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UNPACKING THE BLACK BOX: an econometric analysis of investment strategies in real world firms

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1. Introduction

In mainstream microeconomic theory, conventional Cobb-Douglas production functions capture firm activity as taking place within a black box (Cobb and Douglas, 1928); here the focus is on the combinations and relative costs of the capital and labour factor inputs and the consequent output, for example as analysed in input-output analysis. In this approach, the mechanisms of investment decision-making are not central to the theories of investment and production. More recent research has, however, started to focus on some of these underlying mechanisms of decision-making and expectations formation, for example with the development of q theories of investment. In this paper, these ideas are developed to assess whether or not real world business managers behave as postulated by economic theorists. Do businesses adopt forward-looking approaches based around complex mathematical techniques (referred to here as the 'algorithmic approach') or do they prefer to use simple rules of thumb (referred to here as the 'heuristic approach')? Which approach is more effective?

The aim of this paper is to answer these questions by analysing survey evidence from a sample of Cambridgeshire manufacturing firms. In Section 2, some theories of the firm are presented as a benchmark; in Section 3, these are linked into real world business investment appraisal techniques with a discussion of the associated assumptions about rationality. In Section 4, some survey evidence is presented and analysed using basic statistical tests with more rigorous econometric ordered Probit models being presented in Section 5. In Section 6, some of the behavioural models developed from the survey evidence are used to simulate the performance of business predictive approaches. Section 6 presents some conclusions and policy implications.

2. Fixed Asset Investment Theory

Neo-classical theories of the firm take as their starting point the Cobb Douglas production function (CDPF), incorporating constant returns to scale:

$$Y_i = AK_i^{\alpha} L_i^{1-\alpha} u_i \qquad (1)$$

where Y is output, A captures the current state of technology, K is capital input, L is labour input, α is the elasticity of output with respect to capital and u is a multiplicative stochastic disturbance term. The evidence presented later is cross-sectional evidence taken as a snap-shot in time and for this reason A can be assumed here to be constant. Jorgenson (1963) uses the CDPF as the basis for his theory of fixed asset investment decision-making: profit maximising firms will invest to the point where the relative cost of capital (known as the 'user cost' of capital) is equal to the marginal productivity of capital. Jorgenson's analysis incorporates a number of simplifying assumptions– the most relevant in this context being the assumption of static expectations; effectively, in his model firms do not think about the future except to assume that things will not change. His analysis effectively focuses on the determinate parts of the CDPF – the inputs of capital and labour. Jorgensonian investment theorists developing this static approach neglect in their analysis two aspects of investment decisions: first, how uncertainty and expectations about the future affect decision-making strategies; and second, the psychological, non-deterministic factors. These factors are effectively captured within the stochastic disturbance term of (1), u_i.[1]

3. Real world investment appraisal processes

Jorgenson's model can be used as a basis for investment appraisal techniques used by real world businesses. In a world of static expectations and no uncertainty, net present value (NPV) can be deduced from the CDPF. With no uncertainty and no change, the NPV is just the discounted stream of expected future marginal products of capital derivable from the CDPF, net of factor costs. In an uncertain world but one which is characterised by efficient financial markets and rational expectations, the approach can be extended to capture expectations, as in q theories of investment; for example, Brainard and Tobin (1977) (following Keynes 1936; 1937), Hayashi (1982) and Abel (1983). In essence, q theories use the stock market to give a proxy for the net present value (NPV) of an expected stream of dividends and profits. NPV techniques are of course commonly used in real world investment appraisal. Given that NPV is claimed to be an objective basis for investment decisions tying in with the rational maximising approach of Jorgenson's investment theory, why is that businesses get fixed asset investment decisions wrong in practice? One explanation is that misjudgements emerge at one or more of the three key stages of the investment decision-making process: gathering information; predicting future events (e.g. likely sales) and investment project appraisal. At each of these stages businesses may make mistakes: information may be missing or misinterpreted; information may be processed inefficiently to give misleading predictions; if inappropriate appraisal techniques are used, even accurate predictions may be misused.

In analysing these difficulties in investment decision-making, it is useful to make an analytical distinction between the two broad groups of hypotheses about how businesses behave and react: the 'algorithmic approach' and the 'heuristic approach'. The differences between these approaches can be understood in terms of Simon's (1979) distinction between *substantive rationality* and *procedural rationality*.

3.1 Models of rationality

Substantive Rationality and the Algorithmic Approach

Simon defines *substantive rationality* as focusing on the achievement of objective goals given constraints (Simon, 1979, p. 67). If businesses are substantively rational, then they will form quantifiable expectations of the future and will decide about fixed asset investment using constrained optimisation techniques. In other words they will use *algorithms*, i.e. clear mathematical rules using discounted cash-flow (DCF) methods such as NPV and internal rates of return (IRR) incorporating inter-temporal preferences as captured by discount rates.

Algorithmic approaches assume that investors, using the same information set, will form identical expectations centred about some objective probability distribution of outcomes. They will be forward looking in incorporating a rate of time preference (i.e. discount rate) into their investment appraisal techniques. Thus the substantively rational investor will be operating in a manner consistent with Jorgensonsian investment theory. If these methods are used correctly, then the firm will be optimising some objective function, given constraints and investment will take place to the point at which the manager maximises his/her profits, i.e. by undertaking all investments with an NPV greater than or equal to 0. The discount rate used to derive the NPV calculations will be equal to the real cost of borrowing.

This behavioural hypothesis can be linked to conventional ‘q’ or valuation ratio algorithms in which market capitalisations of firms are balanced against the current replacement cost of a firm’s capital stock. Assuming an efficient markets hypothesis, a substantively rational investor would assume that stock market valuations are an unbiased measure of the discounted stream of expected future profits from the productive capacity of a firm.

Algorithmic approaches are outlined in detail in conventional analyses of fixed asset investment activity, e.g.: Jorgenson (1963) on neo-classical theory; Abel (1983) amongst others on q theory; and Dixit & Pindyck (1994), Pindyck (1991) amongst others, on real options theories. Despite some differences in analysis, these approaches can be understood as refinements of Jorgenson’s basic model with each refinement incorporating more thorough and complex approaches to the analysis of expectations and uncertainty into a basic model of substantively rational profit maximizing firms.

