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Irreversible investment, uncertainty and hysteresis: A New Zealand Investigation

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Irreversible Investment, Uncertainty and Hysteresis: A New Zealand Investigation.

MATTHEW C. GOODSON

Contents

Abstract

This paper revolves on the idea that transitory shocks can leave behind permanent effects. The sunk cost nature of many capital expenditures means firms only commit themselves when they feel sufficiently certain about the future payoffs. Thus investment/abandonment requires certainty of a sustained up/downturn. In between these certainty poles, there exists a range of investment inaction which generates the possibility of hysteretic outcomes. Consider a large negative shock which creates high certainty of a downturn, causing firms to abandon. Later, when the shock disappears, the firm returns to inaction, leaving the economy with a permanently lower capital stock.

Section 1 shows that traditional investment models fail to incorporate uncertainty in a satisfactory manner. Section 2 outlines the recently developed theory of irreversible investment under uncertainty. The range of inaction is shown to be of significant size for plausible parameter values, it depends vitally on the degree of uncertainty, and only small sunk costs are needed for it to emerge. Section 3 uses Engle-Granger cointegration methodology to investigate uncertainty's empirical role. A novel entropy related measure is constructed from business opinion data and is appended to an accelerator-type model. The coefficient on uncertainty is significantly negative and tentative signs of a structural break that were otherwise present are removed.

Keywords: investment, irreversibility, sunk costs, hysteresis, uncertainty, option value, aggregation.

Journal of Economic Literature classification: D81, E22.

Irreversible Investment, Uncertainty and Hysteresis: A New Zealand Investigation.*

MATTHEW C. GOODSON

1: TRADITIONAL INVESTMENT MODELS AND UNCERTAINTY

This paper is motivated by the idea that temporary shocks to an economy can leave behind permanent effects. To date, such theories of hysteresis have been applied largely to the explanation of unemployment. This paper builds on recent literature that considers hysteresis in investment. In looking at existing 'traditional' theories of investment, one is struck with the fact that despite considerable theoretical refinement and econometric advancement, none has achieved anything like a widely recognised robust empirical performance. This section suggests that these theories mistakenly fail to consider how investment irreversibility might interact with uncertainty.

The basic premise of accelerator models is that the desired capital stock is some fixed fraction of output. The flexible accelerator model allows deviations of the capital stock from its desired level via the process of gradual adjustment, which is modelled by a set of distributed lag coefficients;

$$I^N = K - K_{t-1} = \sum_{s=1}^{\infty} \beta_{t-s} (K^D - K^D_{t-s}) \qquad (1)$$

$$\Rightarrow I^N = \alpha \sum_{s=1}^{\infty} \beta_{t-s} . (\Delta Y_{t-s}) \qquad \text{since } K^D = \alpha Y \qquad (2)$$

There are several possible explanations for the capital stock's gradual adjustment, with the crucial one here being the case where investment entails sunk costs. Section 2 shows it may be optimal to wait, rather than invest immediately upon a positive net present value, because the firm cannot disinvest without cost if market conditions turn out to be less favourable than anticipated. However, the distributed lag specification fails to distinguish between adjustment lags and expectations. While adjustment lags mean current investment depends upon past output levels, the intertemporal nature of investment means it also depends upon expected future levels of prices and output. By arbitrarily imposing a distributed lag scheme, backward-looking expectations are implied despite a key explanation for gradual adjustment being based on forward-looking behaviour.

The convex adjustment costs argument posits that the costs of reorganising production lines and retraining workers increase with the size of adjustment. However, the existence of indivisibilities or information costs implies decreasing costs. Once one has the information to train a worker or reorganise a production line, such information can be applied to any number of workers or lines at no extra cost. Moreover, indivisibilities often arise because reorganising just part of a process may not be possible. There is no reason why these arguments for concave costs should be outweighed by the convexity criteria, making a general convex costs explanation for a distributed lag doubtful at best.

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EDITOR'S NOTE: Matthew Goodson's presentation of this paper was a joint winner of the Jan Whitwell Prize for the best postgraduate student paper presented at the NZ Association of Economists' annual conference, August 1994.

One key problem is that cost of capital measures typically use an ad hoc risk premium to handle the risk of investing when the future is uncertain.[4] It will be shown in Section 2 that uncertainty can affect the value of waiting to a sufficient magnitude that the interest rate component (and hence any risk premium) in the cost of capital is swamped. Another uncertainty-based explanation for the cost of capital's poor empirical performance is that Keynes'(1936) concept of "animal spirits" might be important. In this situation, a spontaneous increase in confidence will cause both investment and the cost of capital to rise together, thus obscuring any underlying negative relationship. In a related argument, Shapiro(1986) suggested that econometric implementations have failed to account for positive supply-side shocks which both stimulate investment and raise the cost of capital.

