TILBURG UNIVERSITY
KATHOLIEKE UNIVERSITEIT BRABANT
POSTBOX 90153
5000 LE TILBURG
THE NETHERLANDS

[redacted]

DEPARTMENT OF ECONOMICS

RESEARCH MEMORANDUM

THE FLEXIBLE ACCELERATOR MECHANISM IN A FINANCIAL ADJUSTMENT COST MODEL

Peter Kort

FEW 346

The Flexible Accelerator Mechanism in a Financial Adjustment Cost Model

1. Introduction

In the traditional adjustment cost literature (e.g. Lucas (1967), Gould (1968)) models are known in which the firm faces constant returns to scale concerning its production process and constant prices for its output. If the adjustment cost function is assumed to be convex, this leads to the well known flexible accelerator mechanism:

$$\dot{K}(t) = a\,(K^{*} - K(t)) \tag{1}$$

in which:

- t : time
- $K = K(t)$: stock of capital goods at time t
- K^{*} : desired level of the stock of capital goods
- a : speed of adjustment rate ($a>0$ and constant)

Thus the rate at which the firm accumulates capital goods is directly proportional to the difference between its desired capital stock and its current capital stock, which implies that the optimal level will never be reached in finite time.

In this paper, we extend the analysis by incorporating a downward sloping demand curve for the firm's products and a financial structure which implies, roughly stated, that the firm must earn the money first before it can invest. We use the flexible accelerator mechanism as a first tool to analyse the firm's optimal investment behavior, which can be applied when the firm is in its equilibrium. As a second tool we have the net present value of marginal investment, that can be used to establish whether the firm is in its equilibrium and if it is not, how to reach this equilibrium as soon as possible. In standard books of corporate finance (e.g. Brealy and Myers (1981), Levy and Sarnat (1986)) the net present value criterion is used as a method to evaluate an investment proposal and to compare alternative investment proposals. The net present value of such an investment is defined as the sum of the net cash receipts minus the initial investment outlay (see Levy and Sarnat (1986, pp. 33-34)). In this paper the net present value approach is extended to a dynamic context. We show that on the equilibrium path the net present value of marginal investment is equal to zero. If the net present value is not zero at the start, the firm needs an adjustment phase, in which it invests at its maximum if the net present value is positive and it does not invest at all if the net present value of marginal investment is negative.

The model is presented in Section 2. In Section 3 we analyse the solution that is optimal when the firm is already in its equilibrium at the initial point of time, while in Section 4 we study the case where the firm has to grow or to contract first before it reaches its equilibrium. Our findings are summarized in Section 5 and the net present value formulas are derived in the Appendix.

2. Model Formulation

In this section we present our dynamic model of the firm. Assume that the firm behaves so as to maximize the shareholders' value of the firm. This value consists of the discounted dividendstream over the planning period. The horizon date is assumed to be infinite. Hence:

$$\text{maximize: } \int_0^\infty D(t) \exp(-it)\, dt \tag{2}$$

in which:

$D = D(t)$: rate of dividend pay-out at time t

i : shareholders' time preference rate ($i>0$ and constant)

If depreciation is proportional to the stock of capital goods, we can describe the impact of investment on the amount of capital goods by the nowadays generally used formulation of net investment:

$$\dot{K} = I(t) - aK(t),\ K(0) = K_0 > 0 \tag{3}$$

in which:

$I = I(t)$: rate of gross investment

a : depreciation rate ($a>0$ and constant)

We assume the value of a capital good to be equal to one and that borrowing is not allowed. In this way the balance sheet becomes:

$$K(t) = X(t) \tag{4}$$

in which:

$X = X(t)$: stock of equity at time t.

