Discussion Paper Series

2003 – 03

Department of Economics
Royal Holloway College
University of London
Egham TW20 0EX

TESTING REAL OPTIONS THEORY USING DATA ON CAPITAL ADEQUACY

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Abstract

This paper uses unique survey-based data that record the extent of positive and negative disequibrium in capital stock at industry level. We observe movement in this disequilibrium and model it to take account of long-run plans, short-term revisions to expectations, and the influence of uncertainty on adjustment. We find that increased uncertainty slows the adjustment of fixed capital towards equilibrium levels, in line with the predictions of real options theory and partial irreversibility models.

J.E.L. classifications: E22, C23
Key-words: Investment, Industry, Irreversibility, Real Options, Uncertainty

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Introduction

Several conditions make it difficult to test the real options theory of capital investment (Dixit and Pindyck 1994) or the associated theory of partial irreversibility or non-convex costs of adjustment (Abel and Eberly 1999). Although many empirical studies have found a negative influence of uncertainty on investment, these results do not offer direct support for the above theories.[2] First, the theories predict that the hurdle rate for investment will be raised by irreversibility and uncertainty. This permits a direct test only if the hurdle rate is observed or if restrictive assumptions are made.[3] Investment is, of course, observed but real options theory predicts that a rise in the hurdle rate is accompanied by an increased probability of hitting the hurdle threshold. Thus the effect on the level of the capital stock is ambiguous, though the responsiveness of investment (and disinvestment) to its determinants should be slowed (Dixit and Pindyck 1994; Price 1996). Finally, investment data is usually aggregated over time so that it records a discrete change in the capital stock. Some have argued that this aggregation over periods of zero investment and non-zero investment make it more appropriate to develop hypotheses on the long-run level of the capital stock (Abel and Eberly 1999). Here again, however, there is an ambiguity. The effects of irreversibility, or non-convex costs on the long-run stock comprise two effects: the user-cost effect which incorporates an irreversibility premium due to the exercise of an option; and the "hangover" effect due to the history of previous

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[2] See, for example, Ghosal and Loungani (2000), Price (1996), and Carruth et al (2000).
[3] Chirinko and Schaller (2002) estimate a discount rate with a variable irreversibility premium for different sectors; Harchaoui and Lasserre (2001) test whether expected marginal profit is driven to zero by investment; Bell and Campa (1997) test the volatility of returns in the Chemicals industry; Driver and Temple (2003) analyse the difference between the discount rate and the hurdle rate in the PIMS database.

investments that may be sub-optimal *ex-post* and difficult to reverse due to imperfect second-hand capital markets. Even under restrictive assumptions such as linear cost of adjustment it is difficult to sign the effect of a change in uncertainty on the long-run capital stock.[4]

In this note we use a unique data- set to identify separately the positive and negative components of the stock disequilibrium – the % above and below desired capacity. Then, by modelling dynamic adjustment with a standard model, we can identify the disequilibrium component due to uncertainty for those with excess capacity and also for those with deficient capacity. We test whether these planned disequilibria both rise with uncertainty as they should do under the hypothesis that uncertainty retards adjustment. By comparing the magnitude of the uncertainty effect across the two cases, we are able to make a judgement on the likely effect of uncertainty on the capital stock. The ability to identify the effect of uncertainty arises because our data contains estimates of both the above equilibrium and the below equilibrium states. This allows us at any time to observe whether the distribution around equilibrium widens under increased uncertainty as firms that are in either state of disequilibrium freeze or attenuate their adjustments.

We estimate equations for UK manufacturing over twenty-one years using quarterly panel data with a large number of industries; this data is publicly available in the UK main employers' survey data-base. The large time and industry dimensions provide over 3000 observations for the panel.

