DICHIARAZIONI SOSTITUTIVE DI CERTIFICAZIONI
(art. 46 D.P.R. n. 445/00)

DICHIARAZIONI SOSTITUTIVE DELL'ATTO DI NOTORIETA'
(art.47 D.P.R. n. 445/00)

Il sottoscritto Travaglini Giuseppe, codice fiscale TRVGPP64B14H501K, nato a Roma provincia di Roma il 14-02-1964, attuale residenza a Roma provincia di Roma, indirizzo Via Emilio Draconzio n° 6, c.a.p 00136, telefono 06 35403509 oppure Cell. 347 4414200, ed E-Mail giuseppe.travaglini@uniurb.it, consapevole delle sanzioni penali previste dall'art. 76 del D.P.R. n. 445/00 per le ipotesi di falsità in atti e dichiarazioni mendaci:

D I C H I A R A

che sebbene il lavoro in collaborazione:

G. Travaglini and E. Saltari (2012). "A note on Optimal Capital Stock and Financing Constraints", *Economic Modelling 29, 1177-1180*

presentato ai fini della valutazione scientifica nazionale è il risultato di uno sforzo comune di ricerca, il medesimo Giuseppe Travaglini ha curato la stesura dei **paragrafi 1, 2.**

Roma, 10 novembre 2012.

Il dichiarante, Giuseppe Travaglini

ELSEVIER

Economic Modelling

Volume 29, Issue 2
March 2012

ISSN 0264-9993

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(contents continued on outside back cover)

(This is a sample cover image for this issue. The actual cover is not yet available at this time.)

Economic Modelling 29 (2012) 1177–1180

Contents lists available at SciVerse ScienceDirect

Economic Modelling

journal homepage: www.elsevier.com/locate/ecmod

A note on optimal capital stock and financing constraints☆

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ARTICLE INFO

Article history:
Accepted 7 April 2012
Available online xxxx

JEL classifications:
E22
E51

Keywords:
Capital stock
Financing constraints
Brownian motion
Uncertainty

ABSTRACT

There is a robust literature on the relationship between financing constraints and real investment. Little has been said on the relationship between financing constraints and capital stock in the long run. This note focuses on this last issue. To keep the model tractable, we assume that the firm employs a single input, and this input is used as collateral. We get three main results. Firstly, we show that the optimal capital stock chosen by a firm is affected by financing constraints even when they are slack at the current time. Secondly, we show that the net present value of the potentially constrained firm is always smaller than the one of the never constrained firm. Finally, we find that in the presence of latent financing constraints the firm does not limit itself to reducing its investment when the upper limit is reached. What it actually does is to lower its long run optimal capital stock, amplifying the effects of constraints in the long run.

1. Introduction

During the last twenty years an extensive literature on determinants of real investment has emphasized the role of financial resources in affecting capital accumulation. A considerable body of theoretical research stated that financing constraints may be the result of optimizing behavior of lenders. (Hodgman, 1960; Keeton, 1979; Stiglitz and Weiss, 1981). In addition, other papers provided empirical evidence that investment decisions depend strictly on internal finance and external debt (Bassetto and Kalatzis, 2011; Chirinko, 1993; de Bondt and Diron, 2008; Fazzari and Athey, 1987; Fazzari et al., 1988; Hennessy and Whited, 2007; Hubbard, 1998; Lensink et al., 2001; Pratap and Rendon, 2003).

The basic idea of these models is that so long as the firm does not come up against the constraint it will be able to satisfy the Euler equation. But, one important implication of the optimizing models should be that anticipated future constraints might affect the current investment decisions of firms even when there is no binding constraint at present. Therefore, as Jaffee and Stiglitz argued (1990) the impact of financing constraint "cannot be assessed just by looking at those periods in which there is direct evidence for its presence".