Assuming a fixed labor to capital rate and constant returns to scale, production will be proportional to the inputs:

$$Q(t) = qK(t) = \frac{q}{\ell} L(t) \tag{5}$$

in which:

$L = L(t)$: stock of labor

$Q = Q(t)$: rate of production

ℓ : labor to capital rate ($\ell>0$ and constant)

q : capital productivity ($q>0$ and constant)

We suppose that the output market is imperfect, which implies that the firm faces a downward sloping demand schedule $P(Q)$, i.e. $P'(Q) < 0$. We assume that the corresponding sales function is concave:

$$G(Q) = P(Q)Q(t) \tag{6}$$

in which:

$G = G(Q)$: rate of sales, $G(Q) > 0$, $G'(Q) > 0$, $G''(Q) < 0$

$P = P(Q)$: (net) selling price

Due to the fixed labor to capital rate, earnings, being equal to the difference between sales and labor costs, are a concave function of K. By using (5) and (6) this can be expressed as follows:

$$S(K) = (qP(qK) - w\ell)\ K(t) \tag{7}$$

in which:

$S = S(K)$: rate of earnings, $S(K) > 0$, $S'(K) > a$, $S''(K) < 0$

We further assume that the adjustment costs are a concave function of gross investments and that earnings after deduction of depreciation and adjustment costs, can be used to pay out dividend or to increase retained earnings:

$$\dot{X} = S(K) - aK(t) - A(I) - D(t),\ X(0) = X_0 > 0 \qquad (8)$$

in which:

$A = A(I)$: rate of adjustment costs, $A(I) \geqq 0$, $A'(I) > 0$, $A''(I) > 0$, $A(0) = 0$

Dividend is restricted by a rational lower bound and investment is assumed to be irreversible:

$$D(t) \geqq 0 \qquad (9)$$

$$I(t) \geqq 0 \qquad (10)$$

Using (3), (4) and (8) we get:

$$D(t) = S(K) - I(t) - A(I) \qquad (11)$$

By using (11) and substituting K for X we can express the model as follows:

$$\underset{I}{\text{maximize:}} \int_0^\infty (S(K) - I - A(I)) \exp(-it)\, dt \tag{12}$$

subject to:

$$\dot{K} = I - aK,\ K(0) = K_0 > 0 \tag{13}$$

$$S(K) - I - A(I) \geqq 0 \tag{14}$$

$$I \geqq 0 \tag{15}$$

As an additional assumption we require that:

$$S(K) - aK - A(aK) > 0 \tag{16}$$

By using standard control theory (see e.g. Feichtinger and Hartl (1986)), we define the Lagrangian:

$$L = (S(K) - I - A(I))\ (\exp(-it) + \lambda_1) + \psi(I - aK) + \lambda_2 I \tag{17}$$

The necessary conditions are:

$$\psi = (1 + A'(I))\ (\exp(-it) + \lambda_1) - \lambda_2 \tag{18}$$

$$-\dot{\psi} = S'(K)\ (\exp(-it) + \lambda_1) - a\psi \tag{19}$$

$$\lambda_1 \geqq 0, \ \lambda_1 \ (S(K) - I - A(I)) = 0 \tag{20}$$

$$\lambda_2 \geqq 0, \ \lambda_2 \ I = 0 \tag{21}$$

To facilitate the analysis later on, we distinguish between different paths. Based on the fact that the Lagrange multipliers λ_i $(i = 1,2)$ can be positive or zero, each path is characterized by a combination of positive λ's. To show that one of these combinations is infeasible, we state the following proposition:

<u>Proposition 1</u>

λ_1 and λ_2 cannot together be positive at the same time.

<u>Proof</u>

If both λ's are positive, we obtain from (20) and (21):

$$S(K) - I - A(I) = 0 \tag{22}$$

$$I = 0 \tag{23}$$

These two equations cannot hold at the same time, because, due to (13) and (15), K is positive, and it holds that $S(K) > 0$ for K positive (see below equation (7)). Q.E.D.

The feasible paths are presented in Table 1.

[place Table 1 here]

3. Optimal Solution when the Firm is in its Equilibrium at the Initial Point of Time

In this case path 2 holds throughout the whole planning period and in the Appendix we prove that the following relation holds on path 2:

$$\int_t^\infty S'(K(s)) \exp(-(i + a)(s - t))\, ds - (1 + A'(I)) = 0 \qquad \text{PATH 2} \quad (24)$$