Procedural Rationality, Heuristics and Rules of Thumb

Simon (1979, p. 68) responds to the mathematical approaches subsumed within the substantively rational approaches of rational behaviour by arguing that economic decisions are often the product of a ‘procedurally rational’ process. Procedurally rational behaviour is based on a broad reasoning process rather than the achievement of given representative agent’s goals (Simon, 1979, p. 68). The behaviour of the procedurally rational investor is guided by ‘appropriate deliberation’ and does not involve the optimisation of some objective function in the face of constraints. Developing this idea to the investment context, procedurally rational investors will use common sense rather than complex mathematical techniques in assessing investment plans. This implies that different investors, faced with the same information may form different expectations reflecting arbitrarily assigned margins of error. It is not necessarily the case that these errors cancel out because *mimetic heuristics* (devices such as herding and following the crowd which were first hypothesised by Keynes, 1930, 1936, 1937 and later developed by Scharfstein and Stein, 1990, amongst others) will form part of investment appraisal tool-kits. Whilst these heuristic devices are procedurally rational, they may, nonetheless, foster systematic mistakes and encourage path dependency.

Simon’s concepts can be applied in analysing a procedurally rational investor operating in a world of bounded rationality in which the sensible application of clear and objective mathematical rules will be impossible because the existence of immeasurable uncertainty precludes the quantification of probabilities of future events. Businesses will be forced to rely on appropriate deliberation by doing the best that they can, given the circumstances. They will use simple *heuristics* (or common-sense rule of thumb based on experience) in deciding whether or not to invest in particular projects. For example, a procedurally rational firm will use payback period (PBP) or accounting rate of return (ARR) appraisal techniques which are based around simple assumptions about likely future events and do not require DCF method – as explained in the following sections.

3.2 Expectations Formation

In either the substantive or the procedural approach, some assumption or hypothesis must be formed to explain why and how businesses predict the future. Understanding the differences in hypotheses about expectation formation is essential to understanding the differences between the substantive and procedural approaches. A key constraint on investment decision-making is the existence of uncertainty about the future; investment decision-making is fallible when it is difficult to form clear, reliable predictions of future events. Prediction is particularly complex when it comes to economic processes because the economic world is changeable. Peoples' beliefs about economic structure have the capacity to change that economic structure, as emphasised in the literature on dynamic inconsistency (e.g. Kydland and Prescott, 1977) and the literature on non-ergodicity (e.g. Davidson, 1991). This suggests that Classical statistical or 'frequentist' approaches to the analysis of probability which assume repeatable events, complete information and/or an understanding of the data generating mechanism, will be of little use in understanding the predictions of fixed asset investors for three reasons. First, information is incomplete and the data-generating processes dictating economic outcomes are often unknown; an investment decision is not like dealing a card from a pack of 52 cards or buying a lottery ticket when you know that one million tickets are being sold. Secondly, investment decisions are often about non-repeatable and unprecedented events and this means that information about past outcomes (e.g. as might be captured by frequency data) will be of little use. Thirdly, endogeneity means that economic realities are complex and mutable; expectations affect economic events that determine expectations (e.g. stock prices go up because people believe they will go up because stock prices are going up). Future outcomes will be affected by current decisions based on expectations of the future formed today; inter-temporal feedbacks between past, present and future will determine reality. Given these three sources of complexity, the objective basis for probability judgements may be missing or unknowable and the third source of complexity will undermine, in the investment context, even the more subjectively based Bayesian probability concepts.

In algorithmic theories of substantively rational investors, this quantifying the future is achieved by linking the objective with the subjective. Agents are assumed to be forward looking but aware that the value of money changes over time. They are assumed to process information in an objective, mathematical way, as described in Section 2. A link is created between subjective probability judgements and objective factors in a number of ways most easily understood in terms of the rational expectations hypothesis (REH).

Dwyer, Williams, Battalio and Mason (1993) offer three differing interpretations of rational expectations:

a) Economic agents collect and use information efficiently.
b) Agents will behave as if the objective and subjective parameters that characterise the environment are the same. In other words, expectations are rational if the divergences between the expectations and realisations of a given variable are a white noise process.
c) Expectations, that is the subjective probability distribution of outcomes, tend to be distributed around the objective probability distribution of outcomes given the same information set, i.e.:

$$_{t-1}X^e_t = E(X_t/\Omega_{t-1}) \qquad (2)$$

where $_{t-1}X^e_t$ is the expectation of variable X_t formed in period t-1 given the information available in period t-1(Ω_{t-1}).

Gerrard (1994) discriminates between ‘strong’ versions of the REH, which assume complete information and well-defined probability distributions, and ‘weak’ versions that allow rational expectations formation in the presence of incomplete information and ill-defined probability distributions. Gerrard’s weak version of REH is consistent with version a) of the hypotheses outlined above.

According to Muth (1961) the information set used by rational agents includes the relevant economic theory and therefore modelling strategies that use economic theory to predict outcomes are consistent with REH. Pesaran (1990) also focuses on looking to other economic variables and argues that accurate expectations formation should incorporate information about variables other than the past history of the variable being predicted (Pesaran, 1990, p. 7). Both these views are compatible with version c) above.

Overall, it is recognised that businesses form probability judgements of future events subjectively but it is assumed that these subjective judgments coincide, on average, with some objective probability distribution ensuring that mistakes are not systematic. If this is the case, then some of the problems of prediction in a complex world are reduced. In Tobin’s q theories, subjective (but rational) expectations are formed using stock market data. Assuming efficient financial markets as well as rational expectations, share prices will respond instantaneously to news and so will reflect all currently available information about the future potential of investments; share prices will be an unbiased measure of rational investors’ expectations of the discounted streams of future profits from current investment activity. This sort of approach may work in a world that is immutable: for in such a world, rational agents able to access the same information sets are likely, on average at least, to reach the same conclusions because they will process information efficiently and learn from their mistakes, making full use of all currently available information.

