive a fixed income $z$.

**Output and Productivity Shocks.** Output is given by a linear technology $f(y_t, A_t) = y_t A_t$. The linear technology $y$ with the fixed cost $K$ implies increasing returns to scale. Let $y_t$ denote the aggregate state of the economy, as the outcome of stochastic process is described by

$$y_t = ye^{(\epsilon_t - \bar{\epsilon})},$$

where $\epsilon_t$ is a pure technological shock that follows an autoregressive path

$$\epsilon_t = (1 - \rho_\epsilon) + \rho_\epsilon \epsilon_{t-1} + u_t$$

with $0 < \rho_\epsilon < 1$, $u_t \approx N(0, \sigma^2)$ and $\bar{\epsilon} = 1$ as $\epsilon_t \approx N(0, \frac{\sigma^2}{1-\rho^2})$. Throughout the paper we use a discrete approximation of $y_t$ applying the Tauchen method (see Sargent and Stachurski, 2014) and work with a finite number of states $y_1, ..., y_n$ with $y_i < y_{i+1}$ and a stochastic matrix $P$ such that

$$p_{ij} = prob\left[y_t = i | y_{t-1} = j\right]$$

is the probability that the economy transits from state $i$ to state $j$ in one period.

**Matching** Workers are hired in a search market that is open in the beginning of the period. A Cobb Douglas matching function $x(u, v) = Hu^\alpha v^{1-\alpha}$ relates the number of new matches to the stocks of searching workers $u$ and firms with vacancies $v$.[1] The vacancy to unemployment rate is indicated with $\theta_t$, and define $q$ as $q = x(u, v)/v = H\theta_t^{-\alpha}$. Let $c$ denote the per period cost of maintaining a vacancy. The firms fill a vacancy with probability 1 at cost $c/q$ by positing infinity many vacancies infinitely shortly.[2] The search cost plus the rent guaranteed to the worker will represent a firm *search capital.*

**Funding and Borrowing Constraints** Firms have access to two funding sources to finance their investment needs. First, the entrepreneur has a flow value of income $y_o y_t$. Such cash flow characterizes *external liquidity* and it is fully pledgeable. Second, firms may use the liquidity generated by their investment to finance their investments. This is called *internal liquidity* and has limited pledgeability per unit of investment. We assume that $xA$ of the firm investment is non pledgeable and it is held as private benefit of the entrepreneur. We discuss the details of the financial contract and the nature of $x$ below. The total amount of resources that the firm is able to borrow is the sum of two components.

## Asset values

Value functions are indicated in capital letters. Workers have an (endogenous) outside option $U_t$, where $U$ is the expected net present income flow of a worker that is currently unemployed. The financial

[1] For simplicity and to minimize notation in the exposition we work with matching parameter $H = 1$, but in the calibration we do use the constant to match unemployment rate and the average duration of unemployment.

[2] Formally, this can be obtained by assuming that the matching market is set in continuous time in the beginning of the period and ends arbitrarily quickly.

contract will determine the borrowing constraint and firm size $A$. We discuss its determination below and we now take its value as given.

The expected net present value of the joint income for the entrepreneur and the workers in a firm of size $A$ can be expressed as

$$M(y) = yA + \beta \left\{(1-\lambda)M(y'|y) + \lambda AU(y'|y)\right\} \tag{1}$$

where $y'$ denote next period's aggregate productivity, which is stocastic the period before, and where $M(y'|y) = E^{y'|y}M(y)$. $U(y'|y)$ is defined analogously. The value function reflects that the firm continues with probability $(1-\lambda)$, and with the complementary probability dies and the $A$ workers get the outside option $U(y')$. The outisde option of the firm is assumed to be zero.

It is convenient to define the joint surplus of the match, $S(y)$, as the npv joint income less the outside options of the workers. The firm's joint surplus is

$$S(y) = M(y) - AU \tag{2}$$

Using the joint income, the surplus can be written as

$$S(y) = yA - UA + \beta AU(y'|y) + \beta(1-\lambda)S(y'|y)$$

In what follows we define

$$\rho(y) = \frac{U(y) - \beta U(y|y')}{U(y)}$$

as a time varying returns to the unemployed. $S(y)$ can be then be expressed as

$$S(y) = (y - \rho U)A + \beta(1-\lambda)S(y'|y)$$

Let's indicate with $C(U)$ all the labor related costs that the firm faces for a single worker, over and above compensating him for his outside option. In words, $C(U)$ is the cost of market imperfections. Hence $C(U)$ includes the search costs as well as the rent to be paid in excess of the worker's outside option. Firm profits at given investment size $A$ read

$$V(U(y), y) = \left[S(y) - \phi - C(U(y))\right] A \tag{3}$$

The profits are linear in the aggregate productivity $y$ and the size of the investment. The firm maximize profits subject to the search constraint and the borrowing constraint. We move to those in turn.

## Search and Worker's Rent

Let $W(y)$ denote the expected net present income of a worker hired in a firm, and let $R(y)$ denote the rent offered per employee, $R \equiv W - U$. In order to attract a worker, the firm has to spend $c/q(\theta)$ on search and $R + U$ on wages. In competitive search equilibrium the firm faces a trade-off between offering a high wage, or eqivalently, a high $R$, and paying a high search cost.

We define the search capital associated with aquiring a worker as $C = c/q + R$. Without financial frictions, the firm will choose $R$ so as to minimize $C$ given the trade-off between search costs and worker rents. As we show below, this also holds in the presence of financial frictions. Hence $C$ is given by (4) as

$$C = \min\left[c\theta^{\alpha} + R\right] \qquad \text{S.T.} \qquad \rho(y)U = z + p(\theta)R$$

It follows that

$$R = \frac{c\theta^{\alpha}\alpha}{1-\alpha}$$

Substituting the rent into the objective function, total labor costs are

$$C = \frac{c\theta^{\alpha}}{1-\alpha}$$

Over and beyond the rent, the firm guarantees to the worker the present discounted value of unemployment $U$. This implies that $\theta$ is given by

$$\theta(y) = \left[\frac{\rho(y)U - z}{c}\right] \frac{1-\alpha}{\alpha} \tag{4}$$

Substituted into (4) this gives

$$C(U) = \kappa \left[\rho(y)U - z\right]^{\alpha} \tag{5}$$

where

$$\kappa = \frac{c}{1-\alpha}\left[\frac{1-\alpha}{\alpha c}\right]^{\alpha}$$

We have so far been silent on the time profile of wages. As all agents have utility functions that are linear in NPV income, the time profile of wages does not matter. One possibility is that $R$ can be paid out immediately, and that the worker so receives $(1-\beta)U = \rho(y)U$ thereafter. If a constant wage is preferred, the important condition is that no payment to the worker happens after the firm dies at rate $\lambda$.

## Finance and Pledgeability

As anticipated in the description of the model, an entrepreneur invests in capacity and buys maching. We assume that the entry cost $K$ is financed by effort and does not need finance.

The rest of the funds has to be financed through borrowing. The entrepreneur has access to an exogenous income $y_o y_t$, where $y_o$ is a fixed parameter and $y_t$ is aggregate productivity. The exogenous income $y_o y_t$ can be fully committed to a financier and it is thus fully pledgeable. The liquidity generated by such income flow will be labelled *external liquidity* and it will naturally co move with aggregate productivity.

The other source of funds come from the income generated by the project. These finds can not be fully used to finance the investment needs. This is the key financial friction that we introduce and say that there is *limited pledgeability* on these funds. These form of limited pledgeability emerges for several reasons, as clearly indicated by Holmstrom and Tirole (2011).

A first set of reasons is related to incentives. In order to have the entrepreneur to make the "right "decision, and or take proper care of the firm's assets and machines, she needs to have a stake in the project, and parts of the funds generated can not be pledgead. We refer to the part of the income that the entrepreneur can commit as *pledgeable income*, while the part that can not be commited is the *non pledgeable income*. The liquidity generated by the income flow will be labelled *internal*

A second set of reasons for limited pledgeability refers to the creditor's ability to recover the funds. Holmstrom and Tirole (2011) explictly say that *pledgeable income and collateral are used as synonimous, and can be used interchangeably*. The only exception is that with pledgeable income overcollateralization is impossible. Seen in this view, it is empirically a robust finding that recovery rates are always lower than the income generated. We will use this symilitude extensively in the calibration excericse.

In the paper we do not propose an explicit model of pledgeability and assume that per each machine an amount $x()$ of the income generated can not be pledged, where the dependency of $x()$ will be discussed below. The total amount of non pledgeable income is thus $x()A$ We keep a reduced form approach here, and assume that there are two drivers of limited pledgeability. The first is aggregate productivity $y$ and the second is a pure financial shock, independent of productivity. In other words, in the general from we can this write

$$x = x(y, z) \tag{6}$$

with $x_z > 0$ and $x_y < 0$. In the paper we will say that the effect $x_z$ is a *pure financial shock* and will be the focus of Section 6. In this section we are interested in the second effect, mainly the link between productivity and pledgeability $x_y$, a channel that we will call it the *pledgeability effect of productivity*. The nature of the financial shock will be discussed in Section 6.

The negative link between limited pledgeability and aggregate productivity implies that financial frictions are larger when aggregate conditions are low. There are at least two justification for this channel. First, there may be a time varying availability of funds with the cycle. THe idea of a negative link between funds and the overall cycle has been studied in details by Geaanakoplos (2011), through an effect that he calls *the leverage cycle*. In this respect, the link between $x$ and $y$ is a reduced form of such effect. Second, as long as non-pledgeable income is synonimous of recovery rate, the finance literature has an established tradition of modeling and estimating time varying collateral rates (Livdan et al. 2009)

While in this section we keep $z$ completely fixed, we explore specifications of the model with and without the direct dependence of $x$ to $y$. yet, in deriving the analytical results we will work with a $x = x(y)$ with $x' < 0$. The specif functional forms will be set in the calibration part. Finally, we assume that the entrepreneur cannot save his non-pledgeable income. The assumption is easily rationalized if the non-pleadgeable income is private benefits.

## Borrowing Constraints

The time $t$ financial resources from an ongoing project of size $A$ is the following flow value

$$\tilde{p} = yy_o + (y - w)A - x(y)A$$

The first term is the flow from the exogenous income $y_o$, the second term is the amount of resources left once wages are paid, while the third term is the private benefit of the entrepreneur. The NPV of the pleadgeable for a firm that is entering the market is thus

$$\begin{aligned} \tilde{P(y)} &= y_0 y + (y - w)A_t - x(y)A + (1 - \lambda)\beta P(y'|y) \\ &= Y_0(y) + A(S(y) - R - X(y)) \end{aligned} \tag{7}$$

where

$$\begin{aligned} X(y) &= x(y) + (1 - \lambda)\beta X(y'|y) \\ Y_0(y) &= yy_0 + \beta Y_0(y'|y) \end{aligned} \tag{8}$$

The value of $\tilde{P}$ is the total amount of liquidity available to firm. One interpretation of equation (7) is that the first term is the total amount the entrepreneur can borrow from his own private wealth; the second term is the amount he can borrow on the additional income he receives from the investments. In any event, equations (7) and (8) highlight the two forces driving the dynamics of financial resources over and byond the surplus $S(y)$, whose expression was already discussed. The value $Y_o(y)$ is called the *collateral effect* and refers to the fact that the outside funding of the entrepreneur moves alongside productivity. The value $X(y)$ is called the *pledgeability effect* and refers to the fact that the amount of resources that the firm can pldge depends on the dynamics of the non pledgeable income $x(y)$. These two effects will play a key role in the discussions on volatility of the next section.