In summary, Jorgenson-type neoclassical models suffer three crucial problems in their treatment of uncertainty. Firstly, as with the accelerator model, they are backward-looking. Secondly, the inclusion in the cost of capital of a simple risk premium fails to account for the option value of waiting. Thirdly, "animal spirits" and supply-side shocks give a simple reason for the correlation of investment and user cost being positive rather than negative.

Investment models based on Tobin's q posit that investment occurs when capital is valued more highly in the market than it costs to physically replace it. Since the market value is nothing more than the present value of expected future returns, then if the market is efficient, all relevant information about the future returns of capital should be summarised by q. This obviously provides a far more satisfactory treatment of uncertainty than the models with distributed lag coefficients. However, despite this substantial theoretical advantage, the empirical performance of Tobin's q has been poor.

Although not recognised in the literature to date, sunk costs create a fundamental discontinuity in the q measure. Consider the case of partial irreversibility, where once a unit of capital is installed, its market value falls but its replacement cost is unchanged. With the market value having fallen, a firm will hardly disinvest when q falls to $q < 1$ as the theory predicts, because the effective market value falls below the notional market value when the dividends can only be earned by the initial holder of the capital.[5] Since firms are likely to recognise the degree of sunk costs prior to making an investment, they won't invest immediately upon $q > 1$ either. Thus depending on the degree of sunk costs, there will exist a region of inertia around $q = 1$. This discontinuity in q's formulation means that the dis/investment signal is only acted upon when q moves outside the region of say 0.8 - 1.2. When q moves within this "no response" region, its predictive power over investment is removed entirely.

Moving on from the irreversible investment critique to look at q's basic credibility, Shiller(1981) made the seminal finding that U.S. stock price volatility is between five and thirteen times too high to be attributed to new information about future dividends.[6] For this volatility to be attributed to changes in expected interest rates would require far greater movements in these rates than in fact occurred.[7] Fischer & Merton(1984) criticised these findings on the grounds that stock price volatility was measured by the stationary process of standard deviations of dividends around their long-run exponential growth-path. To reject market efficiency on this basis is to merely assert that Shiller's model of fundamentals, (that dividends follow a stationary process), is better than the market's. Nevertheless, despite considerable econometric advances in market efficiency tests, Shiller's basic

4 A classic example in the NZ context is Clements(1985), who reduces the present value of revenue flows via an additive risk premium R, so that $C = \frac{q}{1-T}[(1-T)i + (1-TB)\delta + R]$, where R is taken as an ad hoc function of the inflation rate; $R = a + b\pi$.

5 In the case of adverse selection, potential buyers of the capital merely believe that the dividend stream will be lower than it actually is.

6 Shiller(1981), pp.433-434.

7 ibid., p.434.

The standard Marshallian investment criteria say that a project should proceed if the present value of its revenues is positive and be abandoned if the value is negative. These trigger values are:

$$W_H = w + \rho k; \quad W_L = w - \rho l \qquad (6)$$

where w = operating costs of production, k = sunk costs of entry, l = sunk costs of exit, W_H = investment trigger level of revenue (P), W_L = abandonment trigger, ρ = discount rate.

If an investment opportunity can be waited upon, rather than immediately taken or refused, these criteria are sub-optimal.[10] In the investment case, one would wait in case an initially positive return proves transitory. If after having waited, one finds $P_{t+1} < W_H$, then one would choose not to invest. On the other hand, if one finds $P_{t+1} > W_H$, then the net worth of investing after having waited is positive. Thus the net worth of waiting before making one's decision is positive, unless $prob(P_{t+1} > W_H) = 0$, in which case the net worth is zero. By continuity, the return to waiting exceeds investing for initial values of P slightly in excess of W_H. Thus the investment trigger is now some value $P_H > W_H$ such that the higher trigger price implies a sacrifice of profits that exceeds the return to waiting. Identically opposite analysis can be employed to consider operating losses, which if sufficient, will induce abandonment.[11]

The mechanics of hysteresis can now be sketched. Abstracting initially from uncertainty, sunk costs alone can produce hysteresis. If $P < W_L$, the firm abandons, and if $P > W_H$, the firm invests. In between there is a zone of inaction, $\rho(k + l)$. Suppose that from this zone, a negative shock causes $P < W_L$, so that the firm disinvests. Next period, when the shock disappears, the firm returns to inaction, leaving the capital stock at a permanently lower level. Hence the temporary shock has permanent effects. Reintroducing uncertainty greatly expands the zone of inaction, with the Dixitian entry trigger becoming $P_H > W_H$ and the exit trigger $P_L < W_L$. Thus our hierarchy of triggers is $\mathbf{P_H > W_H > W_L > P_L}$. Now, a transitory shock has to be stronger to have any effect compared to the certainty situation, but once such a shock occurs, its ability to generate prolonged hysteresis is far greater. Whether this Dixitian region of optimal inertia might be of significant size will now be considered.