The first term is equal to the marginal earnings of investment which consist of the discounted value of the additional earnings due to the new equipment (capital decays, and therefore at each time $s > t$ it contributes only a fraction of what a whole unit of capital would add (Kamien and Schwartz (1981, p.129)). The second term represents the initial outlay including adjustment costs that is required to increase the stock of capital goods with one dollar at time-point "t".
Hence, equation (24) is equal to the benefit of an investment of one dollar and therefore (24) can be interpreted as the net present value of marginal investment. From equation (24) we can derive that the net present value of marginal investment is equal to zero on path 2.
Therefore, marginal earnings equal marginal expenses and the firm is in its equilibrium. Now, the development of the stock of capital goods can be described by the flexible accelerator mechanism, which is explained below.
We define the desired value of capital stock by (see also Nickell (1978, p.31)):

$$1 + A'(aK^*(t)) = \int_t^\infty S'(K(s)) \exp(-(i + a)(s - t))\, ds \qquad (25)$$

Due to (24) and (25) we have $I = a K^{*}(t)$ and if we substitute this into (13), we get:

$$\dot{K}(t) = a\,(K^{*}(t) - K(t)) \tag{26}$$

In this case the desired value of capital stock varies over time. If we assume K small enough (to be more precise: $K < K^{*}$, where K^{*} is defined by (29) below) so that it is optimal for the firm to grow on path 2, then S' decreases over time (because K increases) and we obtain from (25) that $K^{*}(t)$ decreases too. Due to the fact that K increases, $\dot{K}$ is greater than zero but it will decrease, because $K^{*}(t)$ decreases and K increases (cf. (26)). Therefore, K converges to a constant value and from (25) we obtain that $K^{*}(t)$ converges to a constant value too. In this way, for sufficiently large values of "t" the equations (25) and (26) turn into:

$$1 + A'(aK^{*}) = \int_{t}^{\infty} S'(K^{*}) \exp(-(i + a)(s - t))\, ds \tag{27}$$

$$\dot{K} = a\,(K^{*} - K(t)) \tag{28}$$

Equation (28) is the same as (1). Because S' is constant in (27), we can derive from this expression:

$$S'(K^{*}) = (i + a)\,(1 + A'(aK^{*})) \tag{29}$$

K^{*} is the optimal desired level, because from (29) we can derive that the marginal earnings rate equals the marginal cost rate, where the latter

consists of the sum of the shareholder's time preference rate and the depreciation rate, corrected for the fact that $1 + A'(aK^*)$ dollars are required for increasing the capital goods level with one dollar.
The above findings are confirmed in the traditional adjustment cost literature, in which it is derived that (28) holds in case of constant returns to scale and constant prices (see Section 1). In our model we have constant returns to scale (see equation (5)) and, because K converges to a constant value, also constant prices for sufficiently large values of "t". The last assertion can be derived from (5) and (6). Thus as soon as K has almost reached its stationary value, the flexible accelerator rule with a fixed desired level of capital stock starts to function and it may happen that the stationary value will never be reached. The above treated solution is presented in Figure 1.

[place Figure 1 here]

If it holds that $K > K^*$ (cf. equation (29)) at the initial point of time, then the development of K is also described by the flexible accelerator mechanism, but in this case the stock of capital goods will approach its stationary value from above, while $K^*(t)$ increases over time (Figure 2).

[place Figure 2 here]

4. Optimal Solution if the Firm is not in its Equilibrium at the Initial Point of Time

First, suppose that at the initial point of time capital stock is that low that equation (24) dictates an investment level to the firm which exceeds its upperbound described by (20). Then, the optimal policy is to approach this level as much as possible, which implies that investment is situated on this upperbound (path 1). In the Appendix we prove that on path 1 the following relation holds:

$$(1 + A'(I))\ \lambda_1 \exp(it) = \int_t^\infty S'(K(s)) \exp(-(i + a)(s - t))\, ds + \int_t^\infty S'(K(s)) \exp(-a(s - t))\ \lambda_1(s) \exp(it)\, ds + - (1 + A'(I)) \qquad \text{PATH 1} \qquad (30)$$

Recall that λ_1 is the Lagrange multiplier of the upperbound of investment plus adjustment costs, cf. (20). Therefore, λ_1 is equal to the extra value of the Hamiltonian gained if the upperbound of investment plus adjustment costs (S(K)) is increased by one. In this way the left-hand side of (30) represents the gain due to an increase of this upperbound with 1 + A'(I), but then discounted to <u>t</u> (because λ_1 is equal to this extra value discounted to zero). Notice that an extra expenditure on investments plus adjustment costs of 1 + A'(I) implies a one dollar increase of the stock of capital goods.