The more recent debate seems to have acknowledged this original suggestion. D'Autmune and Michel (1985), Milne and Robertson (1996), Whited (1998), Chatelain and Teurlai (2001, 2006), and Saltari and Travaglini (2001, 2003) focused on the relationship between latent financing constraints and current investment decisions. This strand of literature shows that financial constraints need *not* to be currently binding in order to affect investment decisions. A clear analytical inspection of this issue is provided by Saltari and Travaglini (2006). They show that future latent constraints influence the optimal pattern of current investment, altering the marginal q value of the firm over time.

The present model can be seen as an update of previous contributions. The objective of the analysis is the long run capital stock. The main result of the paper is that *latent* financing constraints can affect not only investment in the short run, but also the optimal capital stock in the long run. Therefore, the paper provides a new perspective of financing constraints, scrutinizing the impact of constraints and shocks on the optimal level of capital stock.

We get three main results. Firstly, we show that in a dynamic stochastic context future financing constraints change the firm optimal capital stock even when demand for financing resources is below the critical threshold. Additionally, we show that the firm net present value is smaller than the unconstrained one, even when the constraint is currently slack. Finally, we show that in the presence of latent financing constraints the firm does not limit itself to change its investment when the upper limit is reached. What it actually does is to lower its long run optimal capital stock, amplifying the effects of constraints in the long run.

The paper is organized as follows. In Section 2 we discuss a firm's investment policy under the alternative scenarios of constrained and non-constrained firm. Section 3 compares these solutions. Section 4 concludes.

2. The model

In this section we analyze how financing constraints affect the desired capital stock. In examining this question, it is useful to compare

☆ We gratefully acknowledge Ministero dell'Istruzione, dell'Universita e della Ricerca for financial support (PRIN 2008YYBH7L).
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doi:10.1016/j.econmod.2012.04.006

the behavior of an unconstrained firm, acting in a perfect capital market, with that of a constrained firm which takes its decisions in the presence of latent financing constraints.

2.1. Optimal capital stock without financing constraints

Let us suppose that the firm is risk neutral.[1] Investment decisions are taken in a perfect capital market where r is the equilibrium interest rate. Each firm operates with a large number of projects. Capital is reversible, that is the firm can buy new units of capital and resell the old ones at the same price.

To simplify, we assume that the firm uses a single input K, say capital, with decreasing marginal productivity. The set of production possibilities changes continuously because of a multiplicative shock θ_t whose dynamics is

$$d\theta_t = \sigma\theta_t dz \tag{1}$$

The shock θ_t follows a geometric Brownian motion without drift. The production function is

$$\theta_t f(K_t) = \theta_t K_t^{\alpha} \quad \text{with } 0<\alpha<1 \tag{2}$$

The firm chooses its optimal capital stock maximizing the present discounted value $V(\theta_t, K_t)$ of the expected cash flows

$$V(\theta_t, K_t) = \max_{Is} E_t \int_t^{\infty} [\theta_s f(K_s) - I_s] e^{-r(s-t)} ds \tag{3}$$

where $dK = I_s ds$ is the investment rate. To simplify the analysis we assume that the depreciation rate is equal to zero. The functional Eq. (3) can be rewritten using the Bellman equation

$$rV_t dt = \max_{I_t} \{[\theta_t f(K_t) - I_t] dt + E_t(dV)\} \tag{4}$$

Using Ito's lemma and the stochastic process (1), we can write (see the Appendix for details)

$$rV_t = \max_{I_t} \left\{ \theta_t f(K_t) - I_t + V_K I_t + \frac{1}{2}\sigma^2\theta_t^2 V_{\theta\theta} \right\} \tag{5}$$

Under the assumption of perfect financial markets, and excluding bubbles, the solution of the maximization problem (5) is

$$V_t^U(\theta_t, K_t) = \frac{\theta_t f(K_t^*)}{r} \tag{6}$$

The value of the unconstrained firm (U) is equal to the present discounted value of the expected cash flow which arises from the capital stock K_t^*.