It is assumed that uncertainty arises solely from a stochastic price term and that its evolution is entirely exogenous to the firm.[12] The price follows a random walk, which is approximated by the continuous time Markov process of Brownian motion. Assuming increments to price are independently, identically and normally distributed, the cumulation of these increments over time can be set out;[13]

$$\frac{dP}{P} = \mu dt + \sigma dz \qquad (7)$$

where μ is the expected growth rate of price P, σ^2 is its variance per time-unit, $P \sim N(x,\sigma^2 t)$, where x is any constant and z follows a standardised Wiener process whose increment dz has zero mean and variance dt. This process means that the price becomes increasingly uncertain the further into the future we look. Percentage changes in dP/P are normally distributed and absolute changes dP are log-normally distributed. Hence $E(P_t|P_o) = e^{\mu t}$. That is, given the initial price, the price in some future time period t

[10] The effects of competition, which means an investment opportunity may disappear if not taken immediately upon becoming available are not discussed here. See Goodson(1993), pp.39-43.

[11] As shown later, the more realistic case where temporary shutdown is possible leaves the qualitative results unchanged.

[12] For the firm to have no influence over its price path requires perfect competition but this paper derives the value of waiting for a monopoly firm to avoid the complication that under competition, a firm might lose its investment opportunity while waiting. This apparent inconsistency can be rectified by thinking of P as revenue rather than price because a monopolist's revenue is still subject to shifts in its demand curve. Thus it is demand that is modelled as following a Brownian motion, even though price will continue to be referred to as the stochastic variable.

[13] Dixit(1992c), pp.1-4, provides a proof of this.

Similarly, the value of abandoning at the trigger P_L must at least equal the lump-sum exit cost l;

$$V_1(P_L) = V_0(P_L) - l \tag{11}$$

Diagram 2.1 shows that at Z, the value matching condition (10) is satisfied. The traditional Marshallian trigger W_H merely requires that the value of investing immediately, $V_1(P_H) - k$, is positive. This contrasts with the P_H trigger, where the value of the option of waiting to invest is considered, meaning the value of investing must also exceed this higher value for it to proceed. For the region 0Z of $V_0(P)$, waiting is optimal, but at Z, investment becomes best.[15] At this point of tangency, the slopes of the two functions are equal, meaning the **smooth pasting condition** is fulfilled;

$$\Rightarrow V_0'(P_H) = V_1'(P_H) \tag{12}$$

Similarly, for the disinvestment case;

$$V_1'(P_L) = V_0'(P_L) \tag{13}$$

The following diagrams show intuitively why maximising the expected net present value requires that the smooth pasting condition must hold at the transition point Z;[16]

Diagram 2.2(a), (b)