But do substantively rational firms, adopting the rational expectations approach hypothesised by q theorists, really form superior judgements of future events in comparison with the judgements made by procedurally rational investors? Limits on rationality are likely to be profound if the world is mutable and economic reality reflects endogenous processes. In this case, a consistent, immutable and objective reality may be missing; reality will be changing as expectations change. In such a world, subjective probabilities do not necessarily coincide with objective probability distributions, even on average so investors will be forced to adopt a procedurally rational approach. Without an objective path to follow, procedurally rational investors will use simple heuristics, e.g. they will look to others in deciding what to do, learning from the behaviour of others. In a world of incomplete information it will be procedurally rational to follow the crowd, as explained in Topol (1991), and/or to learn from past output signals about what other investors are doing (Acemoglu, 1993). This sort of approach will lead to rationally justifiable herding, mimetic contagion and path dependency suggesting that any errors in expectations will not be random but instead may follow systematic trends.

If firms are procedurally rational and the logical link between the objective and the subjective is broken, then a range of subjective probability judgements may be defensible. But if these turn out to be wrong, is it because businesses are misguided or is it because the economic reality changed unexpectedly? A large literature has developed analysing the first possibility: that cognitive limits on human information processing mean that individuals' subjective probability estimates are fallible (e.g. see Tversky and Kahneman 1982, Baddeley, Curtis and Wood 2004). If the second possibility holds true, will any predictive tool be unequivocally superior to all others? If complexity and endogeneity operate within limits, then the solution may lie with predictive tools that incorporate fuzzy logic methods, in which the binary concepts of 'true' and 'false' are replaced by *degrees* of truth.

3.3 A Comparative Analysis of Approaches

There is an extensive literature on these competing approaches to investment appraisal techniques exploring the relative merits of simple heuristics, e.g. payback period (PBP) and accounting rate of return (ARR) versus more complex algorithms such as net present value (NPV) and internal rate of return (IRR) (Gordon, 1955; Harcourt, 1968; Sarnat and Levy, 1969; Ramsey, 1970; Dudley, 1972; Wright, 1978; Gronchi, 1986). The use of algorithmic techniques can be problematic. NPV calculations require judgements about discount rates, but making these judgements about the value of expenditure today over income tomorrow are likely to be difficult in a world constrained by endemic and immeasurable uncertainty about the future. There are similar complexities associated with the use of the IRR technique limiting its effectiveness as a practical investment appraisal tool.

Given these problems with algorithmic techniques, identifying simple and reliable proxies for IRRs and/or NPV is important. A procedurally rational investor may decide not to incur the costs involved in identifying a discount rate either because they are ignorant that the value of money changes over time or because they judge that current information is fallible and that the future is too uncertain for calculations based around discounting procedures to be of much use.

In terms of the survey evidence about the use of investment appraisal techniques based around algorithms versus heuristics, it is clear that real world businesses have a preference for the latter and, as Harcourt (1968) notes, there is a pressure to educate businesses in using algorithmic techniques. Does this preference really make a difference? How are heuristic and algorithmic investment appraisal techniques related?

Following the analyses by Gordon (1955), Kay (1976) and Sarnat and Levy (1969) of the connections between IRRs and heuristics such as PBP and ARR, a link can be established. If C is the cost of an investment project and $\overline{q}$ is the annual revenue from the project (assumed to be constant each year given expectations of future revenue based on current conditions). The internal rate of return is the discount rate (ρ) at which the cost of an investment project equals the discounted stream of expected future revenues from the project. This is the profit maximising point at which NPV will be equal to 0.

Assuming a one-year delivery / installation lag before revenues accrue, NPV will be equal to zero when:

$$C = \Sigma \frac{\overline{q}}{(1+\rho)^t} \qquad (3)$$

Multiplying through by $\frac{1}{(1+\rho)}$ gives:

$$\frac{C}{(1+\rho)} = \Sigma \frac{\bar{q}}{(1+\rho)^{t-1}} \tag{4}$$

Subtracting (2) from (1) gives:

$$C - \frac{C}{(1+\rho)} = \Sigma \frac{\bar{q}}{(1+\rho)^{t}} - \Sigma \frac{\bar{q}}{(1+\rho)^{t-1}} = \frac{\bar{q}}{(1+\rho)} \tag{5}$$

$$\therefore \qquad \rho = \frac{\bar{q}}{C} \tag{6}$$

The PBP and ARR are defined as:

$$PBP = \frac{C}{\bar{q}} = \frac{1}{ARR} \tag{7}$$

$$\therefore \qquad \rho = \frac{1}{PBP} \tag{8}$$

Therefore, given some simplifying assumptions, the IRR is equal to the ARR and it follows that it is also the inverse of the PBP. This suggests that the PBP and ARR techniques will give similar answers to the NPV and IRR techniques, implying that judgements about complex and uncertain things (e.g. an appropriate discount rate) may be unnecessary.

This insight can be developed in the context of real options theories (e.g. Dixit and Pindyck, 1994; Pindyck, 1991) which focus on the need to raise hurdle rates of return to take account of uncertainty. Short target payoff periods will be equivalent to high hurdle rates of return.

Overall, the implication from this analysis is that using simple heuristics (if the assumption that current conditions will continue is defensible) may in some cases approximate the results that would emerge if a business had a more sophisticated algorithmic approach to investment appraisal.

4. Some Survey Evidence[2]

In assessing some of the questions posed above, survey evidence is illuminating. Past survey evidence reveals that the pay-back period technique is the technique most commonly used, though many firms use a range of techniques, including DCF and NPV methods (Arnold and Hatzopoulos, 1999, 2000; Drury *et al*. 1992; Neild, 1964). This evidence does not, however, address in detail how and why firms use techniques; it does not reveal much about the rationality and psychology of businesses decision-making process. The aim of the survey analysed in this paper is to get a deeper understanding of the motivations and approaches adopted by a sample of Cambridgeshire businesses.