Finally, from the first-order condition $V_K^U = 1$, and using Eq. (2), we get

$$K_t^* = \left(\frac{\alpha}{r}\theta_t\right)^{\frac{1}{1-\alpha}} \tag{7}$$

This last condition describes the relationship between the shock θ_t and the long run capital stock K_t^*, corresponding to that θ_t, in the unconstrained scenario. This relation is drawn in Fig. 1. The barrier–control curve is the upward-sloping line U. Under the assumption of diminishing returns, a higher θ_t rises the profit from any given level of capital, and therefore justifies a larger capital stock in the long run.

Note that to the left of the U curve we have $V_K^U > 1$, and new investments are made. Hence, when θ_t rises above the U curve the optimal policy is to increase the capital stock so as to satisfy the condition $V_K^U = 1$ in the long run. Similarly, for any point to the right of the U curve we have $V_K^U < 1$, and the firm finds optimal to reduce its initial capital stock.

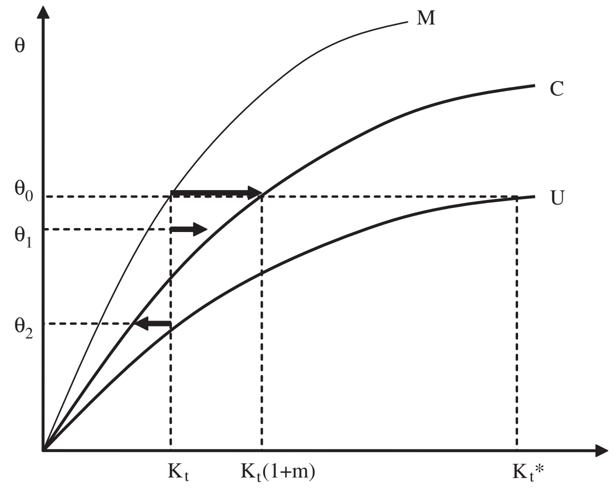

Fig. 1. Investments and financial constraints.

Using this simple argument we reach our first result. If a firm acts without constraints the sole determinants of its optimal capital stock is the value of the shock θ_t and the corresponding marginal productivity $f_K(K_t)$. In any period changes of θ_t modifies the optimal capital stock, but the magnitude of past and future shocks has no effect on the current investment decisions.

2.2. Optimal capital stock with financing constraints

Is this last property valid in the presence of financing constraints?

To analyze this problem, let's assume that to make a new investment the firm raises external resources. Assume that the maximum amount of resources it can get from external lenders is given by the proportion $0<m<1$ of its initial capital stock K_t. In other words K_t is the collateral. Obviously, the maximum amount of capital stock that a firm can obtain in the next period is equal to $K_t(1+m)$.[2] The coefficient m is a parameter independent from the initial amount of capital stock. Though this last assumption might appear restrictive, it is rich enough to study the consequences of financing constraints on the optimal capital stock.[3]

Now let's consider how investment decisions change in the presence of financing constraints. In the present scenario, there is an upper limit to the investment rate

$$I_t \le mK_t \tag{8}$$

A potentially constrained firm observes θ_t, and anticipates that, whatever its actual value, the rate of investment cannot exceed the upper limit fixed by the constraint (8). This upper bound changes the barrier–control curve which describes the dynamic equilibrium

[1] For the case of a risk-averse firm, see Saltari and Ticchi (2005, 2007).

[2] There are several definition of financing constraint. In this context we refer to type 1 credit rationing: the credit contract defines the maximum amount of loan available at the going interest rate.