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[4] This is so even for a monopolist. Further complications arise from the effect of uncertainty on the incidence of pre-emption in oligopolistic markets (Spencer and Brander 1986; Ghosal and Loungani

The Model

We focus initially on one key survey question -the exact wording and further details of the survey are given in Appendix 1. This asks whether the firm's capital is "less than adequate", "adequate" or "more than adequate" to meet future demand. We interpret the answers as indicating the possible incidence of a gap (G) between future desired and current actual capital stock with the incidence of a positive gap being expressed by the "more" response and the incidence of a negative gap being given by the "less" response. The extent and nature of the gap G represents a disequilibrium position. In our data, we have only qualitative indicators of the disequilibrium that should properly be measured as a weighted average over firms of the quantitative disequilibria. Instead, the data comes in the form of a count (%) of firms recording capacity as "more" or "less" than adequate. However, by using the logit transformation of these counts, we obtain serviceable quantitative data.[5]

Information on the disequilibrium gap $G_{i,t}$ is recorded as a $2\times N\times T$ matrix of excess capacity G(MORE) and deficient capacity G(LESS) for each industry, where T is the length of the sample period (t=1,T) and N is the number of industries (i=1,N). To save on

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1996,2000).

[5] If the distribution of actual capacity distribution across firms is assumed to be approximately normal, a logit transformation of the data results in a linear proxy for the utilisation and constraint variables. Specifically, if the utilisation across firms is Sech-square (an approximation to the normal), the observed data (U) on the proportion working above a certain (constant) critical level of utilisation corresponds to the integral of the Sech-square density function from that threshold to the upper limit of the distribution. That integral is a logistic function. Thus U=1/(1+exp(a-bCU)) where the argument of the exponential term is a linear measure of capacity utilisation that can be recovered by taking the logit of U. A similar argument may be made in respect of the "more" or "less" responses to the capacity adequacy question

notation we continue to use for now the generic symbol G to denote the disequilibrium for the LESS and MORE cases.

Using a circumflex on Y to denote expected demand we write the recorded gap $G_{i,t}$ in logarithmic form as the sum of the long-run planned gap $\overline{G}_{it}$ and the short-run revision $\widetilde{G}$ as well as an error term assumed to be white noise

assumed to be white noise

$$\overline{G}_{i,t} = \log(K_{i,t} / \hat{Y}_{i,t|t-1}) \qquad \ldots(1)$$

$$\widetilde{G}_{i,t} = \log(\hat{Y}_{i,t|t-1} / \hat{Y}_{t+1|t}) \qquad \ldots(2)$$

$$G_{i,t} = \log(K_{i,t} / \hat{Y}_{i,t+1|t}) = \overline{G}_{i,t} + \widetilde{G}_{i,t} + \varepsilon_{i,t} \qquad \ldots(3)$$

where $\varepsilon_{i,t}$ is a white noise error term.

Thus, each of the two disequilibria variables ($G_{i,t}$) is decomposed into two components. The long-run component($\overline{G}_{it}$) is due to convex cost of adjustment and would be present even if the cycle in demand were deterministic. To express the variation in this we use the linear-quadratic model in Taylor (1982) and Blanchard and Fischer (1989, pp.299-300) [6]. We show that under simplifying assumptions this component ($\overline{G}_{it}$) may be represented as a linear term in capacity utilisation (CU). The derivation is given in Appendix 2.

$$K_t / Y_{t-1} \approx \overline{G} = \kappa + \lambda[CU_{t-1}]^{-1} \qquad \ldots(4)$$

The second disequilibrium component ($\widetilde{G}$) arises because of current information about the future evolution of demand. We express these short-term expectations changes as follows, where the i subscript is suppressed to save on notation:

$$\hat{Y}_{t+1|t} / \hat{Y}_{t|t-1} = \eta Z_t \qquad \text{...(5)}$$

where Z_t is a vector of predictive variables expressed as deviations from trend and η is a vector of coefficients. In this note, Z_t will be proxied by indicators of change in demand and profitability, namely survey-based measures of capacity utilisation and of change in the price-cost mark-up relative to their trend values. Thus,

$$Z_t = [CU_t / CU_t^*; MU_t / MU_t^*] \text{ ,} \qquad \text{...(6)}$$

where the star indicates the trend value, which may be approximated by a weighted lag.