The survey was designed to test two aspects of decision-making with implications for the rationality and objectivity of investment plans. First, in discovering the types of appraisal techniques used and second, in establishing the methods for formulating expectations and making predictions.

In assessing these factors, the following categories of information were examined: objectives; constraints; length of planning horizon; investment appraisal techniques; expectations formation and post-project auditing.[3] A stratified sample of 450 manufacturing firms was taken from a sampling population of Cambridgeshire manufacturing businesses. 102 of these firms responded to the survey, and 99 responses were usable, giving an effective response rate of 22%.

Firms' Objectives and Constraints

Firms were asked to rank their objectives and Table 1 summarises the proportion of firms adopting each objective. These data reveal that most firms aim to maximise either sales or profits. In terms of other goals, large firms were also concerned about industry leadership, medium-sized firms emphasised growth in productive capacity and capacity utilisation and small firms emphasised the personal satisfaction of running a business.[4]

TABLE 1: Objectives
Proportions and z scores[a]

% of firms adopting objective	**Size of business:**			
	Large	**Medium**	**Small**	**All**
Maximise profits/sales	71%	72% z=-0.12	80% z=-0.78	73%
Target profits/sales	51%	52% z=-0.11	35% z=1.23	48%
Target capacity utilisation	29%	48% z=-2.18[b]	20% z=0.78	33%
Increasing capacity growth	31%	21% z=1.25	40% z=-0.74	30%
Increasing Stock Market valuation	16%	10% z=0.98	5% z=1.26	12%
Establishing industry leadership	65%	38% z=2.99[b]	15% z=3.85[b]	47%
Personal Satisfaction	0%	31% z=-5.25[b]	60% z=-6.62[b]	21%

[a]z scores calculated by comparison with the large firm proportion
[b]significant at 5%, i.e. 95% confidence interval

Businesses were also asked to outline the major constraints that they faced. Financial constraints, including existing financial commitments and the cost /availability of finance were the most important constraints. Fluctuating demand is another constraint rated highly by many firms and suggests that most firms are strongly affected by cyclical factors and volatility. Most firms perceive volatile demand as a far more important constraint than lack of demand. This may reflect the fact that it is easier to plan effectively for stable, low levels of demand. General uncertainty and difficulties predicting the future were also ranked by a substantial proportion of firms as the key constraints on their investment plans.

Similarly to the objectives, ranking of constraints varies with business size. Medium-sized firms score highly the constraint of political and economic uncertainty, with smaller firms more limited than the medium-sized and large firms by cost/availability of finance. Small firms are more likely to have to raise finance independently. Medium-sized firms seem to be less constrained than large firms by the cost / availability of finance (this could reflect the fact that these firms are subsidiaries of larger groups and so are not independently responsible for raising finance). Small firms are also heavily constrained by their inability to forecast future performance, possibly reflecting limits on their resources.

Planning

Respondents were asked if they have a business plan and, if so, how far ahead they plan. Eighty per cent of firms sample reported that they use plans - 90% of large firms, 86% of medium-sized firms and 45% of small firms. The average length of plan overall is 3 years. Large firms' average plan length is 3 years but small and medium-sized firms' average plan length is 2 years. These results suggest that larger firms are more forward looking. Nearly as many medium-sized firms as large firms plan ahead but they have a shorter time horizon. The minority of small firms plan.

Investment Appraisal Techniques

Firms were asked about the precise mathematical techniques they used in their investment appraisal, in an attempt to establish the extent of their reliance on substantively rational investment appraisal techniques. The results are summarised in Table 2. By far the most common method of investment appraisal is the simple PBP, which is used by 81% of firms, compared with 34% using NPV. Investors in this survey are more likely to rely on heuristics such as ARR and PBP, rather than on NPV and other DCF methods. The former techniques do not capture the time value of money via discounting and therefore would not be consistent with an algorithmic approach. However, the firms sampled here do seem to be more reliant on DCF methods than firms in earlier surveys: Neild (1964) found that only 3% of engineering firms used DCF algorithms (Neild, 1964, pp. 30-44). The majority (88%) relied on heuristics such as pay-off periods (67%) or flat rates of return (21%).

Face-to-face interviews revealed more detailed information about the attitudes of local business leaders towards investment appraisal techniques. Many Managing Directors emphasised that uncertainty about the future means that the forward-looking algorithmic approaches associated with DCF methods cannot reliably be used. Instead business experience and instincts play roles in forming expectations and in making the final decision about whether or not to invest in a given project.

Mathematical calculations are only valid if entrepreneurs have clear information about the future, in which case they are the ideal guide to investment. But because, in the real world, the future is not perfectly knowable, mathematical calculations, although an excellent tool in guiding decisions, are flawed and must be supplemented with business experience and gut feel. One managing director (from a large and well established company) commented that:

> It is difficult to assess the right approach - you would like to rely on mathematical calculation but don't believe that you can - although as a tool it's a great asset. But there will always be a gut feel, business experience element as gut feel will tell you to base future expectations on historic information. The future is multifaceted, with many possible interactions and there can be no model to predict. Can you come up with a model more predictable than people just pooling their gut feel reactions?

TABLE 2: Investment appraisal techniques used

Proportions and z scores[a]

% of firms	**Size of business:** Large	Medium	Small	All
DCF methods, including net present value (NPV)	43%	24% z=2.20[b]	25% z=1.42	34%
Pay-off period (PBP)	90%	72% z=2.66[b]	70% z=2.19[b]	81%
Accounting rate of return (ARR)	51%	55% z=-0.44	40% z=0.85	50%

[a]z scores calculated by comparison with the large firm proportion.
[b]significant at 5%, i.e. 95% confidence interval.

The survey evidence revealed information not only about whether firms were using certain techniques but also about whether they were using them properly. Respondents who used DCF techniques were asked how they selected a discount rate. If an incorrect discount rate is used, the link provided by the cost of capital between financing and real asset investment activity will be broken and firms will not be acting in a substantively rational way. Forty-five per cent of the large firms using DCF methods did not realise the importance of a suitable discount rate, e.g. claiming that the question was 'not applicable'. Fifty-five per cent of large firms and 100% of small and medium-sized firms using DCF methods used the post-tax cost of capital or borrowing costs as a discount rate. So some firms using DCF methods do not appear to be allowing, via higher discount rates, for the effects of uncertainty on sunk investments as described by the real options approaches.