Total resource $\tilde{P}$ can be used to finance machines and search costs, hence $\tilde{P} = A(\phi + c/q)$. Inserting for $\tilde{P}$ thus gives

$$Y_0(y) + S(y)A - AR - X(y)A = A(\phi + C)$$

Now define $P(y) = Y_0(y) + S(y)A - X(y)A$. The borrowing constraint thus writes

$$P = A(\phi + c/q + R)$$

It follows that firm size on entry is obtained as

$$A(y) = \frac{Y_0(y)}{\phi + C + X(y) - S(y)} \tag{9}$$

Define

$$k(y) = \frac{1}{\phi + C + X(y) - S(y)}$$

as the financial multiplier, which reflects how many units of worker-machine pair the firm can invest in per unit of collateral $Y_o(y)$.

Before moving to the general equilibrium we define two summary statistics that will be very handy in our quantitative exercise. The firm relative pledgeable income is the amount of resources that the firm can pleadge relative to total productivity and it is simply indicates with

$$\nu(y) = y - x(y)$$

. The firm internal liquidity is the instantaneous value of financial resources that the firm will generate per unit of investment if the worker receives its outside flow $\rho(y)U$, as we argued in the previous section. Internal liquidity thus reads

$$l(y) = y\nu(y) - \rho(y)U \tag{10}$$

### General equilibrium

**Definition 3.1** *General equilibrium is a set of value functions $U(y), C(U), V(U, y)$, a labor market tightness $\theta(U)$ and a firm size $A(y, U)$, stochastic process $y$ and transition matrix $P$ such that such that*

1. *$C(U)$ minimizes the firms' search and hiring costs and $\theta(y)$ is the resulting labor market tightness*
2. *$A(y, U)$ satisfies the borrowing constraint without slack*
3. *$V(U(y), y) = K$ for all $y$.*

Note that equilibrium unemployment $u_t$ is given by the recursive flow equation

$$u_{t+1} = \lambda(1 - u_t) - \theta(U)^{1-\alpha}u_t \tag{11}$$

with $u_0$ given.

## 4 Deterministic equilibrium

Suppose the distribution of $y'|y$ is degenerate, so that $y'|y = y$ with probability 1. Then $\rho = (1 - \beta)$ and equilibrium simplifies to

$$
\begin{aligned}
S &= \frac{y-(1-\beta)U}{1-\beta(1-\lambda)}A \\
C &= \kappa\left[(1-\beta)U-z\right]^{\alpha} \\
A &= \frac{\frac{y_0 y}{1-\beta(1-\lambda)}}{\phi+C(U)-\frac{y-x(y)-(1-\beta)U}{1-\beta}} && (12)\\
K &= \left[\frac{y-(1-\beta)U}{1-\beta(1-\lambda)}-\phi-C(U)\right]A && (13)
\end{aligned}
$$

Note that in the deterministic equilibrium the surplus in given simply by equation 12. In addition, $X(y)=\frac{x(y))}{1-\beta(\lambda)}$ and $Y_o(y)=\frac{yoy}{1-\beta}$. The steady state unemployment reads

$$u=\frac{\lambda}{\lambda+\theta(U)^{1-\alpha}} \tag{14}$$

For the equilibrium to exist, it must be sufficiently "productive" so that firms can recoup $K$. If we define net output as productivity $y$, net of non pledgeable income $x$ and the worker outside option $z$, or $y-z-x$ the the following simple existence theorem on few parameters ensures existence and uniqueness

**Theorem 4.1** *If the present discounted value of netouput is larger than the price of capital, so that*

$$\frac{y-z-x}{1-\beta(1-\lambda)}>\phi \tag{15}$$

*equilibrium exists and it is unique.*

*Proof:* Using equations (12) and (13) and isolating the search cost in the right and side, one easily obtains

$$\tilde{y}-\phi-\tilde{x}\frac{\tilde{K}}{y+\tilde{K}}-\tilde{z}-\tilde{\delta}U=C(U) \tag{16}$$

where we expressed $\tilde{y}=\frac{y}{1-\beta(1-\lambda)}$, $\tilde{x}=\frac{x}{1-\beta(1-\lambda)}$, $\tilde{z}=\frac{x}{1-\beta(1-\lambda)}$, $\tilde{K}=\frac{K(1-\beta)}{Y_o}$ and $\tilde{\delta}=\frac{1-\beta}{1-\beta(1-\lambda)}$. The search cost is an upward sloping function defined for $U\geq\frac{z}{1-\beta}$. Since a viable market clearlly requires $y>z$, the maximum value in the right hand side of (16 )is $C(\frac{y}{1-\beta})$ and $\frac{z}{1-\beta}<U<\frac{y}{1-\beta}$. The left hand side of equation 16 is a downward sloping linear function $H(U)=\Delta-\delta U$, where $\Delta=\tilde{y}-\phi-\tilde{x}\frac{\tilde{K}}{y+\tilde{K}}-\tilde{z}$. The equilibrium exist and it is unique if $H(\frac{z}{1-\beta})>0$ and $H(\frac{y}{1-\beta})<0$. Since $H(\frac{y}{1-\beta})<0$ is true for any set of positive parameter values, existence and uniqueness reduces to $H(\frac{z}{1-\beta})>0$ which simple algebra implies shows that requires

$$\frac{y-z-x}{1-\beta(1-\lambda)}>\frac{y-z-x\frac{\tilde{K}}{y+\tilde{K}}}{1-\beta(1-\lambda)}>\phi$$

where the first inequality immediately follow since $\frac{\tilde{K}}{y+\tilde{K}}<1$. *QED* Having established existence, we can state a basic result of financial friction $x$.

**Result 4.1** *Financial frictions reduce unemployment value and increase the unemployment rate at costant productivity.*

From 12 it follows that an increase in $x$, holding costant $y$, shifts $A$ down. Hence, from (13), $U$ shifts down, and from 14 the unemployment rate increases. The economics of Result 4.1 works entirely through the borrowing constraints. An increase in $x$ (holding y fixed) reduces pledgeable income and the value of the firm. To ensure free entry it is necessary to have lower welfare value for the unemployed. Market tightness moves linearly with the value $U$.

Suppose a planner faces the same financial constraint as the entrepreneurs. Then the following holds

**Remark 4.1** *The equilibrium of the model is constrained efficient.*

The proof is also omitted, since it is just an application of Moen (1997) competitive search.

## Comparative statics on Productivity

Before moving to the calibration of the model, we investigate analytically how financial frictions interact in the model to shape the responsiveness of unemployment to productivity changes.

To derive the comparative static of the model and understand the economics of our theory, it is very useful to write the model compactly as

$$K = \pi(y, U)A(y, x(y)) \tag{17}$$

$$A = \frac{\frac{yoy}{1-\beta}}{\frac{x(y)}{1-\tilde{\beta}} - \pi(y, U)} \tag{18}$$

where $\pi$ is profit per worker, $A(y, U)$ is firm size and $\tilde{\beta} = \beta(1 - \lambda)$. Consistent with (13) it follows that

$$\pi(y, U) = \frac{y - (1 - \beta)U}{1 - \beta(1 - \lambda)} - C(U) - \phi$$

From the system of equation 17 and 18 the equilibrium firm size is analytically determined as

$$A = \frac{y_o y + K(1 - \beta)}{x(y)} \frac{1 - \tilde{\beta}}{1 - \beta} \tag{19}$$

**Remark 4.2** *Productivity is positively related to firm size of entrants firms. Both the collateral effect and the pledgeability effect increase size of new firm in response to a change in $y$*

*Proof.*To proof the previous remark just totally differentiating firm size to obtain

$$\frac{dA}{dy} = \frac{\tilde{\beta}}{1 - \beta} \frac{yo}{x(y)} + \eta(y) \frac{A}{y} \tag{20}$$

where $\eta(y) > 0$ is the absolute value of the elasticity of pledgeability $x(y)$ to productivity $y$. The first component in equation 20 is the *external effect* of productivity, the second effect is the *pledgeability effect* . In other words, productivity interacts with financial frictions in two forms. The external effect refers to the link between the entrepreneur outside income and productivity while the pledgeability effect refers to the effect of productivity on the size of the firm pledgeable income

We are now in the position to derive a key comparative static result

**Result 4.2** *An increase in productivity leads to higher profits per worker, higher firm size $A$ as well as higher value of unemployment.*

*Proof* The effect of firm size is obtained by equation (20). Totally differentiating equation (17) with respect to $y$ one has

$$-\frac{K}{A^2(y)} \frac{dA}{dy} = \pi_y + \pi_u \frac{dU}{dy}$$

where $\pi_y$ and $\pi_u$ are the partial derivatives of the profits per worker and respectively read

$$\pi_y = \frac{1}{1 - \tilde{\beta}} > 0; \quad \pi_u = -\frac{1}{1 - \tilde{\beta}} - C'(U) < 0;$$

The total derivative $\frac{dU}{dy}$ reads

$$\frac{dU}{dy} = \frac{\pi_y + \frac{K}{A^2} \frac{dA}{dy}}{-\pi_u} > 0 \tag{21}$$

*QED*

The previous result deserves a comment. In Pissarides (1988) an increase in output leads to an increase in $U$ up to the point where the productivity increase is balanced by higher search and wage costs. In our model, there is an additional effect, as firm size $A$ also grows. The increase in A, in turns, depends on the pledgeability and on the collateral effect. As will be clear below, this allows for a bigger response in $U$ after a change in output than in the standard Pissarides model.

**The Excess Volatility of Financial Frictions**

The elasticity of unemployment to productivity is defined as

$$\Psi_{u,y} = \frac{du}{dy}\frac{y}{u}$$

The elasticity of unemployment to productivity has the same dynamics of the elasticity of the unemployment value to productivity, and in this section we study $\Psi_{U,y} = \frac{dU}{dy}\frac{y}{U}$.[3] Conversely, the numerical simulations rely on the quantitative value of $\Psi_{u,y}$. It is very useful to introduce a benchmark model in which there are no borrowing constraints and optimal capacity is fixed $\overline{A}$. When capacity $\overline{A}$ is fixed, the firm can not expand beyond $\overline{A}$. When productivity changes, the fixed capacity can not be adjusted. This baseline alternative model is a pure imperfect labor market model, since the the search part of the model is identical to the model of the previous section. In terms of the economic literature, the model with fixed size $\overline{A}$ is a version of the DMP model coherent with Pissarides (1988 and 2000), chapter 2). We can say that in such model the value of unemployment is determined by only one equation

$$K = \pi(y, U)\overline{A} \tag{22}$$

In the model described by equation (22), the elasticity $\Psi_{U,y}(\overline{A})$ read

$$\psi_{U,y}(\overline{A}) = -\frac{\pi_y}{\pi_U}\frac{y}{U} \tag{23}$$

where footscript denotes the partial derivatives introduced above. With endogenous firm size, making use of the result in equation 21 we have that

$$\begin{aligned}\psi_{U,y} &= \frac{\pi_y + \frac{K}{A^2}\frac{dA(y)}{dy}}{-\pi_U}\frac{y}{U} \\ &> \psi_{U,y}(\overline{A})\end{aligned} \tag{24}$$

The analytical experiment that we undertake is to consider the value of the elasticity when the two models operate at the same level of capacity and at the same welfare value of unemployment. In other words we want to discuss the two models when $A(.) = \overline{A}$ and $U(x, A) = U(\overline{A})$. The analytical results immediately follow.