The first and the third term on the right-hand side of (30) can also be found in equation (24). The second term represents the indirect marginal earnings of investment. An extra dollar of investment at the instant "t" implies an increase in the stock of capital goods of exp(-a(s - t)) at time-point s > t, generating an extra return of S'(K(s)) exp(-a(s - t)). The upperbound of investment plus adjustment costs will be increased with this value and in this way the Hamiltonian discounted to "t" is increased by

$S'(K(s)) \exp(-a(s - t)) \lambda_1(s) \exp(it)$, because $\lambda_1(s) \exp(it)$ is the shadow price of this upperbound discounted to "t".

To conclude: the right-hand side of (30) is equal to the net present value of marginal investment on path 1. Due to the fact that λ_1 is greater than zero on path 1 (see Table 1), we can conclude that this net present value is greater than zero, so marginal earnings are greater than marginal expenses of investment and therefore it is optimal for the firm to invest at its maximum.

Because the firm grows at its maximum on path 1, $A'(I)$ increases (because I increases) and $S'(K)$ decreases (because K increases). Therefore, the net present value will be equal to zero at some instant. As soon as this happens, path 1 will pass into path 2 and (30) turns into (24). Then, the firm is in its equilibrium, and as in Section 3, the firm's investment policy can again be described by the flexible accelerator mechanism with decreasing desired level of the stock of capital goods. The above described solution is depicted in Figure 3.

[place Figure 3 here]

At last, we turn to the case where capital stock is that high that the net present value of marginal investment is negative at the start of the planning period. Then, marginal expenses exceed marginal earnings of investment and it is optimal to invest nothing at all (path 3). To confirm the negativity of the net present value on path 3, we have proved in the Appendix that the following relation holds on this path:

$$- \lambda_2 \exp(it) = \int_t^\infty S'(K(s)) \exp(-(i+a)(s-t) \, ds - (1 + A'(I)) \quad \text{PATH 3} \quad (31)$$

On path 3 the stock of capital goods decreases and S'(K) increases. Therefore, the net present value of marginal investment will increase and become equal to zero after some time. Then, path 3 passes into path 2 and (31) turns into (24). After this has happened, the firm adopts the investment policy described in Section 3 for the case that $K > K^*$ (see Figure 2). The solution with a negative net present value at the initial point of time is presented in Figure 4.

[place Figure 4 here]

5. Summary

In this paper the traditional adjustment cost models are extended by incorporating a downward sloping demand curve for the firm's output and a financial structure. The firm's optimal investment policy in the equilibrium phase can be described by the well known flexible accelerator mechanism, but here the desired level of the stock of capital goods decreases and converges to a desired level instead of being constant all over the planning period, as is the case in the traditional adjustment cost literature.

In this paper we also show that the concept "net present value of marginal investment" is a useful tool to develop the firm's optimal investment policy. The investment decision rule that leads to this policy can be described as follows:

- if the net present value of marginal investment is positive, it is optimal for the firm to invest at its maximum;

- if the net present value of marginal investment is zero, the firm is in its equilibrium and it determines its investment policy to maintain this position;
- if the net present value of marginal investment is negative, it is optimal for the firm to contract as much as possible.

Appendix. Derivation of the Net Present Value Formulas

Here, we prove that the equations (24), (30) and (31) hold on path 2, path 1 and path 3, respectively. From (19) we can derive that on path 2 ($\lambda_1 = \lambda_2 = 0$) it holds that:

$$\psi(t) = \exp(at) \int_t^\infty S'(K(s)) \exp(-(i + a) s) \, ds + \exp(at) \, C \tag{32}$$

in which:

C: arbitrary constant

The steady state of ψ and K follows from (3), (18) and (19) and can be expressed as:

$$\psi = (1 + A'(aK^*)) \exp(-it) \tag{33}$$

$$S'(K^*) = (i + a)(1 + A'(aK^*)) \tag{34}$$

The determinant of the Jacobian of the system (3), (18) and (19) equals $-a(i + a) + S''(K)/A''(I)$ which is less than zero, so that the dynamics correspond to a saddlepoint (see e.g. Feichtinger and Hartl (1986, pp. 90 -91)). After substituting (33) and (34) into (32) we obtain that $C = 0$

and after combining this with (18) (notice that $\lambda_1 = \lambda_2 = 0$ on path 2), we get the desired relation (24).