Using equations 3,4 and 2,5,6 and denoting the lag operator by (L), we may approximate the logarithmic expression for G as :

$$G_t = \kappa + \gamma_1(L)\log(CU_t) + \gamma_2(L)\log(MU_t) + \varepsilon_{it} \qquad \text{...(7)}$$

We also allow for an uncertainty effect by positing that an uncertainty variable (σ_t) will slow down adjustment, thus increasing the absolute size of disequilibrium G. Initial estimation allowed us to simplify the lag structure giving a final estimating equation for

[6] As in Blanchard and Fischer we will represent the disequilibrium as the gap between capital and expected demand, though more generally we could think of a target capital stock influenced by a vector of variables.

the panel as:

$$G_{it} = \omega_0 + \omega_1 G_{it-1} + \omega_2 \log(CU_{it}) + \omega_3 \log(MU_{it}) + \omega_4 \sigma_{it} + \theta_i + \nu_t + \varepsilon_{it} \qquad ...(8)$$

where the last three terms are respectively industry, time and industry-time error terms.[7]

Measurement of uncertainty

We measure uncertainty by the dispersion of responses within an industry to the survey question on business optimism in respect of the *industry.* The exact question asked is detailed in Appendix 1. We measure dispersion by the entropy of the three possible responses (up, down, and same) giving a maximum entropy of log(3). This measure has been used in the literature to measure disagreement across survey respondents (Fuchs et al 1998). It has also been established that dispersion across forecasts is correlated with intra-personal ranges of uncertainty (Zarnowitz and Lambros 1987). Other possible measures of uncertainty include volatility indices estimated as a moving standard deviation or as the variance of residuals from an ARMA model. Such measures are only applicable when the data are stationary and they may also imply inconsistent estimators (Pagan and Ullah 1988). The use of conditional volatility or GARCH measures may avoid some of these problems but these measures are sensitive to the exact model (usually univariate) employed for the underlying variable e.g. whether seasonals or dummies for large shocks are included (Carruth et al 2000). Furthermore, ARCH effects are obtained only in a minority of our industries. Dispersion measures can suffer from similar criticisms to volatility measures if the dispersion is measured over separate

[7] Given that the CU term is measured from the survey data as the % below capacity, we express it as a logit rather than a log. Note also that the κ term in (7), which is a function of a number of parameters (see Appendix 1) may, without loss of generality be treated as a cyclical term.

markets which are differently affected by common shocks (Engle 1983). However, in our case the survey question relates to optimism in relation to a common industry.

Estimation

In estimating (8) we are particularly concerned with the parameter ω_4, which captures the effect of the uncertainty variable. Recall that we have data for each industry on the incidence of positive and negative adjustment gaps, termed G(MORE) and G(LESS). Our null hypothesis is that uncertainty should slow adjustment of the capital stock and thus increase both of these gaps.

Focusing first on the "more than adequate" survey response data that we have termed G(MORE), we are capturing here the extent of excess capacity This should increase in the uncertainty term σ. The coefficients of CU and MU in (8) are of less interest though they help to establish the plausibility of the overall results. We expect that perceived excess capacity will fall, the higher the utilisation and the higher the mark-up.

When the estimation is carried out with the gap measured by the incidence of "less than adequate" responses, that we have termed G(LESS), we expect an opposite signed response i.e. that the perceived lack of capacity will rise the higher the utilisation and the higher the mark-up. In this case also, however, we expect the deficient capacity to be *increasing* in uncertainty. Thus the two sets of estimations for excess (deficient) capacity are expected to show a negative (positive) sign for the CU and MU variables but the same (positive) sign on the uncertainty variable for both sets of estimations.

Results

The results of the basic model for both dependent variables are shown in Table 1. A fixed effects specification was adopted as there is a large number of observations for each industry so efficient use of the data is not of prime concern and as the full set of industries is represented in the data. A priori it also seems plausible that the fixed effects are preferable due to omitted variables such as risk attitude which may be correlated with other regressors such as the uncertainty level. A Hausman test confirms that correlation between the regressors and the fixed effects cannot be rejected for the first two columns of Table 1 , though the test cannot be computed for the final four columns as the covariance matrix is not positive definite.