**Result 4.3** *Financial frictions increase the elasticity of unemployment to productivity changes*

*Proof.* Since $\frac{K}{A^2}\frac{dA(y)}{dy} >$ the result is obvious and is also illustrated in equation (24).

The intuition for the result is clear. With a fixed size, an increase in $y$ is matched by an increase in $U$ so that the value of a worker net of search costs stays constant. With endogenous $A$, this is not

[3] To see this, write $u \equiv u(p(\theta(U(y))))$. Now $el_p u = \frac{p}{p+\lambda} \approx 1$, $el_\theta p(\theta) = 1 - \alpha$, and $el_U(1-\beta)U - z\theta = 1$. Hence $el_y u \approx (1-\alpha)el_y[(1-\beta)U(y) - z]$. Since $el_U[(1-\beta)U - z] = \frac{(1-\beta)U}{1-\beta U+z}$ it follows that

$$el_{uy} \approx (1-\alpha)\frac{(1-\beta)U + z}{(1-\beta)U}el_{Uy}$$

sufficient, as the size of the firm also increases. Hence, in order to satisfy the zero profit condition, the value of a worker net of search costs has to fall. Finally, we can also study the analytics of the excess volatility and show that

**Result 4.4** *The excess volatility of financial frictions is the sum of two effects, the pledgeability effect and the external effect*

*Proof* The excess volatility is just obtained by substituting from $\frac{dA}{dy}$ in the elasticity result

$$\frac{K}{A^2}\frac{dA(y)}{dy} = \frac{\eta(y)A + \frac{1-\tilde{\beta}}{1-\beta}\frac{y_o y}{x(y)}}{U\pi_u}$$

The questions is at this point quantitative. Note that also the economics discussion of the previous results is taken up in section 4.1 when we discuss the results of the simulations.

# 5 Calibration

We calibrate the model around the steady state. The labor market parameters are taken either from standard reference values in the literature or from baseline empirical moments for the US labor market. The main references for calibrating the labor market side of the model are Shimer (2005) and Hagedorn and Manovski (2008). The financial parameters are novel in the model and we proposed an original calibration. Note that our basic calibration is for normal times and does not particularly aims at modeling crises time. Nevertheless, in section 6 we deal with financial schocks and we deal with crisis situattions.

There are 10 parameters to be set for the steady-state: $\beta, y, z, \alpha, \lambda, c, M, \phi, K/y0, x,$. Note that we point out to the ratio $K/y0$ as the fraction of the two parameters are what matter in the key labor steady state conditions of equations (13) and (12).

### Basic Values

Let us begin with 4 parameters that are taken from standard values in the literature: $\beta, y, z, \alpha$

We calibrate the model to quarterly values and we accordingly set the discount rate $\beta$ to 0.99. The baseline productivity is set as a reference value to 1. The elasticity of the matching function $\alpha$ is a parameter that shows wide variation in the literature, from Shimer (2005) that sets 0.72 to Hall (2008) that sets 0.28. We position ourself in the the central value of the range and we set $\alpha = 0.5$, a value that is also coherent with the central estimate of Pissarides and Petrongolo (2001). The unemployed income $z$ is 0.5. It is now well known that $z$ is a key parameter for simulating business cycle. Shimer sets 0.4 while Hagedorn and Manovski (2008) set 0.955. We do not want to enter in such a debate and fix a value of 0.5, knowing that our baseline calibration will display insufficient volatility with respect to the US labor market.

### Key Labor Market Moments

The first key moment that we match is the job finding rate. Shimer (2005) shows that the average monthly probability of not finding a job in the US is 0.55. This means that the average probability of not finding a job in a quarter is 0.1663 and the quarterly job finding probability is 0.8336. The second key labor market moment that we match is market tightness. We refer to Hagedorn and Manovski (2008) and target $\theta = 0.663$. Finally, we also match an average unemployment rate of 0.060, higher than the 0.057 in Shimer for the period 1951 to 2003. The main reasons is that our calibration include the last surge in unemployment that followed the great recession.

These targets allow us to pin down three key labor market parameters: $m$, the matching function elasticity, $c$, the search cost and the separation rate $\lambda$. Specifically, the separation $\lambda$ ensures the average unemployment rate at given job finding rate since $u = \frac{s}{s+0.8366}$. The matching function constant is set so as to ensure that market tightness matches the Hagedorn and Manovski reference value of 0.663. Given $\theta$, there is a one to one correspondence between the search cost and the equilibrium value of of unemployment. From equation

$$\theta = \left[\frac{U(1-\beta)-z}{c\beta}\right]\frac{1-\alpha}{\alpha}$$

there is a one to one correspondence between $c$ and $U$ once $z$ is set at 0.5. Shimer (2005) proposes 0.228 as the value for $c$, while Hagedron and Manovski (2008) work with endogenous capital stock which imply a larger value of $c$. Since in our model there are increasing returns to scale linked to the entry cost $K$, the value of $c$ is larger than in Shimer. In Table 2 and 3 the value of $c$ corresponds to a value of unemployment $U^* = 80$.

**Productivity Shock and Functional Forms**

The stochastic process is calibrated alongside the standard in the business cycle literature

$$\rho = 0.97; \quad \sigma^2 = 0.007 \tag{25}$$

For discretizing the state space, Sargent and Stuchurski (2014) show that Tauchen method requires the specification of two key parameters: $n$ the number of states of the discrete approximation and $b$, an integer that parameterizes the width of the state space. We choose $b$ and $n$ in a parsimonious way to ensure that number of states is limited and the model with endogenous borrowing constraints converges smoothly. This amounts in setting $n = 3$ and $b = 1.2$. In the simulation, the productivity shocks are detrended around a HP filter trend with smooth parameter 1600.

The productivity shocks affects the borrowing constraints in two channels. The collateral effects is specified by the recursive equation

$$Y_o(y_t) = yoye^{(\epsilon_t-\overline{\epsilon})} + \beta Y_o(y_{t+1}|y_t)$$

while the pledgeability effect is driven by

$$X(y_t) = xye^{-\gamma(\epsilon_t-\overline{\epsilon})} + (1-\lambda)\beta X(y_{t+1}|y_t)$$

with $\gamma$ is the elasticity $\eta(y)$.

**Accounting for Leverage**

Before entering the calibration strategy of financial variables we need to be more specific on the institutional details we are modeling. The distinction between internal and external liquidity is very clear in our theoretical perspective, but it is not readily immediately available from financial data.

In real life financial institutions, the credit relationship with a given client is specified by three different variables. The *credit plafond* refers to the maximum amount of credit that an institutions is willing to invest in the client. Such credit plafond is typically not revealed to the client/firm. The *contractual line* refers to contractual arrangement between the financial institution and the firm. Such contractual lines take typically different financial forms, including mortgages, long and short term loans, pure cash lines as well as covenants of derivative products. Finally, the *drawn line* is the amount of liquid cash that has left the financial institution and is directly available within the firm's asset. In our theoretical perspective, the credit plafond is not modeled. Conversely, our pledgeability concept gets closer to the *total agreed line*, independently of whether it is actually drawn. In Boeri et al. (2014) we explore the role of liquidity and we present a model in which firms distinguish between cash reserves and other forms of debt. For the purpose of this paper we abstract from such difference. Let's introduce some definitions

**Definition 5.1** *Total Asset (TA) are the amount of assets, either in the form of cash or real investment physically within the firms. Total Borrowing (TB) is the amount of resources borrowed by the firm. Firm equity (E) is the firm value.*

If we indicate with $TA$ total assets within the firm we have that

$$TA = (C(U) + \phi)A + K$$

where $A$ is the size of the firm as well as the investment size whose price is indicated with $\phi$. $K$ is the effort cost necessary to enter the market. It is sunk but it has been invested in the firm. If the we indicate with $TB$ total borrowing we have that

$$TB = (C(U) + \phi)A,$$

so that the firm borrows all the resources beyond the entry cost $K$.

Leverage in the financial literature (Adrian and Shin, 2008) is typically indicated as the fraction of total asset to the firm equity. The equity ratio is the inverse of leverage. We follow such definitions. In the context of our accounting total equity ratio $ER$ is the fraction between the value of the firm and its total assets so that

$$ER = \frac{V}{(C(U) + 1)A + K} = \frac{K}{(C(U) + 1)A + K}$$

where $V$ is the value of the firm. In equilibrium, as we have seen, such value is equal to the entry cost. Our key financial variable is thus leverage and we define it as

$$lev = \frac{(C(U) + \phi)A + K}{K} \tag{26}$$

### Calibration of Financial Parameters

The complete calibration requires setting specific values to four parameters: $\phi$, the steady state price of machine; $x$ the average level of non pledgeable income, and $\gamma$, the elasticity of non pledgeable income to productivity shocks, and the ratio of $K/y_o$, the ratio of entry cost to outside income, since the model can determine only the relative ratio $K/y_o$. We turn to these in turn

### Non pledgeable income parameters

The literature on limited pledgeability, and Holmstrom and Tirole (2011) in particular, has not been particularly applied to calibrated models. Yet, as we anticipated, we can use the similarity between pledgeability and collateral to obtain proper calibration numbers. Livdan et al. (2011), argue that the unit of recovery $r(\epsilon)$ per unit of investment is

$$r(\epsilon) = s_o e^{s_1(\epsilon_t - \overline{\epsilon})} \tag{27}$$

where $s_o$ is the mean recovery rate and $s_1$ is the elasticity of recovery rate with respect to productivity shock. The complement of the recovery rate is called the cost of liquidation. Our main calibration assumption is thus

$$\underbrace{\overline{x} y e^{-\gamma(\epsilon_t - \overline{\epsilon})}}_{Non\ Pledgeable\ Income} = \underbrace{1 - s_o e^{s_1(\epsilon_t - \overline{\epsilon})}}_{Cost\ Of\ Liquidation} \tag{28}$$