Due to (19) and the fact that path 1 passes into path 2, we can derive for path 1 (notice that $\lambda_1 > 0$ and $\lambda_2 = 0$ on path 1):

$$\psi(t) = \exp(at) \int_t^{t_{12}} S'(K(s)) (\exp(-(i + a)s) + \lambda_1(s) \exp(-as)) \, ds + \exp(-a(t_{12} - t)) \, \psi(t_{12}) \quad (35)$$

in which:

t_{12}: point of time at which path 1 passes into path 2

After substituting (18) with $\lambda_2 = 0$ and (32) with $C = 0$ into (35), we obtain that equation (30) holds on path 1.

From (19) and the fact that path 3 passes into path 2, we derive for path 3 ($\lambda_1 = 0$, $\lambda_2 > 0$):

$$\psi(t) = \exp(at) \int_t^{t_{32}} S'(K(s)) \exp(-(i+a)s) \, ds + \exp(-a(t_{32}-t)) \, \psi(t_{32}) \quad (36)$$

in which:

t_{32}: point of time at which path 3 passes into path 2

After substituting (18) with $\lambda_1 = 0$ and (32) with $C = 0$ into (36), we get that (31) holds on path 3.

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Figure and Table Captions

Table 1. Features of feasible paths.

Figure 1. Optimal solution if $K_0 < K^*$ and the firm is in its equilibrium at the initial point of time.

Figure 2. Optimal solution if $K_0 > K^*$ and the firm is in its equilibrium at the initial point of time.

Figure 3. Optimal solution in the case of a positive net present value at the initial point of time.

Figure 4. Optimal solution in the case of a negative net present value at the initial point of time.

Table 1.

Path	λ_1	λ_2	I	D	Policy
1	+	0	max	0	maximum growth
2	0	0	> 0	> 0	equilibrium policy
3	0	+	0	max	contraction

Figure 1.

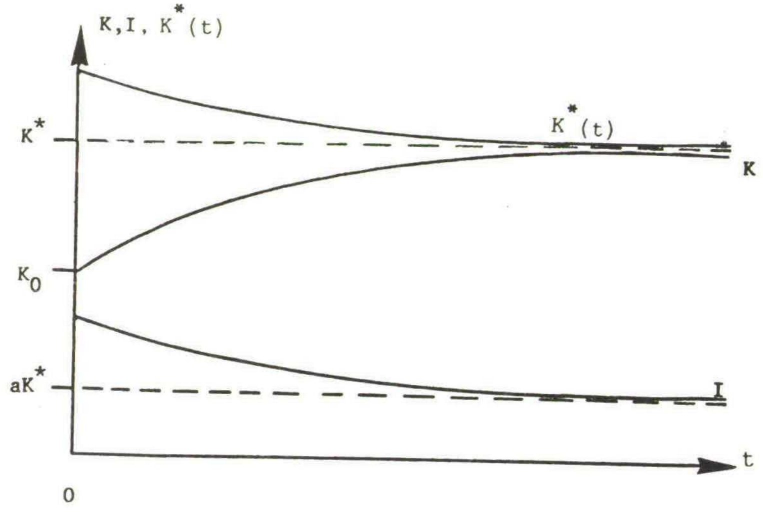


Figure 2.

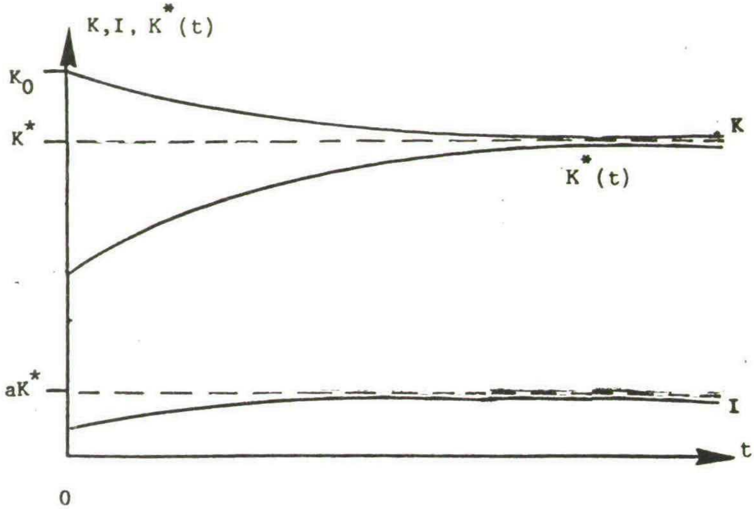


Figure 3.