Columns 2 and 5 give the results for the basic specification with the indicators of capacity utilisation and the mark up being highly significant and signed oppositely in the specification for G(MORE) and G(LESS) as predicted above. The coefficients on the uncertainty variable are positive in both these specifications, again in line with predictions.

[TABLE 1 ABOUT HERE]

Columns 3 and 6 repeat the basic specification with an interaction term in uncertainty to account for the possibility that dispersion as a measure of uncertainty may not be invariant to the heterogeneity of the broad industry group. This heterogeneity is measured by the index *hetindex* which is a dummy variable taking values 0 to 2 with a higher number indicating greater herterogeneity as described in appendix 1. The results with the hetindex interaction show that the more heterogeneous industries have less uncertainty effect than the homogeneous industries in both columns but that the effect is still positive even for the maximum hetindex.[8]

The measure of uncertainty is a transformation of the survey responses on optimism and there may be some doubt as to whether it is acting as a proxy for the movement in the optimism index itself. To resolve that question we report in columns 4 and 7 the basic specification with the balance (ups over downs) of the optimism responses replacing the index of mark-up. Comparing these results with the basic specification it is clear that the capacity utilisation, the constant term and the coefficient on the lagged dependent variable remain broadly stable. The uncertainty coefficient is now more significant in the case of G(MORE) but is only significant at 5% in a one-sided test for G(LESS). Nevertheless the overall pattern of results is fairly robust under this change of specification.

It is of interest to compare the magnitude of the uncertainty effect for the G(MORE) and the G(LESS) specifications. It appears that for all three specifications, the effect is larger for G(LESS). This means that a given rise in uncertainty increases the negative disequilibrium (too little capacity) more than the positive disequilibrium (too much

[8] The results here may suggest that in the heterogenous industries, some of the dispersion is reflecting structural change that is positive for investment and is counteracting the negative effect of uncertainty.

capacity). This is consonant with the observation in much of the literature of a negative effect of uncertainty on aggregate investment.

Conclusions

In this paper we have shown how increased uncertainty results in an increase in both tails of the capacity adequacy distribution, conditional on a model of long-run plans and short-run revisions of expectations. We interpret these increases as reflecting the influence of uncertainty in slowing down the adjustment of fixed capital towards equilibrium levels, in line with the predictions of real options theory. Upward adjustment of capacity appears to be slowed more than downward adjustment, suggesting that the overall effect of uncertainty reduces investment growth, in line with the results of previous studies.

References

Abel, A.B. and J.C. Eberly (1999) "The effect of irreversibility and uncertainty on capital accumulation", *Journal of Monetary Economics*, 44, 339-77

Bell,G.K. and Campa, J.M. "Irreversible investment and volatile markets: a study of the Chemical Processing Industry", *Review of Economics and Statistics*, LXXIX, 1, 79-87

Blanchard, O. J. and S. Fischer (1989). *Lectures on Macroeconomics.* Cambridge Massachusetts: The MIT Press.

Bloom, N. (2000) "The real options effect of uncertainty on investment and labour demand", Institute for Fiscal Studies WP 00/15

Carruth, A., A. Dickerson and A. Henley (2000) "What do we know about investment under uncertainty?", *Journal of Economic Surveys*, vol. 14, pp. 119-136.

Chirinko, R.S. and H. Schaller (2002) "The irreversibility premium", paper presented to the 2002 AEA conference, Atlanta, 4-6 January

De Menil G. and S. Bhalla (1975) "Direct measurement of popular price expectations", AER 65, 169-80

Dixit, A. and Pindyck,R. (1994). *Investment under Uncertanty*. Princeton: Princeton University Press

Driver,C. and P. Temple (2003) "Investment, strategy and risk", paper given to the Royal Economic Society annual conference, Warwick, UK

Engle,.R.F. (1983), "Estimates of the variance of U.S. inflation based upon the ARCH model", *Journal of Money, Credit and Banking*, 15, 286-301

Fuchs, V.R., A.B. Krueger and J.M. Poterba (1998) "Economists' views about parameters, values, and policies: survey results in labor and public economics", *Journal of Economic Literature* XXXVI , 1387 -1425

Ghosal, V. and P. Loungani (1996) "Product market competition and the impact of price uncertainty on investment", *Journal of Industrial Economics* 45, 217-29