Since $y = 1$, this assumption allows us to set two parameters, $\overline{x}$ and $\gamma$. $\overline{x}$ represents the average level of pledgeable income. Livdan et al. (2015) argue that empirical studies imply a proportional liquidation cost of in the range of $10\% - 15\%$ Hennessy and Whited (2007). in particular, estimate liquidation costs to be at 10.4% of the value of the assets. Petrosky-Nadeau (2014), in his labor market application, assumes a recovery rates $s = 0.9$ so as to imply liquidation cost of 0.10%. We follow the latter and stay on the lower side, and assume that $\overline{x} = 0.10$

The second parameter we need to calibrate is $\gamma$. Livdan et al. (2009) work on the assumptions. First they set $s_o = e^{s_1(\epsilon_t - \overline{\epsilon})} = 0.85$ when the model is in steady state, or when $\overline{\epsilon}_t = \overline{\epsilon}$. They set $s_1$ so that $s_o = e^{s_1(\epsilon_t - \overline{\epsilon})} = 0.75$ when $\epsilon_t$ is one standard deviation below the average. This is akin to assuming that liquidation costs double when productivity is one standard deviation from its steady state value. Following Livdan et al. the calibration condition would be $e^{-\gamma(\epsilon_t(\sigma) - \overline{\epsilon})} = 2$, where $\epsilon_t(\sigma) = 0.917$ when $\sigma^2 = 0.007$ as we set above. This simple equation implies a value of $\gamma = 8.35$. Petrosky Nadeu, in his model of credit shocks, estimates $s_1$ trhough a non linear regression of gdp and credit shock, and obtains a value of $s_1$ that is 25% smaller than the value of Livdan et al. In the calibration we follow the more conservative value and we work with a value of $\gamma = 6.26$

### Targeting Leverage and Calibration of Entry Cost

Having calibrated the pledgeability parameters, we are left with $\phi$ and the $K/y_o$ fractio. As $y_o$ is somewhat redundand, and since in steady state when $y_{t+1} = y_t$ and $\overline{\epsilon}_t = \overline{\epsilon}$, $Y_o = \frac{y_o}{1-\beta} y$, we set $y_o = (1 - \beta)$ so as to basically eliminate the parameter.

The key moment that we match is leverage of US non-listed non-financial firms in 2006. Kalemili-Ozcab et al. (2011) in their vast empirical work on leverage around the great recession show that leverage in non listed non financial firms was 2.4 in 2006. We thus target $lev$ from equation (26) to be 2.4. The basic intuition for the calibration is to choose $K$ and $phi$ to match leverage as well as the target value of unemployment. We proceed in the following way. Recalling the definition of leverage in equation 26, and that the free entry conditions is $K = \pi(U^*)A$

$$\begin{cases} \frac{K}{A(U^*)} = \frac{C(U^*)+\phi}{lev-1} \\ \\ \frac{K}{A(U^*)} = \pi(U^*) \end{cases} \tag{29}$$

Using the value of profit per worker in the first equation as $\pi(U) = \frac{y-(1-\beta)U}{1-\lambda(1-\beta)-C(U)} - \phi$, we obtain the value of $\phi$ as

$$\phi = \frac{lev - 1}{lev} \left\{ \frac{y - (1-\beta)U^*}{1 - \beta(1-\lambda)} \right\} - levC(U^*)$$

where $U^*$ is the target value of $U$. The appendix shows that the value of $K$ is

$$K = \frac{\frac{yoy}{1-\beta} \left( \frac{K}{A(U^*)} \right)}{\frac{x(y)}{1-\beta(1-\lambda)} - \left( \frac{K}{A(U^*)} \right)} \tag{30}$$

where $\left( (\frac{K}{A(U^*)} \right)$ is an expression for the ratio of $K$ to $A$. See appendix for details.

Table 2: Matching the Calibration Target

| | Target | Source | Value | |
|---|---|---|---|---|
| | | | Data | Model |
| 1. | Average Job Finding Rate, $M\theta^{(1-\alpha)}$ | Shimer (2005) | 0.8336 | 0.8366 |
| 2. | Average Market tightness, $\theta$ | Hagedorn Manovski (2008) | 0.634 | 0.6634 |
| 3. | Firm Leverage , $lev$ | Kalemli-Ozcan et al. (2011) | 2.4 | 2.3990 |

Based on Shimer (2005) monthly probability of not finding a job set at 0.55
*Source:* Authors' calculation

Table 3: Calibrated Values and Steady State Statistics

| Parameter | Notation | Value |
|---|---|---|
| Pure Discount Rate | $\beta$ | 0.990 |
| Baseline productivity | $y$ | 1.000 |
| unemployed income | $z$ | 0.500 |
| Death Rate | $\lambda$ | 0.053 |
| matching function elasticity | $\alpha$ | 0.500 |
| matching function parameter | $m$ | 1.027 |
| search cost parameter | $c$ | 0.457 |
| own income flow | $y_o$ | 0.010 |
| Financial Friction | $x$ | 0.100 |
| entry cost | $k$ | 4.878 |
| Price of Capital | $\phi$ | 1.137 |
| *Productivity Values* | | |
| Persistence of productivity process | $\rho$ | 0.970 |
| Variance of innovation in productivity process | $\sigma$ | 0.007 |
| Number of states | $n$ | 3.000 |
| Withd of the state space | $b$ | 1.200 |
| Minimum pledgeability effect | $\gamma$ | 0.000 |
| Maximum pledgeability effect | $\gamma(max)$ | 6.000 |
| *Equilibrium Values* | | |
| value of unemployment | $U$ | 80.000 |
| firm size | $A$ | 3.695 |
| labor market frictions | $C(U)$ | 0.724 |
| job finding probability | $p(\theta(U))$ | 0.837 |
| vacancy unemployment ratio | $\theta(U)$ | 0.663 |
| unemployment rate | $u$ | 0.060 |
| Leverage | $lev$ | 2.410 |

*Source:* Authors' calculation

## 5.1 Productivity Shocks and Financial Frictions: Quantitative Results

The first quantitative exercise deals with the amplification power obtained by the financial frictions. Analytically we did show that the model implies an increase in the volatility of unemployment and market tightness to productivity change along two channels that we labeled collateral and pledgeability effect. The question is quantitative.

In the model productivity shocks induce fluctuations to firm's profitability as well as to the financial multiplier. The effect on firm profitability is the standard fluctuation modeled in the business literature of the DMP model. It has attracted the key attention of Shimer (2005), Hagedorn and Manovski (2008) and Hall (2005). We basically ask what financial shocks imply with respect to such baseline models. We thus run two different version of our models as a way to understand the quantitative impact of both the collateral effect and the pledgeability effect.

**Steady State Comparison**

Specifically, our method is as follows. First, we obtain a pure DMP model by considering an economy where firm size is fixed at $\overline{A}$ and there are no financial frictions. All firms reach the optimal size upon entry and productivity affects profits per worker. The model with fixed is obtained as

$$\left[\frac{y-U(1-\beta)}{1-\beta(1-\lambda)}-C(U)-\phi\right]\overline{A}=K \qquad \textit{Model I}\text{: Basic DMP}$$

In the steady state model with financial frictions and only the collateral effect we have

$$\left[\frac{y-U(1-\beta)}{1-\beta(1-\lambda)}-C(U)-\phi\right]\frac{\frac{yY_o}{1-\beta}}{\phi+C(U)-\frac{y-U(1-\beta)}{1-\beta(1-\lambda)}+\frac{x}{1-\beta(1-\lambda)}}=K \qquad \textit{Model II}\text{: collateral effect}$$

When we consider also the pledgeability effect the model reads

$$\left[\frac{y-U(1-\beta)}{1-\beta(1-\lambda)}-C(U)-\phi\right]\frac{\frac{yY_o}{1-\beta}}{\phi+C(U)-\frac{y-U(1-\beta)}{1-\beta(1-\lambda)}+\frac{x(y)}{1-\beta(1-\lambda)}}=K$$

*Model III*: collateral and pledgeability

Note that formally the difference between Model II and Model III is the fact that the latter includes also the collateral effect of productivity $x(y)$ Note also that the calibration exercises imposes that the initial size be identical across the three models.

$$\overline{A}=\frac{\frac{yY_o}{1-\beta}}{\phi+C(U)-\frac{y-U(1-\beta)}{1-\beta(1-\lambda)}+\frac{x}{1-\beta(1-\lambda)}}=\frac{\frac{yY_o}{1-\beta}}{\phi+C(U)-\frac{y-U(1-\beta)}{1-\beta(1-\lambda)}+\frac{x(y)}{1-\beta(1-\lambda)}} \tag{31}$$

Equation (*Model I*: Basic DMP) is the baseline DMP representation of our model. Firm size if fixed and there are no financial frictions. Equation (*Model III*: collateral and pledgeability) is the model with endogenous financial frictions. It is natural to consider the responsiveness of the two models starting from the same initial size, as we do in equation (31).

**The size of the external and the pledgeability effect in steady state**

Table 4 uses the steady state calibration and consider a fall in productivity by four percent in the three Models. We start with the equation of *Model I*: Basic DMP. First, recall that in equilibrium profit per worker multiplied by the financial multiplier must ensure that the zero profit conditions hold at all times. The first line of Table 4 shows that the entry cost $K = 4.87$ is obtained by the product between a profit per worker equal to 1.32 and a size/ financial multiplier equal to 3.69. The associated market clearing value of unemployment is 80. The second line of the Table considers a fall in average productivity by 4% to a low value of $y = 0.96$.[4]. Since financial markets and borrowing constraints are not operating and firm size is fixed, a new equilibrium requires a fall in the value of unemployment to ensure that profits per worker remain constant at 1.32. This is obtained by a fall in $U$ to 76.85. This is a fall approximately equal to 4% which implies that the model has not enough volatility to match the data. This is the well known Shimer paradox.

The key finding of our quantitative exercise are the model (2) and (3) in the Table 4. Consider first model 2. The starting point is identical to that of model 1, as indicated by the condition of equation (31). Financial constraints are now binding and the same fall in productivity to 0.96 implies a fall in the size of new entrants firms to 3.675. In this model the collateral effect is operating. Consider for a moment profit per workers equal to 1.32 as they are in the second line. Such level of profits can not be an equilibrium since the value of a new firm is lower than the entry cost. To ensure an equilibrium

[4]Incidentally, this is not too distant from the lowest value of the grid in the calibrated state space of productivity

Table 4: Amplification with Endogenous Leverage

| | Model | Prod | Plead. income | profits worker | Size New Firms | Entry Cost | Welfare Unempl. | Lev | Int Liq | Mkt Tightness |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $y$ | $\nu(y)$ | $\pi$ | $A$ | $K$ | $U$ | $lev.$ | l(y) | $\theta$ |
| (1) | Fixed Size [a] | 1 | - | 1.320 | 3.69 | 4.87 | 80 | - | - | 0.66 |
| | Fixed Size [a] | 0.96 | - | 1.320 | 3.69 | 4.87 | 76.85 | - | - | 0.594 |
| (2) | Endog. Lev [b] | 1 | 0.90 | 1.320 | 3.69 | 4.87 | 80 | 2.41 | 0.10 | 0.66 |
| (2) | Endog. Lev [b] | 0.96 | 0.90 | 1.327 | 3.673 | 4.87 | 76.80 | 2.37 | 0.097 | 0.593 |
| (3) | Endog. Lev [c] | 0.96 | 0.87 | 1.63 | 2.98 | 4.87 | 75.02 | 2.11 | 0.092 | 0.55 |

[a] Model with fixed and maximum capacity of new firms $A = \overline{A}$

[b] Model with endogenous leverage and and capacity of new firms $A = A(U)$ and fixed non pledgeable income $x$. Pure collateral effect

[b] Model with endogenous leverage and and capacity of new firms $A = A(U)$ and non pldgeable income $x(y)$. Collateral effect and pledgeability effect

See main text for steady state equations

Sources: Author's calculation.

it is necessary to obtain an *additional fall in the welfare value of unemployment*. Such additional fall is exactly the amplification power of financial market imperfections that we are investigating. Table 4 makes clear that the additional fall in the value of unemployment is tiny and negligible, and lower than 1 percent.