Qualifications

Firms were also asked about the qualifications held by their investment decision-makers: 79% of respondent firms (92% of large firms, 79% of medium-sized firms and 45% of small firms) had employees with some form of business training. 'Other of business training' (outside of MBAs, accountancy training and other business degrees) is the most common form of qualification, followed by accountancy training, business/commerce/economics degrees and finally MBAs. This pattern is maintained across all sizes of firms. The fact that a greater proportion of large companies have more qualified staff may explain why they tend to focus more on the algorithmic approaches consistent with a substantively rationality.

Expectations Formation

The other aspect of business planning, particularly important in the use of investment appraisal techniques, is the way in which firms predict future output and revenues. Pesaran (1990) notes the wide consensus that accurate expectations formation should incorporate information about variables other than the past history of the variable being predicted (Pesaran, 1990, p. 7).

The methods used by the firms surveyed in this sample are outlined in Table 3. The most common method used is to rely on available information, business skills and common sense (94%), followed by gut feel (39%). A more-or-less equal proportion of firms use modelling, published forecasts, adaptive and/or extrapolative expectations with the smallest proportion of firms overall relying on the assumption that existing conditions would continue unchanged.

In terms of firm size, large firms are more likely than medium-sized and small firms to use modelling, published forecasts, adaptive expectations and/or static expectations. The proportion of firms using gut feel to form expectations increases with decreasing firm size whereas the proportion of firms using business experience increases with increasing firm size. It seems that, for smaller firms, gut-feel substitutes for mathematical algorithms. The overwhelming reliance on business skills and common sense is consistent with a procedural rationality hypothesis.

TABLE 3: Methods used to make predictions

Proportions and z scores[a]

% of firms	Size of business:			
	Large	**Medium**	**Small**	**All**
Adaptive expectations	34%	29% z=0.59	25% z=0.75	31%
Regressive expectations	34%	43% z=-1.03	25% z=0.75	35%
No change	24%	21% z=0.40	13% z=1.04	22%
General business skills	97%	93% z=1.08	88% z=1.60	94%
Gut feel	28%	50% z=-2.52[b]	63% z=-2.80[b]	39%
Modelling	45%	21% z=2.77[b]	13% z=2.55[b]	33%
Published forecasts	45%	21% z=2.77[b]	25% z=1.57	35%

[a]z scores calculated by comparison with the large firm proportion.
[b] significant at 5%, i.e. 95% confidence interval.

In a follow-up survey, more information was requested from the respondent firms to clarify their expectations formation procedures. Fifty-seven firms responded to the follow-up questionnaire. The results from this indicated that, in predicting future cash-flow, 61.4% of firms use desired cash-flow, 29.8% rely on current or past realisations of cash-flow; 10.5% extrapolate past trends and 8.8% use regression or sensitivity analysis. The follow-up indicates that, for many firms, current and past values are extrapolated into the future. The finding that the majority of respondents base their expectations upon their *desired* outcomes may indicate that expectations have limited objective basis and that some firms might adopt overly optimistic business strategies.

The proportion of firms using an algorithmic approach to prediction, i.e. by using statistical / econometric modelling strategies, is 33% of all firms. Econometric modelling is particularly prevalent amongst the larger firms: 45% of large firms form their predictions via modelling and/or use published forecasts but smaller firms tend to adopt simpler approaches (such as adaptive, regressive or extrapolative expectations).

Finally, attitudes to risk were assessed by asking firms if they used risk appraisal techniques: 70% of firms carried out risk assessments (74% of large firms, 68% of medium-sized firms and 63% of small firms). The form of these risk assessments was not very clear with patchy given about how firms' risk assessment methods. Some respondents did say that they conducted sensitivity analyses. Firms were asked about their attitudes to risk in the follow-up survey; this revealed that only 3.5% of respondents claim to be risk-seeking; 70.1% claim to be risk-averse and 33.3% claim to be risk neutral. Risk aversion appears to decline with increasing firm size: 56.8% of large firms are risk averse and 37.8% are risk neutral.

Survey Evidence on Post-project auditing and past performance

In assessing the relative optimism or pessimism of investment activity, businesses were asked whether past investments had matched expectations or not. The results are summarised in Table 4.

Under-performance seems to be a function of firm size, with 8% of large firms, 14% of medium-sized firms and 32% of small firms experiencing under-performance and 10% of large firms and 14% of medium-sized firms and no small firms experiencing over-performance of investments. The relative performance also increases with decreasing firm size and the distribution of responses also differs according to firm size.

Large firms' investment performance is most closely concentrated around no mistakes, with a slight skew towards under-estimating performance. Medium-sized firms' responses are exactly symmetrical around no mistakes but with a greater variance of response. Although on average mistakes are exactly equal to zero, they are more likely to make mistakes than the large firms. The small firms' distribution reflects a yet greater variance of responses compared with medium-sized firms, and the distribution is fat, flat and heavily skewed towards under-performance. Thus whilst large and medium-sized firms distribution of outcomes relative to expectations does seem to be consistent with strict rationality (although perhaps there is a slight tendency amongst larger firms towards pessimism), the distribution for small firms does not. This could reflect either a strong tendency towards over-optimism or a consistent failure to correct mistakes in implementation of investment plans.

TABLE 4: Performance of past investments relative to expectations
Proportions and z scores[a]

% of firms	Size of business: Large	Medium	Small	All
Under-performed	8%	14% z=-1.11	32% z=-2.71[b]	14%
Performed as expected	82%	72% z=1.34	68% z=1.32	77%
Over-performed	10%	14% z=-0.70	0% z=1.48	9%

[a] z scores calculated by comparison with the large firm proportion.
[b] significant at 5%, i.e. 95% confidence interval.