Ghosal, V. and P. Loungani (2000). "The differential impact of uncertainty on investment in small and large businesses." *Review of Economics and Statistics*, LXXXII, 338-43

Harchaoui, T.M, and P. Lasserre "Testing the option value theory of irreversible investment", *International Economic Review,* 42(1), 141-66

Pagan, A. and A. Ullah (1988), "The econometric analysis of models with risk terms", *Journal of Applied Econometrics*, 3, 87-105

Price, S. (1996). "Aggregate uncertainty, investment and asymmetric adjustment in the UK manufacturing sector." *Applied Economics* vol. 28, pp.1369-79.

Spencer, B. and J. Brander, (1992) "Pre-commitment and flexibility: applications to oligopoly theory", *European Economic Review* 36, 1601-1626

Taylor, J.B. (1982). "The Swedish investment funds system as a stabilisation policy rule", *Brookings Papers on Economic Activity*, 1, 57-105

Zarnowitz, V. and L.A. Lambros (1987), "Consensus and uncertainty in economic prediction", *Journal of Political Economy*, 95, 591-621

TABLE 1 PANEL DATA RESULTS

	Independent Variables					
	G(MORE)	**G(MORE)**	**G(MORE)**	**G(LESS)**	**G(LESS)**	**G(LESS)**
	Coef. (t-value)[a]	***Coef. (t-value)***	***Coef. (t-value)***	***Coef. (t-value)***	***Coef. (t-value)***	***Coef. (t-value)***
Constant	*-0.42(9.6)***	*-0.42(9.6)***	*-0.44(10.4)***	-1.50(13.0)**	-1.51(13.1)**	*-1.42(12.4)***
Lagged dependent variable	*0.22(13.61)***	*0.22(13.6)***	*0.22(14.52)***	0.24(14.2)**	*0.24(14.2)***	*0.24(14.6)***
CU	*-0.22(29.0)***	*-0.22(28.9)***	*-0.21(28.2)***	*0.30(16.5)***	*0.30(16.6)***	*0.28(15.2)***
MU	*-0.04(3.7)***	*-0.04(3.7)***	-	*0.06(2.4)**	*0.06(2.4)**	-
OPT	-	-	*-0.27(9.9)***	-	-	*0.61(8.40)***
Sigma	*0.40(3.21)***	*0.97(3.6)***	*0.47(4.0)***	*0.83(2.6)**	*2.39(3.41)***	*0.56(1.78)*
Sigma*Hetindex	-	*-0.42(2.4)**	-	-	*-1.13(2.50)***	-
No.Obs	**3141**	**3141**	**3280**	**3196**	**3196**	**3333**
No. of Groups	**42**	**42**	**44**	**42**	**42**	**43**
Joint F test PROB	0.000	0.000	0.000	0.000	0.000	0.000
R_squared	0.39	0.36	0.25	0.42	0.17	0.26
Huasman test for fixed/random effects [b]	**$Chi^2(4)$=259.40****	**$Chi^2(5)$=293.35****	**NA**	**NA**	**NA**	**NA**

Notes: [a] ** = significant at 1 % level. *= = significant at 5 % level.

[b] The Hausman specification test checks for the equality of the coefficients estimated by the fixed effects model and random effects model. If the test rejects the hypothesis, it can be inferred that, if the model is specified correctly, the assumption that the random effect v_i are uncorrelated with the regressors is incorrect. As noted in the text, the inverse of the covariance matrix can only be calculated for the first two columns but there are also a priori reasons to prefer the fixed-effects specification.