**Remark 5.1** *The additional fall in the welfare value of unemployment implied by the model with only the collateral effect is quantitatively negligible.*

Consider now the model 3 in Table 4. With respect to the model 2 the pledgeability effect is now operating. This can be seen from the fact that alongside a fall in productivity to 0.96 there is also a fall in non pledgeable income to 0.87. The fall in the unemployment value is now amplified to 6 percent against a fall in productivity around 4 percent, thus there is an additional increase in volatility of 50 percent with respect to the baseline model. Note also that this increase in volatility is associated to a drop in the size of new entrant firms by 20 percent. The drop in the new entrant size is thus driven by both internal liquidity and leverage.

### Quantifying Elasticities in Steady State

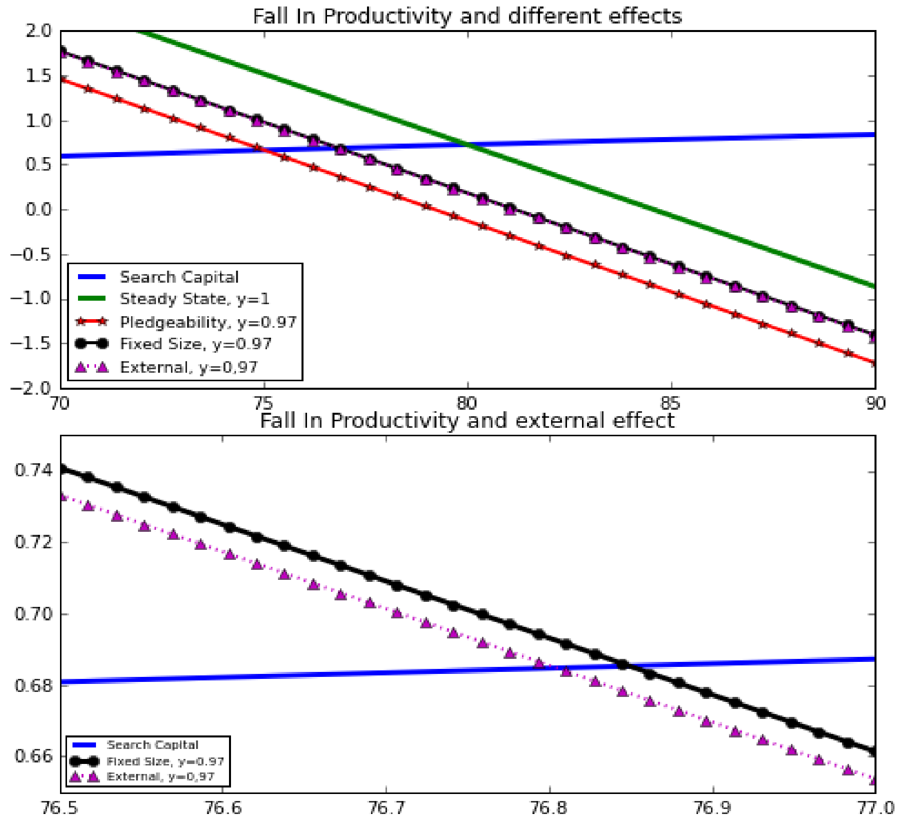
Before moving to the dynamic simulations, we can use the results from the existence theorem to get some estimate of the size of the steady state elasticity of the three effects. The exisbtence proof showed that the equilibrium can be described by equation 16, where the welfare value of unemployment is the crossing between a downward sloping line in $U$ and an upward sloping function described by $C(U)$.

$$\tilde{\delta}U + \kappa\left[(1-\beta)U - z\right]^{\alpha} = \frac{ye^{(\epsilon-\bar{\epsilon})}}{1-\beta} - \phi + \frac{\tilde{K}}{ye^{(\epsilon-\bar{\epsilon})} + \tilde{K}} xye^{-\gamma(\epsilon-\bar{\epsilon})} \tag{32}$$

Taking a linear approximatation around the steady states $U = U^*$ we have

$$\left[\tilde{\delta} + \alpha(1-\beta)C(U^*)\right] dU = \tilde{y}e^{(\epsilon-\bar{\epsilon})}d\epsilon + \frac{\tilde{K}}{(y+\tilde{K})}\gamma xye^{-\gamma(\epsilon-\bar{\epsilon})}d\epsilon + \frac{\tilde{K}}{(y+\tilde{K})^2} yxye^{(\epsilon-\bar{\epsilon})}d\epsilon \tag{33}$$

Figure 1: Decomposition of Productivity Effects: Steady State




We can thus quantify the elasticity of U with respect to a pure productivity shock $\epsilon$ and evaluate its value at steady state ($\epsilon = 0$). If we indicate the elasticitiy with $\Psi$ to distinguish it from the productivity shock with $\epsilon$ we have that

$$\Psi_{U,y(\epsilon=\bar{\epsilon})} = \frac{\bar{\epsilon}}{U^*}\left[\frac{y}{1-\beta} + \frac{\tilde{K}}{(y+\tilde{K})^2}yxy + \frac{\tilde{K}}{(y+\tilde{K})}\frac{\gamma x}{1-\beta}\right] \tag{34}$$

In the previous equation the three elements inside the square brackets correspond to measures of the elasticities of the three model (*Model I*: Basic DMP), (*Model III*: collateral and pledgeability) and (*Model III*: collateral and pledgeability ) . IN other words, the total elasticity is a sum of three effects. Since, we have already shown that

$$el_u y \approx (1-\alpha)\frac{(1-\beta)U + z}{(1-\beta)U} el_U y$$

, we can obtain steady state estimates of the elasticity of unemployment to productivity.

Table 5 reports the decomposition of the elasticity in the various effect. Three results are immediately evident. First, the baseline model features an unemployment productivity elasticiy of 1, a value that can not match the unemployment volatility of the US, as we show in the dynamic simulation that follows. Second, the collateral effect is negligible. Third, the pledgeability effect is sizeable, and total elasticity increase up to 1.5.

Table 5: Amplification with Endogenous Leverage

| | Model | Effect | $\Psi_{U,y}$ Welfare vs Productivity | $\Psi_{u,y}$ Unemployment Rate vs productivity |
|---|---|---|---|---|
| (1) | Fixed Size [a] | $\frac{1}{1-\beta}$ | 1.25 | 1.01 |
| (2) | Endog. Lev [b] | $\frac{\tilde{K}}{(y+\tilde{K})^2}y^2x$ | 0.001 | 0.002 |
| (3) | Endog. Lev [c] | $\frac{\tilde{K}}{(y+\tilde{K})}\frac{\gamma xy}{1-\beta}$ | 0.62 | 0.50 |
| | Total Effect | | 1.872 | 1.521 |

[a] Model with fixed and maximum capacity of new firms $A = \overline{A}$

[b] Model with endogenous leverage and and capacity of new firms $A = A(U)$
and fixed non pledgeable income $x$. Pure collateral effect

[b] Model with endogenous leverage and and capacity of new firms $A = A(U)$
and non pldgeable income $x(y)$. External effect and pledgeability effect

See main text for steady state equations

Sources: Author's calculation.

**Dynamic Simulations**

To begin with, we generate quantitative simulations for a pure DMP model. The first set of simulations refers to the general equilibrium of the model when firm size is fixed at its steady state $A$. We perform 500 simulations of a labor market draw of 20000 periods, out of which we get rid of the first 2000 observations to reduce the effect of initial conditions. All simulated data are logged and detrended with an Hodrick Filter parameter of 1600. In the Table we report the correlation coefficients and standard deviations of these simulated cyclical variations.

Let us focus on Table 6. The baseline model with fixed size can not match the US labor market statistics. Remember that in the US data compiled by Shimer (2005) and Hagedorn and Manovski (2008) the standard deviations of they key variables are approximately the following $\sigma_y = 0.01$ , $\sigma_u = 0.1$ $\sigma_v = 0.1$ and $\sigma_\theta = 0.2$, so that unemployment fluctuates 10 times as much as productivity and market tightness as much as twenty times. The volatility of the basic model is an order of magnitude lower than that presented in the data. Such lack of volatility of the standard DMP model is labeled in the literature as the *Shimer Paradox*.

In light of literature that followed the Shimer findings, the results on the relative standard deviations in Table 6 are hardly surprising. Our basic model with a fixed firm size and time invariant financial multiplier is just a variant of Pissarides (1988). The two main differences are the fixed entry cost $K$ and the fact that wages are modeled in the spirit of competitive search (Moen, 1997). When the Hosios conditions are satisfied, competitive search is identical to the Nash bargaining solution of Pissarides (1988).

In principle, increasing the value of non market activity $z = .5$ to $y = 1$ would generate enough volatility in the model. That is what Hagedorn and Manovski (2008). Shimer (2010) has also shown that modeling rigid wages can lead the model to feature as much volatility as in the data. That is not the point of our exercise. We want to ask ask how much additional volatility is introduced in the model when borrowing constraints are endogenous and are subject to the business cycle fluctuations. In other words, we are interested in understanding how much *amplification* power is obtained by the financial frictions.

The results are reported in Table 7 and Table 8. The procedure of the simulation is identical to that of Table 6 but financial constraints are now operating. Table 7 deals only with the pledgeability effect. Comparing the simulations of Tables 6 7 it is clear that the difference is negligible. The increase in the volatility between the two models is around 1 percent. Fluctuations in firms' leverage due to the collateral effect basically do not amplify the unemployment volatility.

Table 8 reports the simulation when both the collateral effect and the pledgeability effect are operating. Results are quantitatively significant. Since the quantitative impact of the collateral effect is negligible, as illustrated in Table 7 all the additional volatility featured by Table 8 is due to the pledgeability effect. The relative standard deviation of unemployment increase from 1.4 of Table 6 and 7 to 2.08 in Table 8. This amounts to an increase in volatility by 50 percent. Similar results are obtained for vacancies and market tightness. Note that the increase in volatility is driven by the volatility of the financial multiplier and firm size at entry, which appears in Table8 to be 20 times more volatile that in the model of Table 7. Recall that in Table 8 pledgeable income fluctuates around 3 percent with respect to the baseline calibration. The model thus appears very sensitive to small cyclical changes in pledgeability $x(y)$, as we show in the following discussion.