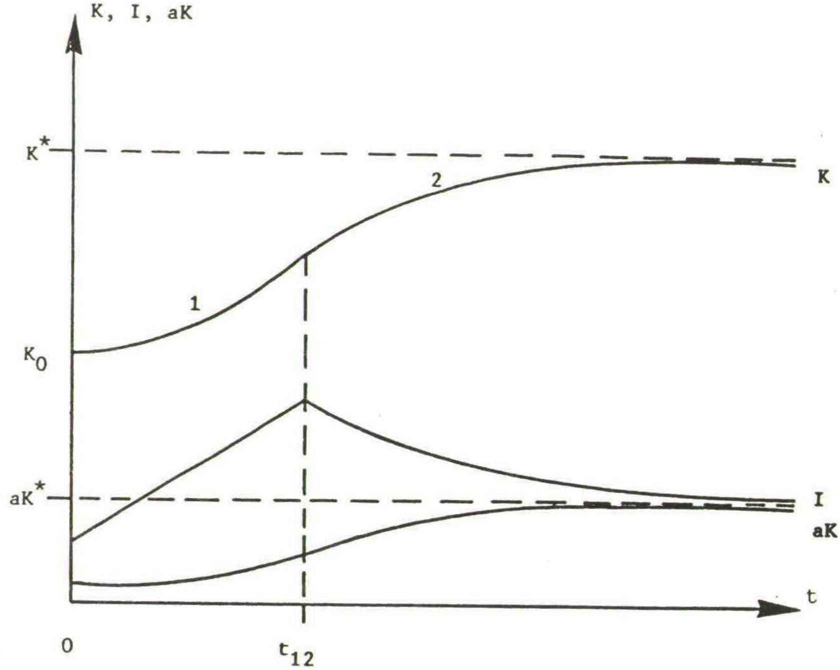
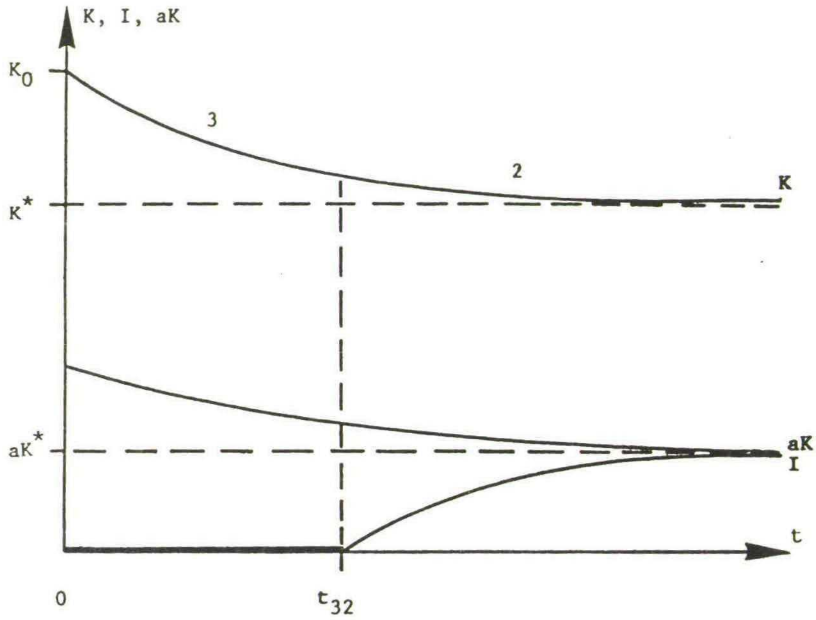


Figure 4.



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