[3] We do not attempt to derive this constraint endogenously. However, Hart and Moore (1994), and Kiyotaky and Moore (1997) give an argument to show the nature of this contract: creditors know in advance the liquidation value of assets in place utilized as collateral. So they take care never to allow the loan to exceed the value of the collateralized capital stock K_t.

between shocks and capital stock. In this setting the general solution of the problem

$$rV_t dt = \max_{I_t} E_t\{[\theta_t f(K_t) - I_t]dt + E_t(dV)\} \tag{9}$$

under the credit constraint $I_s \le K_s m$ for any $s \ge t$, with $0 < m < 1$, is

$$V^C(K_t, \theta_t) = A(K_t)\theta_t^{n_1} + B(K_t)\theta_t^{n_2} + \frac{\theta_t f(K_t)}{r} \tag{10}$$

where C denotes the constrained firm, and $n_1 > 1$ and $n_2 < 0$ are the roots of the characteristic equation. In the constrained scenario, $A(K_t)$ and $B(K_t)$ are "constants" of integration whose value depends on the current capital stock and the boundary conditions. The last term on the right hand side of Eq. (10) is the fundamental value. If — as in the previous scenario — the rate of investment may change without bounds, then the optimal solution would be the same as before, and the two constants must be set equal to zero to satisfy condition (6).

But, in the present scenario the investment rate is limited by the upper bound $I_t = K_t m$, and this constraint influences both the value of the firm and the corresponding desired capital stock. To get the values of the two constants, recall that given θ_t the fundamental value of the constrained firm is $V^C(K_t, \theta_t) = \frac{\theta_t f(K_t)}{r}$. In addition, notice that as θ_t decreases the value of $\theta_t^{n_2}$ rises because $n_2 < 0$. This implies that as θ_t tends to zero the term $B(K_t)\theta_t^{n_2}$ increases, rising the value of the firm. To ensure that $V^C(K_t, \theta_t)$ goes to zero as θ_t goes to zero, we should set the coefficient of the negative power of θ_t equal to zero; thus, $B(K_t) = 0$. Therefore, Eq. (10) becomes

$$V_t^C = A(K_t)\theta_t^{n_1} + \frac{\theta_t f(K_t)}{r} \tag{11}$$

The remaining constant $A(K_t)$ depends on the constraint $I_t = K_t m$. At this threshold, it is optimal for the firm to acquire an asset whose marginal value is $V_K^C = 1$, by incurring the constrained investment I_t. Therefore, the optimal constrained policy must satisfy the condition

$$V_K^C = A_K(K_t)\theta_t^{n_1} + \frac{\theta_t f_K(K_t)}{r} = 1 \tag{12}$$

But this expression alone is not sufficient to determine both $A_K(K_t)$ and the trigger value of θ_t. We need a further condition. It requires that when the constraint is binding, infinitesimal changes of θ_t do not alter the firm investment decisions. Therefore, at the upper bound the condition $V_{K\theta}^C = 0$ must be satisfied

$$V_{K\theta}^C = A_K(K_t)n_1\theta_t^{(n_1-1)} + \frac{f_K(K_t)}{r} = 0 \tag{13}$$

Putting these two conditions together, we get

$$A_K\left(K_t^C\right) = -\frac{(n_1-1)^{n_1-1}}{(n_1 r)^{n_1}}\alpha^{n_1}\left(K_t^C\right)^{n_1(\alpha-1)} \tag{14}$$

$$K_t^C = \left(\frac{n_1-1}{n_1}\frac{\alpha}{r}\theta_t\right)^{\frac{1}{1-\alpha}} \tag{15}$$

Expression (14) is eloquent. Since $A_K(K_t^C)$ is negative, the term $A_K(K_t^C)\theta^{n_1}$ of Eq. (12) measures the marginal loss suffered by the firm that cannot invest beyond the threshold $K_t m$. Intuition suggests that if $K_t(1+m)$ is the maximum capital stock available starting at K_t, the firm is forced to give up the marginal profits which would derive from a further expansion of the investment beyond the constraint $K_t m$. Using the solution for $A_K(K_t^C)$, we find by integration

$$A_K\left(K_t^C\right) = \int_{K_t}^{\infty} -[A_K(k)]dk = \frac{(n_1-1)^{n_1-1}}{(n_1 r)^{n_1}}\alpha^{n_1}\frac{\left(K_t^C\right)^{n_1(\alpha-1)+1}}{n_1(\alpha-1)+1} \tag{16}$$

Thus, the constant $A_K(K_t^C)$ is *negative*.[4]

This result makes good economic sense: it states that, since the firm anticipates the possibility to meet future constraints, *latent* financing constraints *reduce* the present value of the firm and the desired capital stock to $K_t^C < K_t^*$.