**Remark 5.2** *The additional fall in the welfare value of unemployment implied by the model when the pledgeability effect is operating is around 50 percent.*

To summarize, we learned that

- the value of unemployment $U$ moves marginally more than $y$ in the baseline model with fixed size;
- the value of unemployment $U$ moves significantly more that in the baseline model with fixed size when the pledgeability effect is operating.
- labor market variables are highly responsive to changes in pledgeable income.

Table 6: Simulation statistics:
Baseline DMP Model with fixed size

| | $y$ | $U$ | C(.) | A | k | v | $\theta$ | u | $p(\theta)$ | lev |
|---|---|---|---|---|---|---|---|---|---|---|
| $y$ | 1.000 | 1.000 | 0.999 | 0.005 | - | 0.904 | 0.999 | -0.717 | 0.999 | 1.000 |
| $U$ | | 1.000 | 0.999 | 0.005 | - | 0.904 | 0.999 | -0.717 | 0.999 | 1.000 |
| $C$ | | | 1.000 | 0.005 | - | 0.905 | 1.000 | -0.717 | 1.000 | 1.000 |
| $A$ | | | | 1.000 | - | 0.004 | 0.005 | -0.005 | 0.005 | 0.005 |
| $k$ | | | | | - | - | - | - | - | - |
| $v$ | | | | | | 1.000 | 0.905 | -0.352 | 0.905 | 0.904 |
| $\theta$ | | | | | | | 1.000 | -0.717 | 1.000 | 1.000 |
| $u$ | | | | | | | | 1.000 | -0.717 | -0.717 |
| $p(\theta)$ | | | | | | | | | 1.000 | 1.000 |
| *Relative Standard Deviations (%)* | | | | | | | | | | |
| | 1.000 | 0.573 | 1.537 | 0.000 | - | 2.296 | 3.075 | 1.400 | 1.537 | 0.349 |

*Source:* Authors' calculation

Table 7: Simulation Statistics:
Model with Collateral effect

| | $y$ | $U$ | C(.) | A | k | v | $\theta$ | u | $p(\theta)$ | lev |
|---|---|---|---|---|---|---|---|---|---|---|
| $y$ | 1.000 | 1.000 | 0.999 | 1.000 | -1.000 | 0.904 | 0.999 | -0.713 | 0.999 | 1.000 |
| $U$ | | 1.000 | 0.999 | 1.000 | -1.000 | 0.904 | 0.999 | -0.713 | 0.999 | 1.000 |
| $C$ | | | 1.000 | 0.999 | -1.000 | 0.904 | 1.000 | -0.713 | 1.000 | 1.000 |
| $A$ | | | | 1.000 | -1.000 | 0.903 | 0.999 | -0.713 | 0.999 | 1.000 |
| $k$ | | | | | 1.000 | -0.904 | -1.000 | 0.713 | -1.000 | -1.000 |
| $v$ | | | | | | 1.000 | 0.904 | -0.346 | 0.904 | 0.904 |
| $\theta$ | | | | | | | 1.000 | -0.713 | 1.000 | 1.000 |
| $u$ | | | | | | | | 1.000 | -0.713 | -0.713 |
| $p(\theta)$ | | | | | | | | | 1.000 | 1.000 |
| *Relative Standard Deviations (%)* | | | | | | | | | | |
| | 1.000 | 0.577 | 1.548 | 0.115 | 0.383 | 2.312 | 3.096 | 1.410 | 1.548 | 0.419 |

$\gamma = 0$ See main text for equations on the pledgeability effect
*Source:* Authors' calculation

Table 8: Simulation Statistics:
Model with Collateral and Pledgeability effect

| | $y$ | $U$ | C(.) | A | k | v | $\theta$ | u | $p(\theta)$ | lev |
|---|---|---|---|---|---|---|---|---|---|---|
| $y$ | 1.000 | 1.000 | 0.995 | 0.996 | 0.996 | 0.899 | 0.995 | -0.697 | 0.995 | 0.992 |
| $U$ | | 1.000 | 0.998 | 0.994 | 0.993 | 0.902 | 0.998 | -0.699 | 0.998 | 0.988 |
| $C$ | | | 1.000 | 0.983 | 0.982 | 0.904 | 1.000 | -0.700 | 1.000 | 0.976 |
| $A$ | | | | 1.000 | 1.000 | 0.888 | 0.983 | -0.690 | 0.983 | 0.999 |
| $k$ | | | | | 1.000 | 0.887 | 0.982 | -0.689 | 0.982 | 0.999 |
| $v$ | | | | | | 1.000 | 0.904 | -0.327 | 0.904 | 0.880 |
| $\theta$ | | | | | | | 1.000 | -0.700 | 1.000 | 0.976 |
| $u$ | | | | | | | | 1.000 | -0.700 | -0.685 |
| $p(\theta)$ | | | | | | | | | 1.000 | 0.976 |
| *Relative Standard Deviations (%)* | | | | | | | | | | |
| | 1.000 | 0.845 | 2.297 | 7.217 | 6.721 | 3.435 | 4.595 | 2.087 | 2.297 | 4.764 |

$\gamma = 6$ See main text for equations on the pledgeability effect
*Source:* Authors' calculation

# 6 Unemployment Response to financial shocks

In this section we embark in the second quantitative exercise of the paper and focuses on the labor market effects of financial and liquidity shocks. In the previous section we showed that labor market variables are highly responsive to pledgeability shocks. The idea of this section is to consider a pure shock to pledgeable income, independently of productivity changes.

Holmstrom and Tirole (2011) show in great details the effects of sudden changes in liquidity generated by the investment of size $A$. In terms of our pledgeability function $x = x(y, z)$, this section is concerned with the effect $x_z$, where $z$ is a pure financial shock. Most importantly, a financial shock $z$ does not have any direct impact on firms' profitability. It only affects its borrowing constraint. In the aftermath of a liquidity shocks $z$, new entrants face lower resources for investments at given productivity level. The action in the model comes from the entry margin. The evidence reported by Siemer (2014) is coherent with such an approach. [5]

[5]From the labor market perspective, the action in the model is all on the the job creation margin emphasized by Pissarides (1988). We do not model the effect of liquidity on the job destruction margin. In Boeri et al. (2014) we study the effects of refinancing shocks on the firm choice of liquid assets and we also show that such shocks can lead firms to liquidate assets and destroy jobs.

## The Model with Pledgeability Shocks

In this section we assume that productivity is constant at its steady state value $y$. Conversely, the economy is subject to stochastic liquidity shock in the form of pleadgeability shock. Formally, the pleadgeability function of equation(6), at time $t$ is defined as

$$x_t = yxe^{\gamma_z (z_t - \overline{z})} \tag{35}$$

where $y$ and $x$ are the steady state values of productivity and pledgeability, $\gamma_z > 0$ is a parameter and $z_t$ is a pure financial shock that follows an autoregressive path

$$z_t = (1 - \rho_z) + \rho_z z_t + \omega_t$$

with $\rho_z < 1$ and $\omega_t$ is $N(0, \sigma_z^2)$. We use a discrete approximation of $x_t$ and work with a finite number of states $x_1, ...., x_n$ and a stochastic matrix $P^x$ such that

$$p_{if}^x = prob[x_t = i | x_{t-1} = j]$$

The value functions need to be specified with respect to $x$ and $x'$. Note that financial shocks do not enter directly in the value of the surplus, nor in the value of unemployment. Conversely, they affect the financial multiplier and the firm size. The borrowing constraint now reads

$$A(\phi + C) = Y + A(S + \tilde{\rho}(x)) \tag{36}$$

where $Y = \frac{y_o y}{1-\beta}$ while $\tilde{\rho}(x)$ solves the recursive equation

$$\tilde{\rho}(x) = x + \beta(1 - \lambda)\tilde{\rho}(x'|x)$$

Firm size along the borrowing constraint becomes

$$\begin{aligned} A &= \frac{\frac{yoy}{1-\beta}}{\phi + C + \tilde{\rho}(x) - S} \\ &= \frac{yoy}{1-\beta} k(x) \end{aligned} \tag{37}$$

The firms' maximization problem and the equilibrium value of unemployment can now be written as

$$\begin{aligned} V(U(x), x) &= K \\ &\text{s.t.} \quad A(\phi + C) = Y + A(S + \tilde{\rho}(x)) \end{aligned} \tag{38}$$

where

$$V(U(x), x) = [S(x) - \phi - C(U(x))]\, A$$

## Frequency and Intensity of Liquidty Shocks

The quantitative challenge is to calibrate the financial shocks. With respect to the steady state calibration offered in Section 4 we need to calibrate two additional parameters: $\rho_z$, the persistence of the liquidity shock as well as $\sigma_\omega^2$, the variance of the innovation of the financial shock. The choice of the persistence parameter $\rho_z$ is obtained in using the evidence on the financial crises outlined in Section 2. The idea is that the most severe adverse financial conditions take place at very low frequencies, since financial crises are rare events. In section 2 we argued that financial crises take place every 22 years while systemic financial crises take place every 45 years.

Formally, the economy can settle in $s$ liquidity and financial states $x_i, i = 1.....s$, so that $x_i$ is the value of liquidity in financial state $i$. We thus indicate with $p(x)^s$ the steady state distribution of such financial shock. Let's begin with the calibration of variance $\sigma_\omega^2$. To this purpose we introduce the definition of financial distress.

Table 9: Steady States with average liquidity and with Financial Distress

| | Model | Prod | Plead. income | profits worker | Size New Firms | Entry Cost | Welfare Unempl. | Lev | Int Liq | Mkt Tightness |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $y$ | $\nu(x)$ | $\pi$ | $A$ | $K$ | $U$ | $lev.$ | l(y) | $\theta$ |
| (4) | Average liquidity [a] | 1 | 0.90 | 1.320 | 3.69 | 4.87 | 80 | 2.41 | 0.10 | 0.66 |
| (5) | Financial Distress [b] | 1 | 0.57 | 5.62 | 0.86 | 4.87 | 55.51 | 1.21 | 0.01 | 0.12 |

[a] Model with endogenous leverage and pledgeable income calibrated as in the baseline model of Table 3

[b] Model with endogenous leverage and a pledgeable income to distress level.

See main text for steady state equations

Sources: Author's calculation.