One explanation for the fact that small firms are more likely to make mistakes in forming their expectations of performance could be that smaller firms tend to be younger and therefore may not have learnt either how to form accurate expectations and/or how effectively to implement investment plans. If this is the case, then the tendency towards under-performance can only be explained in terms of the age of a firm if mistakes are due to inefficiency in implementing investment plans.

These results indicate that overall large firms are more effective at accurately predicting the future rewards of business investment plans. However, the reasons behind the results are hard to separate - particularly as the reasons for fulfilment or over-fulfilment of expectations could either be that the initial expectations were more accurate, that expectations were just more pessimistic or that investment projects were implemented more effectively in the larger firms. The fact that lack of demand, an exogenous factor, is a reason for non-fulfilment amongst the small and medium-sized firms indicates that thwarted expectations are the result of uncertainty rather than a firm's effectiveness in implementing its investment plans.

Another explanation may be that large firms are less likely to suffer disappointed expectations because they are able to incorporate safety nets or margins of error into their expectations of future performance. Such firms will avoid the adverse consequences of negative errors, realising that they cannot always anticipate effects of adverse shocks on demand for their products. This is consistent with the finding that large firms are also more likely to operate below full capacity; they allow some spare capacity to take advantage of positive shocks in demand for their products. Large firms seem to allow for mistakes in their expectations in either direction: they build the possibility of over-estimating demands into their expectations and they allow for under-estimation of future increases in demand by building some spare capacity into their capital stock. Thus their reactions to different types of possible mistakes are asymmetric depending on the direction of the mistake. If margins for error are built into expectations, businesses are more likely to find that their investments perform as well as (or better than) expected.

The fact that the small firms in this sample were less likely to have their expectations met and were more likely to experience performance below expectations, may mean that they are not building the same safety nets into their expectations because they do not have the resources to do so.

Analysis of Statistical Significance in Survey Responses

The analysis of the survey findings in the preceding section has indicated some broad trends and differences according to firm size. But are these differences in the behaviour of different types of firms significant? The z scores in Tables I-IV show the extent to which differences in investment decision-making emerge according to firm size (in terms of number of employees). The z scores are testing the null (with a 5% significance level, 95% confidence interval) that the proportion for the medium or small firms is the same as the proportion for the large firms.

From Table 1, it can be seen that in terms of basic objectives, the maximisation of profits and sales is important to all firms. Interestingly, medium size firms are significantly more interested in targeting capacity utilisation than large firms. This may reflect the fact that the large firms have more market power and therefore are under less pressure to maintain capacity utilisation. On the other hand, small firms may be operating with limited capital stock anyway and so capacity utilisation is less of a concern. Unsurprisingly, the large firms are significantly more interested in establishing industry leadership than either the small or medium sized firms. The small and medium sized firms are significantly more interested in the personal satisfaction of running a business. This may reflect the fact that the investment decision makers in the larger firms are more likely to be middle managers with less long-term influence (past and future) over the long-term strategy of the firm.

In terms of the primary motivation of this paper in assessing the behavioural approach of investment managers, it might be expected that the large firms are more likely to have the resources and expertise to devote to rigorous investment appraisal projects so will be more likely to use algorithmic approaches. From Table 2, it is clear that the larger firms are significantly more likely to use algorithmic approaches, that is DCF and NPV techniques. But the results here also show that they are significantly more likely to use heuristic techniques too, in this case the use of PBP appraisal methods is significantly more likely for the larger firms.

In forming expectations, the z scores recorded in Table 3 show that the large firms are significantly less likely than both the medium and small firms to use the more subjective approaches of operating according to gut feel and are significantly more likely to use objective techniques such as modelling. They are also significantly more likely than the medium sized firms to use published forecasts.

In terms of anticipated performance, the z scores in Table 4 show that the small firms are significantly more likely than the large firms to have under-performed. There are no significant differences between the relative performance of the large versus medium firms, whether in terms of under-performing, over-performing or performing as expected.

Overall, the z scores show that the large firms in this sample behave significantly differently from small and medium sized firms in key ways, including firm objectives, investment appraisal techniques, expectations formation and investment performance.

5. Econometric analysis

In Section 2, some of the objective factors underlying investment decisions were analysed in the context of production theory. Production theory focuses on an analysis of the inputs of capital and labour; and, with an appropriate model of expectations, this approach tells us about the objective factors underlying the decision-making process. In Sections 3 and 4, some concepts and findings were presented about the more subjective aspects of investment decision (for example, how investment appraisal techniques are used in practice) and the factors associated with expectations formation and prediction. In this section, all these ideas are brought together econometrically by comparing the empirical performance of four sets of models when applied to the survey data described above.

The dependent variable in each case is turnover.[5] The turnover response was sorted into 5 categories. For this reason linear estimation techniques would be inappropriate for the analysis of the survey results and so the cross-sectional models are estimated using maximum likelihood estimation based around ordered Probit estimation techniques. The four models estimated are: a ‘black box’ model, focussing just on inputs and outputs; a techniques model; a techniques + planning model and an encompassing model. The details of all these models are described below.

Model 1 – The Black Box Model

For the basic model, the analysis of the relationship between output (as captured by turnover) and capital and labour, is a simplification of the Cobb Douglas Production function described in Section 2, which given the ordinal context has been simplified to:

$$T_i = f(K_i, L_i) \tag{9}$$

where T is turnover, K is capital stock and L is labour force. This is a black box model in that it focuses just on the inputs and the outputs, without addressing the processes of decision-making. The results from the estimation of this model are recorded in column 1 of Table 5 and show, unsurprisingly that K and L are significantly associated with T, a result broadly consistent with production theory. Firms with larger capital capacity and larger workforces have greater turnover.

Model 2 –Techniques Model

Model 2 focuses on the techniques used in investment appraisal in getting a broad picture of whether or not a techniques driven approach is associated with more firm success in terms of turnover.

$$T_i = f(NPV_i, ARR_i, PBP_i) \tag{10}$$

The techniques are captured using dummy variables taking the value 1 if the technique is used by a specific firm i and the value zero if not. That is, NPV=1 if the business uses net present value techniques, ARR=1 if it uses accounting rates of return and PBP=1 if payback appraisal methods are used.