3. Constraints and investment

Condition (15) describes the optimal relationship between θ_t and K_t in the constrained scenario. Observe that since $n_1 > 1$, the factor $\frac{n_1-1}{n_1}$ is positive and lower than 1. Therefore, in the constrained scenario the threshold value of the shock θ_t must exceed the threshold value of the unconstrained one to get the same capital stock. The C curve in Fig. 1 is drawn using Eq. (15), and it describes this property graphically. Therefore, what is the net worth of the constrained capital K_t^C? The contribution of a marginal unit of capital to the cash flow is $\theta_t\alpha(K_t)^{\alpha-1}dK_t$. Its user cost is rdK_t. Hence, Eq. (15) says that in the constrained scenario the marginal addition of a unit of capital is justified when its expected present value exceeds the cost by the multiple $\frac{n_1}{n_1-1}$. This condition also implies that the C curve must be traced on the left of the U curve.

The position of the C curve in the space (K, θ) depends on the positive root n_1, which is a function of r and σ^2. When the interest rate r rises the value of n_1 rises as well, and correspondingly the critical value θ_t increases. This means that the credit constraint loosens. On the other hand, when the variance σ^2 rises the value of the root n_1 reduces, and, hence, the trigger value θ_t reduces too.

Finally, let us focus on the investment policy, in the alternative scenarios, when θ_t changes. To discuss this issue, a third curve labelled M is drawn in Fig. 1. It describes, for any initial capital stock the corresponding trigger value θ_t that boosts the constrained firm to make the maximum investment $I_t = K_t m$. Thus, given a value of θ_t and the corresponding $K_t^C = K_t(1+m)$ along the C curve, the initial capital stock K_t^M along the M curve is given by the expression

$$K_t^M = \left(\frac{n_1-1}{n_1}\frac{\alpha}{r}\theta_t\right)^{\frac{1}{1-\alpha}}\frac{1}{1+m} \tag{17}$$

Note that the M curve is not a barrier–control, but just a ceiling helpful to compare the investment decisions under alternative scenarios. The horizontal distance between the M and the C curves measures the maximum constrained investment $K_t m$, given the trigger value θ_t of the shock. Therefore, from condition (17) we get that $K_t^M < K_t^C < K_t^*$ for any value of θ_t.

For concreteness, let us look at Fig. 1 and assume that K_t is the current stock of capital. Then, θ_0 is the value of the shock which stimulates the unconstrained firm to invest until the desired capital stock K_t^* along the U curve. But, the constraint (16) prevents the potentially constrained firm to get this same capital stock. Thus, the difference $K^* - K_t(1+m)$ provides a measure of the financing constraint tightness. This effect is shown in Fig. 1: when the shock reaches the trigger value θ_0 along the ceiling M, the constraint binds and the investment rate is at most equal to $K_t m$.

It is interesting to study what happens when the shock is lower than θ_0. For instance, this happens when the shock is θ_1. We know that above the C curve $V_K^C > 1$ so that the investment rate is positive but less than $K_t m$. Although the constraint is slack the firm cannot invest to get the optimal capital stock as defined by the U curve. Intuitively, this happens because the firm anticipates the possibility to meet the future constraint *even when* it is slack at the current time. This result confirms our earlier intuition: the latent financing constraint leads to a reduction in overall demand for capital.

[4] Calculating the integral, we get $-\frac{(n-1)^{n-1}}{(nr)^n}\alpha^n\frac{k^{n(\alpha-1)+1}}{n(\alpha-1)+1}\Big|_{K_t(1+m)}^{\infty}$ For convergence of the integral, α must be sufficiently less than one so that $n(\alpha-1)+1<0$.