APPENDIX 1: *CBI and Industry Characteristics Data*

<u>The Industrial Trends Survey</u>

In this paper, we draw upon the Industrial Trends Survey carried out by the main employers' organisation, the Confederation of British Industry (CBI). With approximately1000 replies on average each quarter It has been published on a regular basis since 1958 and has been widely used by economists. Our panel data set is restricted to the period 1978 Q1 to 1999 Q1. The responses in the survey are weighted by net output with the weights being regularly updated. The survey sample is chosen to be representative and is not confined to CBI members

Survey Questions
CBI Industrial Trends Survey Questions

Question 1
Are you more, or less, optimistic than you were four months ago about the general business situation in your industry? [More/same/less]

Ques*tion 4*
Is your present level of output below capacity (i.e., are you working below a satisfactory full rate of operation)? ('Yes', or 'No')

Question 8 11 12
Excluding seasonal variations, what has been the trend over the PAST FOUR MONTHS, with regard to: Volume of output? /Domestic prices/ Average cost ('Up', 'Same' or 'Down')

Question 16(a)
In relation to expected demand over the next twelve months is your present fixed capacity
[More than adequate/adequate/less than adequate]

Appendix 1 continued…

DERIVED VARIABLES	
Variable	**Definition and Source**
G(MORE) and G(LESS)	Logit of response to question 16a, separately estimated for "more" and "less"
CU	Logit of question 4 (No)
MU	Log of Q12(up) - The % raising price –minus log of Q11 (up) – the % raising cost. This is interpreted as an index of change in the mark-up
Sigma(σ)	we measure dispersion across forecasting agents by the entropy measure: $\sigma_t = \sum_{i=1}^{3}[-S_{i,t} \log S_{i,t}]$ where $S_{i,t}$ is the share of each of the three reply categories ('up', 'down' and 'same') in Question 1 on the degree of being 'more' or 'less' optimistic about the general business situation compared with the situation four months at time t. When the answers are equally divided, s_t reaches its maximum of log(3). It may be noted that the question relates to optimism in respect of the industry rather than the firm so that the dispersion recorded should not reflect different objective circumstances but rather different expectations in respect of a common variable.
Hetindex	CBI database dummy variable =0 for industry groups comprising a single 4-digit industry; =1 for a single 3-digit industry; and =2 for more than one 3-digit industries
OPT	Balance of "ups" over "downs" for CBI Question 1. Under restrictive assumptions the balance may be shown to correspond to a growth rate in the underlying variable (De Menil G and S Bhalla 1975)

Appendix 2: The Long Run Disequilibrium Component

Maximising the value of the firm with capital as the only quasi-fixed factor subject to a production function with exogenous demand yields a closed form solution if the implied cost minimand is approximated by a quadratic form. Specifically, the industry is assumed to minimise the discounted sum of a penalty function (C_t) comprising the cost of being out of equilibrium and quadratic adjustment costs which reflect supply conditions when the industry as a whole attempts to invest. Writing K_t for capital, Y_t for net output, I_t for gross investment, a_t for the desired capital-output ratio, we have:

$$C_t = 0.5[aY_t - K_t]^2 + 0.5bI_t^2 \qquad \ldots\text{(A1)}$$

Where the usual depreciation condition applies:

$$K_t = (1-\delta)K_{t-1} + I_t \qquad \ldots\text{(A2)}$$

Using a discount factor, β, it is straightforward (see Blanchard and Fischer 1989, Chapter 5 appendix), to derive a solution for K_t of the form:

$$K_t = \lambda K_{t-1} + \beta\lambda \sum_{i=0}^{\infty} (\beta\lambda)^i FE[Y_{t+i} \mid t] \qquad \ldots\text{(A3)}$$

where λ is a calculable root[9] depending on b, β, δ and $0 < \lambda < 1$ and where F depends on a, b, β, δ .

Where demand follows a random walk, immediate past output may provide the best guide

[9] λ_t is the smallest root of $\lambda^2 - [\frac{1+b}{\beta(1-\delta)b} + (1-\delta)]\lambda + \frac{1}{\beta} = 0$

$$F = -\frac{a}{b}\frac{1}{(1-\delta)\beta}$$

to future summed, discounted demand. If so we may replace the expectation term in (6) by Y_{t-1} and (6) may be written as :

$$K_t / Y_{t-1} \approx \overline{G} = \kappa + \lambda [CU_{t-1}]^{-1} \qquad \ldots\text{(A4)}$$

where $CU_{t-1} = Y_{t-1} / K_{t-1}$ is a measure of the previous period capacity utilisation and κ is a composite parameter of a, b, β, δ .