The results from the techniques model are recorded in column 2 of Table 5 and show that the use of NPV and PBP techniques is associated with significantly higher turnover, at a 5% significance level. However, this may be picking a spurious impact if the larger firms (which inevitably have higher turnover) are more likely to use relatively rigorous investment appraisal techniques and/or are more likely to have more highly qualified managers who are familiar with these techniques. The results controlling for manager qualifications are addressed in Model 3 and the impact of firm size is captured in Model 4 (see below).

Model 3 – Techniques, Planning and Qualifications Model

For Model 3, the impact of forward-looking, substantively rational decision-making is is introduced by estimating a model that controls for the impact of planning horizon and managerial qualifications, as follows:

$$T_i = f(NPV_i, ARR_i, PBP_i, PLAN_i, QUALS_i) \qquad (11)$$

where PLAN is the length (in years) of each firm's business plan and QUALS is an ordinal variable capturing the level of business education amongst managers (0=no business qualifications; 4=MBA qualifications held). The results from the estimation of this model are recorded in column 3 of Table 5 and show that, once planning and business qualifications have been controlled for, the impact of the different types of investment appraisal techniques has an insignificant impact on turnover performance; whether or not a firm used relatively sophisticated DCF/NPV techniques has no significant association with turnover. This finding lends support to the arguments about equivalence of techniques presented in Section 3.3.

Model 4 – An Encompassing model

For the preceding models, assessing the individual contribution of different variables is complicated by the errors and inaccuracies that may be introduced via omitted variable bias. For this reason, an encompassing model was estimated, including all explanatory variables as follows:

$$T_i = f(K_i, L_i, NPV_i, ARR_i, PBP_i, PLAN_i, QUALS_I) \qquad (12)$$

The results from the estimation of this model are recorded in column 4 of Table 5. It should be noted that multicollinearity between the various explanatory variables is likely to be relatively high in this sample because firms with larger capital stocks and labour forces are more likely to have more highly qualified business managers and are therefore more likely to use relatively sophisticated investment appraisal techniques. This means that the power of z scores in separating the individual influences of the different factors is reduced. For this reason, each set of variables was also tested for joint significance using a likelihood ratio test and the results are recorded Table 6. Overall, the results show that the black box model of inputs has independent explanatory power and that the planning, qualifications elements of the techniques based models have independent explanatory power. Apart from that, the types of techniques used do not have a significant association with turnover category, perhaps confirming the insights noted above, namely that different investment appraisal techniques will approximate each other in practise. However, the extent to which businesses plan for the future does have a significant positive association with turnover, suggesting that being forward-looking at least may have benefits in terms of performance.

TABLE 5 – ORDERED PROBIT ESTIMATIONS
Dependent variable: Turnover (ranked into 5 categories)
Sample: 99 Cambridgeshire firms

		1 MODEL 1: BLACK BOX	2 MODEL 2: APPRAISAL TECHNIQUES	3 MODEL 3: TECHNIQUES & PLANS	4 MODEL 4: ENCOMPASSING
K	Parameter estimate	0.657[b]	…	…	0.687[b]
	z statistic	3.778	…	…	3.638
	p value	0.000	…	…	0.000
L	Parameter estimate	1.665[b]	…	…	1.382[b]
	z statistic	4.793	…	…	3.791
	p value	0.000	…	…	0.000
NPV	Parameter estimate	…	0.706[b]	0.155	0.109
	z statistic	…	2.906	0.575	0.340
	p value	…	0.004	0.565	0.734
ARR	Parameter estimate	…	0.044	0.065	0.213
	z statistic	…	0.195	0.277	0.763
	p value	…	0.845	0.782	0.446
PBP	Parameter estimate	…	0.520[b]	0.162	-0.082
	z statistic	…	1.871	0.543	-0.237
	p value	…	0.061	0.587	0.813
PLAN	Parameter estimate	…	…	0.275[b]	0.233[b]
	z statistic	…	…	3.384	1.890
	p value	…	…	0.001	0.059
QUALS	Parameter estimate	…	…	0.344[b]	0.094
	z statistic	…	…	3.578	0.938
	p value	…	…	0.000	0.349
Akaike information criterion		1.716	2.775	2.463	2.039
Schwarz Bayes criterion		1.878	2.957	2.697	1.741
LR index (Pseudo-R^2)		0.420	0.048	0.176	0.450
LR statistic		108.174[b] (p=.000)	13.427[b] (p=.004)	48.663[b] (p=.000)	115.798 [b] (p=.000)

[b]significant at 5%, i.e. 95% confidence interval

TABLE 6 – LIKELIHOOD RATIO MODEL COMPARISON TESTS

Tests of Encompassing Model (Model 4) against:	
Black box model (Model 1) df = 2	134.27[b]
Techniques model (Model 2) df = 3	1.536
Techniques, planning and qualifications model (Model 3) df = 5	15.248[b]

[b]significant at 5%, i.e. 95% confidence interval

6. Empirical Matching of Simulated Results with Actual Outcomes: Simulation Results

In analysing the survey results, it should be emphasised that the respondents were being asked to make subjective judgements of the performance of their investment projects. In this section, to assess the objective performance of their expectations formation, the average firm responses are used to simulate investment and output performance over the planning period. This simulated performance is matched with actual performance of manufacturing businesses in Cambridgeshire County, as outlined in ONS Regional Accounts data. The survey evidence was used to assemble a profile of the typical behaviour of a surveyed firm. This profile was used to simulate investment and output activity over the 1995-9 period. This timing was based on a lag of 3 years from the conclusion of the survey because the survey revealed that the average planning horizon for the sample group was 3 years (as mentioned above). These simulations were matched with performance in the sampling population of Cambridgeshire manufacturing firms.