Now consider a shock θ_2 smaller than the one required to stay along the C curve. In this case $V_K^C < 1$, and the constrained firm finds optimal to *reduce* its current capital stock to go back along the C curve where $V_K^C = 1$. But, the main implication of this "optimizing" behavior is to enforce the credit constraint over time. In fact, since the capital stock is the collateral, the smaller is the current capital stock the smaller will be the amount of external resources the firm will obtain to finance new investments when eventually $\theta > \theta_2$. This result also implies that in the constrained scenario it is not just current capital, but its entire path over time that affects both investment and constraints over time.

In addition, it is remarkable that the optimizing behavior of the constrained firm tends to feed a vicious circle. During recessions firms can find optimal to decrease their capital stock. But, as time passes this initial choice tends to reinforce the financing constraints. The inertial impact of the change in capital stock on the tightness of the financing constraints can be thought as a form of financial accelerator mechanism (Bernanke et al., 1999; Nolan and Thoenissen, 2009).

4. Conclusions

In this paper we have studied the relationship between investment decisions and optimal capital stock under financing constraints. In our model constraints affect investment decisions in all periods, even when they are currently slack. To derive our analytical solution we have assumed that the firm employs a single input K_t which is used as collateral.

We get three main results. Firstly, the logic of the model is that potentially constrained firms, free from constraints at the current time, find optimal to make decisions in order to achieve an optimal investment plan at the outset, anticipating the effects of latent constraints. Secondly, we find that when the investment rate is constrained, the limited financial resources act as an upper bound on the optimal capital stock. Therefore, financing constraints produce an overall decrease of the present value of the potentially constrained firm, capturing the expected loss of profits. Hence, the potentially constrained firm is always worth less than its fundamental value. Finally, we have shown that in the presence of latent financing constraint the firm does not limit itself to reducing its investment rate when the upper limit is reached. What it actually does is to lower its desired capital stock, amplifying the effects of financing constraints in the long run.

Appendix

Using Ito's lemma and the stochastic process (1), we obtain the expected capital gain

$$E_t(dV) = V_K dK + \frac{1}{2}\sigma^2\theta_t^2 V_{\theta\theta} dt \tag{A.1}$$

Substituting this expression into the Bellman Eq. (4)

$$rV_t dt = \max_{I_t} \{[\theta_t f(K_t) - I_t]dt + E_t(dV)\} \tag{A.2}$$

we can write

$$rV_t = \max_{I_t} \left\{\theta_t f(K_t) - I_t + V_K I_t + \frac{1}{2}\sigma^2\theta_t^2 V_{\theta\theta}\right\} \tag{A.3}$$

The first-order condition is

$$V_K = 1 \tag{A.4}$$

Substituting for V_K in the previous equation we have the differential equation

$$rV_t = \theta_t f(K_t) + \frac{1}{2}\sigma^2\theta_t^2 V_{\theta\theta} \tag{A.5}$$

whose characteristic equation is

$$r = \frac{1}{2}\sigma^2 n(n-1) \tag{A.6}$$

The values of the two roots are respectively $n_1 = \frac{1}{2} + \sqrt{\frac{1}{4} + 2\frac{r}{\sigma^2}} > 1$ and $n_2 = \frac{1}{2} - \sqrt{\frac{1}{4} + 2\frac{r}{\sigma^2}} < 0$. The general solution of (A.5) is

$$V(K_t, \theta_t) = A(K_t)\theta_t^{n_1} + B(K_t)\theta_t^{n_2} + \frac{\theta_t f(K_t)}{r} \tag{A.7}$$

Ruling out speculative bubbles, i.e. setting to zero the two constants $A(K_t)$ and $B(K_t)$, we get

$$V^U(\theta_t, K_t) = \frac{\theta_t f(K_t^*)}{r} \tag{A.8}$$

which is Eq. (6).

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