**Definition 6.1** *A firm (and the economy) is in financial distress when internal funding completely dries up.*

In light of the previous definition, we are interested in the lowest tails of the distribution of $x^{'s}$. Working with the steady state definition of liquidity we can say that a distress level of pledgeability $x_d$ is such that

$$\frac{y-(1-\beta)U+x_d}{1-\beta(1-\lambda)} \approx 0 \tag{39}$$

In other words, we set $\sigma^2_\omega(x)$ to be large enough to satisfy the financial distress condition. This exercise- with a grid size of width $n = 9$ implies that $x'_i$ varies from a $x_1 = 0.02$ to $x_9 = 0.42$ . The values of $\sigma^2_z = 0.007$ and $\gamma_z = 2$

While the definition of financial distress may seem ad hoc, few remarks are in order. First, it is a natural definition from the model, especially once the steady state definition of $x$ was calibrated to match the leverage of the non financial US firms. The exact empirical counterpart of $x_d$ is not obvious. We do know that during the great recession there was a sizable fall in financial flows to the non financial business. Using Flow of Funds Accounts Amaral (2011) show that no other post-WWII recession comes remotely close to the great recession in terms of the magnitude of the reduction in borrowing flows. While in most recessions recessions borrowing flows fell by at most 2 percent of GDP, in the great recessions it fell by 5 percent. This means that during the financial recession the reduction was twice as large than in normal recession. Nevertheless, the empirical counterpart of our $x_d$ applies to the financial flows of *new* business rather than to the average business firm. The work of Siemer (2014) reviewed at the beginning gives support to this idea.

To set the persistence parameter $\rho$ we work with the idea that the firm and the economy end up in financial distress at very low frequency, and such frequency correspond to the low probability events of a crisis. We thus choose $\rho$ so that $1 - p(x_d)$ matches the low frequency of financial crisis. In terms of quarterly specification, $\rho_z$ must implies a crisis probability coherent with the rare events outlined in Section 2, so that

$$1 - p(x_d) = \frac{1}{4 * 45}$$

The steady state quarterly frequency of systemic crisis is around 0.005. This exercise implies $\rho_z = 0.978$, so that liquidity shock have higher persistence than productivity shock.

**The unemployment Elasticity of a pure financial shock**

Before moving to the dynamic simulations, we can replicate the estimates provided in Table 5 for a pure financial shock. Using the same logic of productivity shock, and the existence theorem, the value of unemployment can be approximated as

$$U \approx \frac{\Lambda}{\tilde{\tilde{\delta}}} + \frac{y}{1-\beta} - \frac{\phi}{\tilde{\tilde{\delta}}} + \frac{\tilde{K}}{y+\tilde{K}} \frac{x}{1-\beta} y e^{-\gamma_z (z-\overline{z})} \tag{40}$$

We can quantify the elasticity of U with respect to a pure shock $z$ and evaluate its value at steady state ($z = 0$). If we indicate the elasticitiy with $\Psi$ to distinguish it from the productivity shock with $\epsilon$ we have that

$$\begin{aligned} \Psi_{U,x(z=\overline{z})} &= \left[ \frac{\tilde{K}}{(y+\tilde{K})} \frac{x\gamma_z}{1-\beta} \right] U \\ &= 0.42 \end{aligned} \tag{41}$$

This elasticity value is particularly large when the economy is in financial distress. Note that in our calibration non pledgeable income increase for 0.1 to 0.4, which implies that $x$ triple. With an unemployment elasticity of 0.42, the increase in unemployment can be larger than 100 percent.

**Result 6.1** *If non pledgeable income jumps to financial distress level, the unemployment rate can potentially double.*

**Impulse Response of Financial Shocks**

The calibrated level of $x$ allows us to embark enter in the the second exercise of the paper. We do not aim at accounting for the average fluctuations. Distress is a rare event and can not account for the average business cycle shock. Yet, we are still interested in the macro effects of extreme financial shocks. These rare events are best analyzed in terms of impulse response functions, to which we turn next. The exercise we perform is the following.[6] We assume that the stochastic economy is currently settled around its steady state, and defines such condition as quiet. Given a particular time path time of $T$ periods, we assume that at time $t*$, $x_{it}$ jumps from a quiet situation to a crisis situation. Specifically, we construct a time path in which at quarter $t = 10$ the financial shocks jumps from a comfort zone with $x_t = x$ to a situation in which $x_t = xe^{z_d}$. In light of the persistence parameter $\rho_z$ and the stochastic matrix $P_x$ such jump is almost a zero probability event. At time $t = 20'$ the value of $x_t$ goes back one step at a time toward its quiet level. The economy is back in quiet zone at time $t = 45$

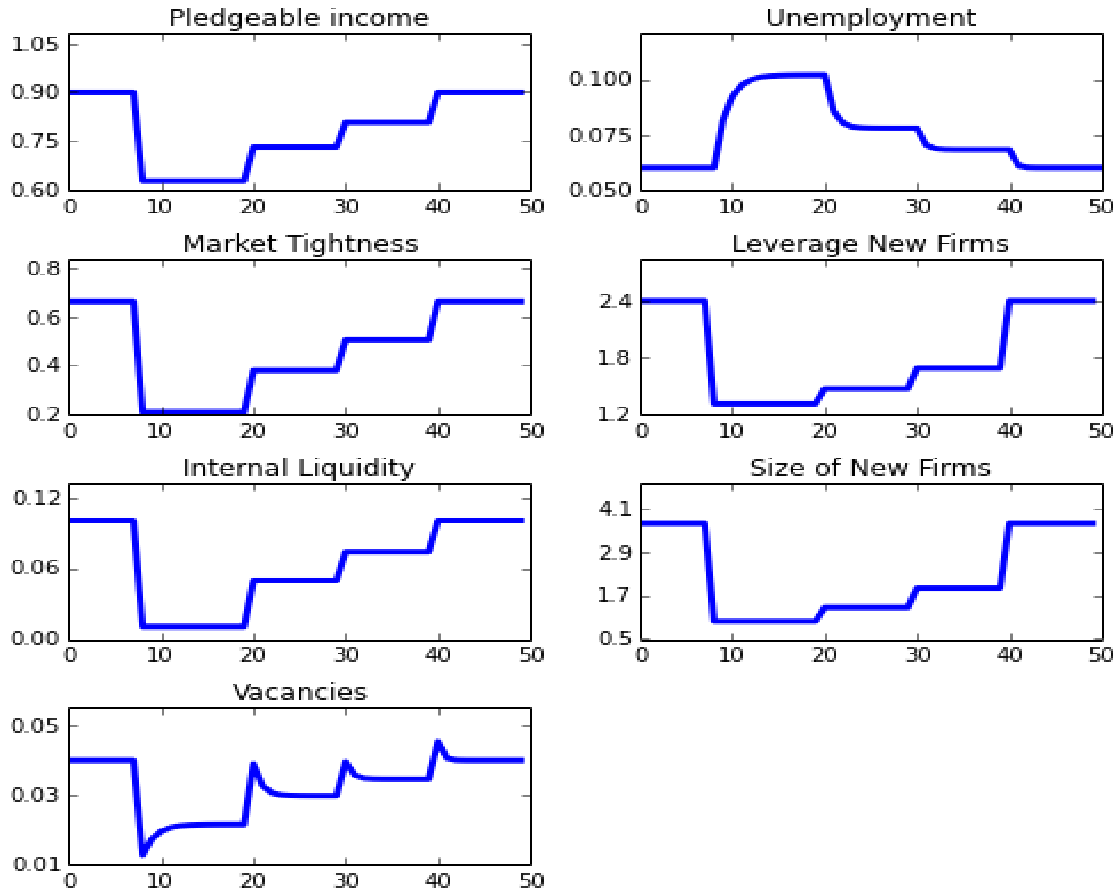
Figure 2 reports the time profile of key macro variables. The first panel is just the shock profile of non pledgeable income. The second chart is the unemployment rate. The level of unemployment increases up to 10 percent in 4 quarters, with an increase as large as 60 percent percent. Vacancies fall by 50 percent and market tightness by 70 percent. Note that the second row of Figure 2 highlights the one to one link between market tightness and unemployed welfare. Leverage, the financial multiplier and the long run size of new firms follow similar patterns.

**US Labor market around 2007 and the Time Profile of the Financial Recession**

In light of the dynamics of Figure 2, it is tempting to recall the behavior of the US economy around 2007 and 2009. This is done in Figure 4. Job openings fell from a peak of 3.2 percent in the second quarter of 2007 to a through of 1.8 percent in 2009. In the same second quarter of 2007 unemployment started to rise and reached a maximum of 10 percent three years later, but it was already above 9

[6]The time path in Figure 2 uses $\gamma_z = 5.5$.

Figure 2: One Time Financial Shock




percent in 2009. Most importantly, productivity did not fell and actually increased after a mild fall in 2008. In terms of financial time line of the financial crisis compiled at the Federal Reserve Bank of St. Louis starts in February 2007, when Freddie Mac announced that would stop buy the most risky sub-prime mortgages. In April 2007 New Century Financial Corporation, a leading sub-prime lender, filed for Chapter 11. In June 2007 Bear Stearns- a leading investment bank, informed investors that it was suspending redemptions from one of its Structured Leveraged Funds. Given these facts, it is not surprising that Christiano et al. (2015) use financial shocks to rationalize the behavior of the US economy in the great recession.

For pure comparison, Figure 3 reports the same time path experiment that we performed on pledgeability also for productivity shock. In Figure 3 the driving force is a drop in productivity of 10 percent. We basically have a fall in labor productivity from its steady state value to a value such that internal liquidity dries up. In Figure 3 productivity shock induces a much milder increase in unemployment and fall in vacancies. Overall, the shape of the dynamics in the two shocks is similar, but the the intensity of the reaction of the economy is much smaller with respect to the pledgeability shock of Figures 2. In addition, we should also recall that such fall in productivity did not take place during the last great recession.