As explained above, the survey evidence indicates that the majority of firms sampled in the survey use PBP techniques for investment appraisal, adopt a planning horizon of three years and use regressive and extrapolative expectations in forming their predictions of future output. Putting this information together, if the typical firm in Cambridgeshire operates in a similar way to the firms described in this sample, then:

1. Expectations of output will be a weighted average of current and past output, over a three-year period, γ being the weight:

$$O_{et} = \sum_{i=1}^{3} \gamma^i O_{t-i} \tag{13}$$

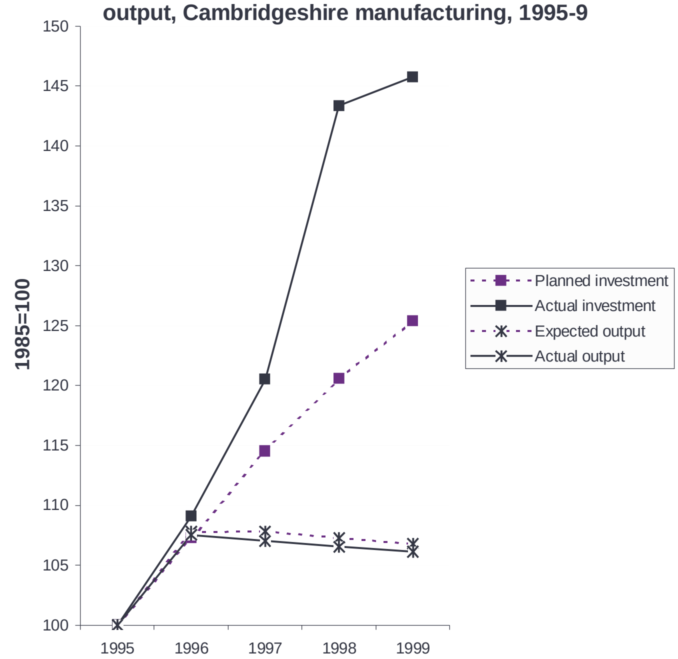
   where $0<\gamma<1$

2. Investment plans will be determined by the interaction between the payback period and output expectations. Assuming a payback period of 3 years, consistent with the stated planning horizon for these firms, planned investment in a given period will be the sum of expected output over the following three years with all years weighted equally:

$$I_{pt} = \sum_{i=1}^{3} O_{t+i}^{e} \tag{14}$$

Simulations of both output and investment based on the simple behavioural hypotheses outlined in (13) and (14) were calculated. These simulations are matched in Figure 1 against actual and realised values of both output and investment over the period 1995-9. This matching evidence shows that firms' planned investment persistently under-shoots realised investment, suggesting that plans are not realised and that planning mistakes are systematic. This result is consistent with evidence from the survey, which suggests that firms commonly use adaptive and regressive expectations. These are commonly known to lead to systematic mistakes. By comparison, firms seem to have more success in matching their output expectations with delivered output. These findings suggest that the use of procedurally rational heuristics, as outlined above, will lead to good judgements in the case of output expectations but systematically incorrect judgements in the case of investment plans. Given the greater uncertainty that characterises investment, this finding is not surprising. Also, it is a

Figure 1: Simulated versus actual investment and output, Cambridgeshire manufacturing, 1995-9



Source: ONS Regional Accounts

result consistent with findings outlined in the growing literature on cognitive bias in economic decision-making (Kahneman and Tversky, 1982; Baddeley, Curtis and Wood, 2004).

7. Conclusions and Policy Implications

In the literature on fixed asset investment it is often assumed that businesses adopt complex, forward-looking approaches to investment appraisal strategies, and this assumption is based around Jorgenson's model of business investment in which profit maximising firms continue to invest to the point at which the marginal productivity of capital is equivalent to the relative cost of capital inputs. This 'black box' model of business behaviour forms the basis of theories of firms as substantively rational maximisers operating using complex mathematical techniques (an algorithmic approach).

In assessing the predictive power of theories based around the Jorgensonian view, survey evidence was analysed using statistical and econometric techniques. The evidence from these analyses showed that whilst some firms, that is large firms do operate in a techniques driven fashion, they are as likely to use a simple heuristics based around PBPs and ARRs as they are to use more complex forward looking techniques such as NPV and IRR. Nonetheless, the econometric evidence did show that the more forward looking firms (measured in terms of the length of their business plans) were generally more successful in terms of turnover, even after controlling for firm size.

In judging the desirability of a range of possible investment strategies, businesses must form probabilistic judgements about future events, e.g. the future productive potential of investment projects. The objective basis underlying these judgements may be very uncertain and not quantifiable; limits on human cognitive processing abilities may further compromise the process of prediction. The simulation evidence presented in the final part of this paper suggests that, when it comes to forecasting output, the most effective method is to assume that current conditions will continue. The simulation evidence presented suggests that this simple technique is more effective in practice than more complex algorithmic methods looking at a wider range of information (e.g. past values or Stock Market information).

Overall, it seems that a procedurally rational business, using heuristics, is as likely to form accurate predictions and make good decisions as a substantively rational business using complex algorithms. So the costs involved in incorporating complex algorithms, whether in investment project appraisal or in expectations formation, may outweigh the benefits in terms of a better decision. In practice and given constraints on prediction (and on accurately judging the discount rate), the use of simple heuristics is not necessarily always inferior to the use of complex, mathematical algorithms. Rational agents may therefore have an incentive to save the costs involved in using more complex procedures by adopting simple, common sense rules of thumb.

Notes

[1] For a survey of other problems with the Jorgensonian approach, i.e. limitations not associated with uncertainty, expectations and psychology, see Baddeley 2002, 2003.

[2] The survey was conducted with the support of the Cambridgeshire Unit and Cambridge Enterprise Agency.

[3] Details of the survey design have been omitted because of space limitations but are available from the author upon request.

[4] That only 12% of firms aim to increase Stock Market valuation may be explained by the fact that many of the firms surveyed are not independently listed.

[5] This necessitated the use of non-linear estimation techniques because the survey respondents were asked to rank turnover outcomes rather to give precise figures. This was to maximise response rates because asking for exact figures on turnover would have discouraged respondents by making the questionnaires relatively time-consuming to complete. The response options for the profits, capital stock, investment and labour force questions were also categorised.

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