Figure 3: One Time Productivity Shock

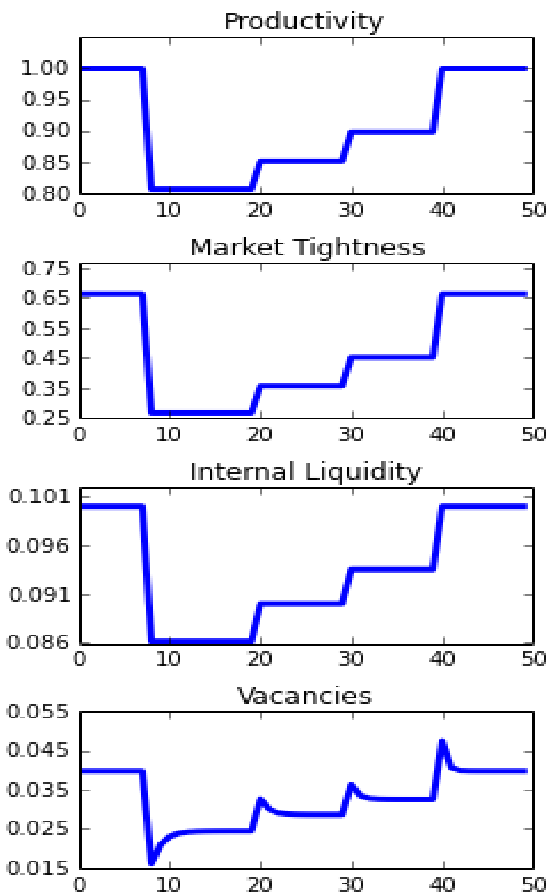
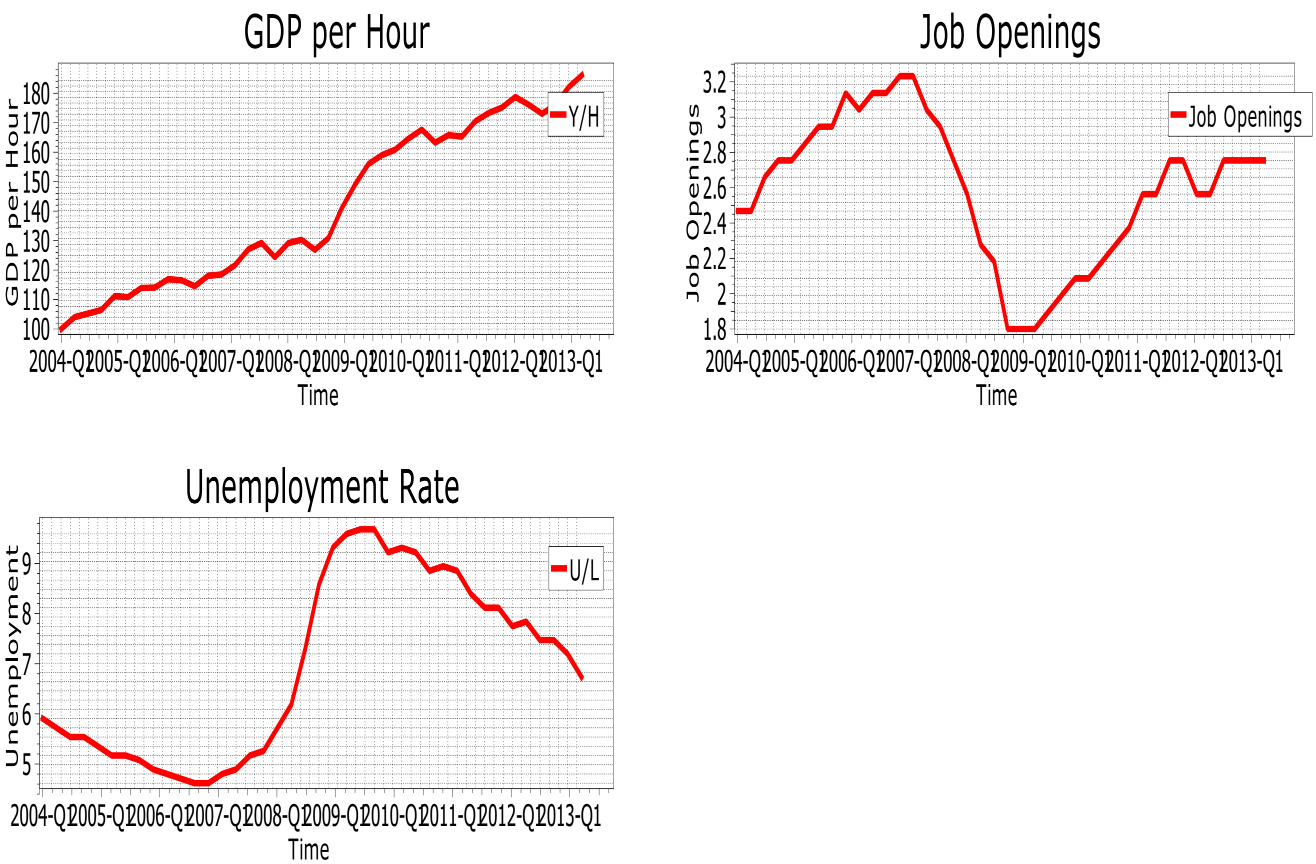


Figure 4: US Key Labor Market Statistics; 2004-2013




Source: Bureau of Labor Statistics at www.bls.gov

# 7 Final Remarks

There is an ongoing vibrant research on the labor market consequences of financial market imperfections. This paper has offered a contribution to such research along three lines.

First, it has presented and solved a simple aggregate model of financial constraints, internal liquidity and labor that relies on two key contributions in the existing literature. The labor market is a traditional DMP model with wage posting, in the spirit of Pissarides (1998), Mortensen and Pissarides (1994) and Moen (2007). The financial frictions rely on limited pleadgeability in the spirit of Holmstrom and Tirole (1997) and (2011). The model is very simply and can be applied to different issues in labor and finance, as we are currently doing in Boeri et al. (2014) where we study the effect of liquid assets on firms hiring and firing decisions in the presence of refanincing shocks.

Second, we asked whether borrowing constraints enhance and amplify the labor market response of aggregate productivity shocks. The theoretical is clear, and we showed that fluctuations in productivity affect pledgeable income and amplify shocks over and beyond what a standard Pissarides (1988) model would imply. The analytical results identify two channels through which productivity changes affect financial frictions and enhance aggregate fluctuations. The first effect is a collateral effect and the second effect is a pledgeability effect. In the calibration exercise, we match not only the key labor market statistics, but also the average leverage of US non financial non listed companies. The calibration of the model clearly suggests that the collateral effect is neglibile while the pledgeability effect increases the response of unemployment to productivity changes as much as 50 percent.

Third, we ask whether financial shocks can help improve our understanding of labor market dynamics. Extreme financial shocks are a very rare event, as documented by the literature on systemic financial crises. Using the low frequency of such events, we asked what happen into the aggregate labor market when shocks to pleadgeable income completely dry up firms internal liquidity. The definition of such shock is very natural in the context of the model. The quantitative results show that these adverse financial shocks can not account for the average fluctuation in the US labor market, but can easily rationalize dramatic increase in unemployment and fall in vacancies, throwing new light on what happened in the US between 2007 and 2009.

# Appendix

## Solution Algortim

The model needs to determine three vectors: $U(y), A(y)$ and $S(y)$. The most stable vector is the following

1. Assume a vector of A Assume a vector of $U(y) = \begin{bmatrix} U(y_1) \\ .. \\ U(y_i) \\ U(y_n) \end{bmatrix}$ and obtain immediately $U(y'|y)$ as $\begin{bmatrix} \sum_{j=1}^{j=n} p_{1j} U(y_j) \\ .. \\ \sum_{j=1}^{j=n} p_{ij} U(y_j) \\ \sum_{j=1}^{j=n} p_{1j} U(y_j) \end{bmatrix}$

2. Obtain the85 vectors $\theta(U, U'(y'|y_i)$ $C(U, U'(y'|y_i)$

3. Assume $S(U, U')$ and iterate over surplus value function to obtain $\hat{S}(U, U'(y'|y))$

4. Given $S$ calculate profit to obtain $\pi(\hat{S}(U, U'(y'|y)), \hat{U}, \hat{U}')$

5. Calculate difference $\Delta = \pi(\hat{S}(U, U'(y'|y)), \hat{U}, \hat{U}') - K$ and obtain $\hat{U} = U + \delta\Delta$ where $\delta$ as an adjustment factor
6. Update $\hat{U}'(\hat{U}(y'|y)$ and go to 2 until convergence
7. Update A with respect to the values of $U, U'$ and go to 1 until convergence

## The calibration of $\phi$ and K

Recalling the definition of leverage in equation 26, and that the free entry conditions is $K = \pi(U^*)A$

$$\begin{cases} \frac{K}{A(U^*)} = \frac{C(U^*)+\phi}{lev-1} \\ \\ \frac{K}{A(U^*)} = \pi(U^*) \end{cases} \tag{42}$$

Using the value of profit per worker in the first equation as $\pi(U) = \frac{y-(1-\beta)U}{1-\lambda(1-\beta)-C(U)} - \phi$, we obtain the value of $\phi$ as

$$\phi = \frac{lev-1}{lev}\left\{\frac{y-(1-\beta)U^*}{1-\beta(1-\lambda)}\right\} - levC(U^*)$$

where $U^*$ is the target value of $U$. The appendix shows that the value of $K$ is

$$K = \frac{\frac{yoy}{1-\beta}\left(\frac{K}{A(U^*)}\right)}{\frac{x(y)}{1-\beta(1-\lambda)} - \left(\frac{K}{A(U^*)}\right)} \tag{43}$$

where $\left(\frac{K}{A(U^*)}\right)$ is an expression for the ratio of $K$ to $A$. See appendix for details.

Since $\pi(U) = \frac{C(U)+\phi}{lev-1}$ we obtain a value of of $\left(\frac{K}{A(U^*)}\right)$ ratio is

$$\left(\frac{K}{A(U^*)}\right) = \frac{C(U)+\phi}{lev-1} \tag{44}$$

Recall then that $A = \frac{\frac{yoy}{1-\beta}}{\frac{x(y)}{1-\beta(1-\lambda)}-\pi(y)}$ and that $\pi(y) = \frac{K}{A(y)}$, this implies that

$$\left(\frac{K}{A(U^*)}\right)A(U) = \frac{\frac{yoy}{1-\beta}}{\frac{x(y)}{1-\beta(1-\lambda)} - \pi(y)}\left(\frac{K}{A(U^*)}\right) \tag{45}$$

$$K = \frac{\frac{yoy}{1-\beta}\left(\frac{K}{A(U^*)}\right)}{\frac{x(y)}{1-\beta(1-\lambda)} - \left(\frac{K}{A(U^*)}\right)} \tag{46}$$

## Restrictions on parameters

We require that $y - z > 0$ and either that $\phi < \frac{y-x-z}{1-\beta(1-\lambda)}$ or that

$$\frac{Y_0}{\phi - \frac{y-x-z}{1-\beta(1-\lambda)}}\left[\frac{y-z}{1-\beta(1-\lambda)} - \phi\right] > K \tag{47}$$

## Numerical solutions to asset values

$$R = w - U + \beta U(y'|y) + \beta(1-\lambda)R(y'|y).$$

This can be solved forward to yield

$$R = \sum_{j=0}^{\infty} \beta^j (1-\lambda)^j \{E[w_{t+j}|y_t] - E[U(t+j|y_t)] - \beta E[U(t+j+1|y_t))\}$$

In words the rent is the expected value of the wages in excess of the value of unemployment. Using the resolvent operator (See Sargent Ljunqvist, 2012) we have that the expected value of productivity is

$$\begin{aligned}\sum_{j=0}^{\infty} R^j (1-\lambda)^j E[y_{t+j}] &= (I - \beta(1-\lambda)P - \beta^2(1-\lambda)^2 P^2 - ...)y_i \\ &= \left[(I - \beta(1-\lambda)P)^{-1}\overline{y}\right]_i = \Delta(y_i)\end{aligned}$$

where $P$ is the stochastic matrix and $\overline{y}$ is a column vector of the state space. In other words $\Delta(y_i)$ is the $i-th$ row of the square matrx $\left[(I - \beta(1-\lambda)P)^{-1}\overline{y}\right]$. Note that $\beta(1-\lambda) < 1$ ensures convergence of $\Delta(y_i)$. Applying the resolvent operator to the outside flow $y_o$, we compactely define $\Delta_o(y_i)$ as

$$\sum_{j=0}^{\infty} \beta^j (1-\lambda)^j E[y(t+j|y_t)] = \left[(I - \beta P)^{-1}\overline{y}\right]_i = \Delta_o(y_i).$$

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