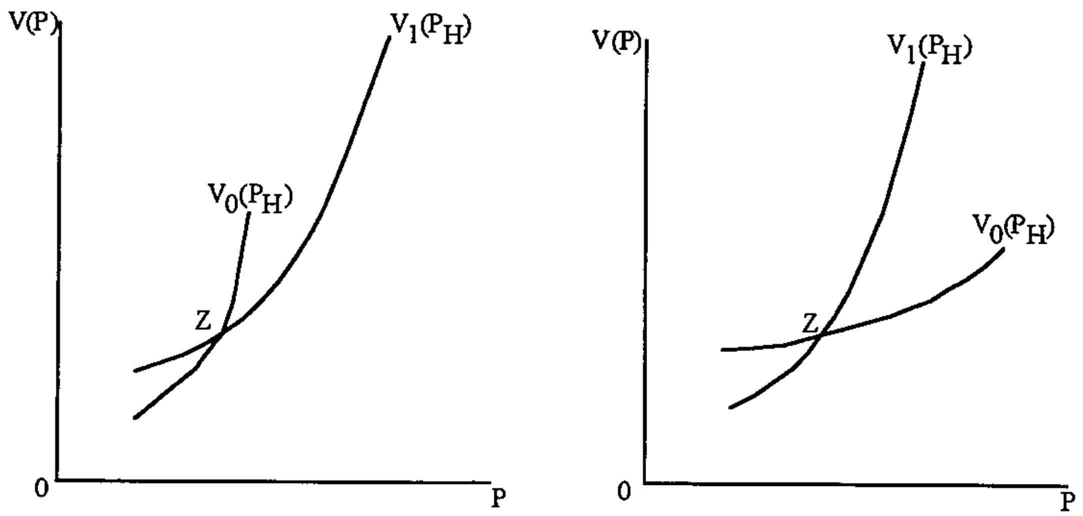

Diagram 2.2(a) shows that instead of being equal at Z, $V_0'(P_H) > V_1'(P_H)$. Hence to the left of Z, $V_1(P_H) > V_0(P_H)$, meaning the option to wait is terminated, (i.e. the firm enters), before what is supposedly the optimal point at Z. Conversely, Diagram 2.2(b) shows $V_0'(P_H) < V_1'(P_H)$ at Z, so that $V_1(P_H) > V_0(P_H)$ to the right of Z. Here, rather than terminating the option and investing at Z, we wait for one more period. If the subsequent change is an ⇑P, then we move to the right along $V_1(P_H)$ and we terminate the option of waiting to invest. If the change is a ⇓P, we move to the left along $V_0(P_H)$, and continue to hold the option. This policy raises V(P) relative to terminating at Z because the average of the move to the right up the steeper curve and a move to the left of the same horizontal distance along the flatter curve is positive. Thus the required optimality of Z is violated. With the same story being viable for P_L, it must be the case that the smooth pasting conditions (12) and (13) hold.

[15] As pointed out by Dixit(1992a), p.114, the value of waiting ceases to have a meaningful interpretation past Z because waiting would then be purely speculative in the hope of even higher returns. That of course is absurd because with the prospect of even greater revenue, firms will invest; the point in waiting is to avoid **downside** risk.

[16] What follows here owes its origins to Dixit(1992c), pp.40-41.

before such a project is abandoned, because once you exit, you exit forever. Supposing B= 0, and simultaneously solving (15) and (17) for A to find P_L gives;

$$P_L = \frac{\rho-\mu}{\rho} \cdot \frac{\alpha}{\alpha+1} W_L \tag{19}$$

By similar reasoning to the last case, $P_L < W_L$ requires $-\alpha\mu < \rho$, which is trivially true for all $\mu \geq 0$.

Having established the existence of a Dixitian range of inaction, its quantitative size will now be examined to see if it likely to be of real world significance. Dixit(1989) considers this point by setting plausible values for the parameters in equations (14) - (17) and solving numerically.[20] The ratio of variable costs to sunk costs is set at ten-to-one implying $w= 10\rho k$. Normalising w at $w= 1$, and taking a discount rate of $\rho= 0.025$, means $k= 4$ in order for $\rho k= 0.1$. For the degree of uncertainty, $\sigma= 0.1$ is taken as the central case. This means lnP has a variance of 1% per annum, implying the standard deviation of price fluctuations is 10% over one year, 20% over four years, 30% over nine years etc. The price path is assumed to be stationary, meaning $\mu= 0$. Finally, exit costs are assumed to be $l= 0$. Substituting all these parameter values into equation (A5) gives $m= 0$, $r= 5$ which yields **$\beta= 2.7913$** and **$-\alpha= -1.7913$**. Thus Dixit finds that for these parameter values, equations (14) - (17) imply;

$$P_L = 0.7657 \; < \; W_L = 1 \; < \; W_H = 1.1 \; < \; P_H = 1.4667 \tag{20}$$

This shows the Dixitian gap is approximately seven times its Marshallian counterpart, meaning the option value of waiting in the presence of uncertainty accounts for most of the P_H - P_L gap. Furthermore, the optimal entry trigger P_H requires an operating profit of 0.4667, which is over four times the normal return to capital, ($\rho k= 0.1$). Conversely, losses of around a quarter of variable costs have to be incurred before exit occurs.

The sensitivity of the Dixitian gap to changes in the parameters can be considered by varying them one at a time from the base case. It is not possible to derive a general analytical result linking the Dixitian and Marshallian investment triggers, but we can consider the limit case linkages of the two triggers as given by equation (18), (i.e. no value of waiting to exit), and equation (19), (i.e. no value of waiting to enter). From these it is obvious that as $\beta \to \infty$, so $P_H \to W_H$ and as $-\alpha \to -\infty$, so $P_L \to W_L$. Thus in the analysis that follows, an increase in β over our base case value means that P_H tends to W_H from above, while a decrease in $-\alpha$ towards negative infinity means P_L tends to W_L from below.[21]

Firstly and centrally, consider the effects of altering the **degree of uncertainty, σ**. If firms are very certain of the future, there is a lower value of waiting because less information is revealed. Thus one would expect the Dixitian gap to be reduced, making hysteresis less likely. Supposing $\sigma= 0.01$ instead of 0.1 as in the base case gives **$\beta= 22.8663$** and **$-\alpha= -21.8663$**. This confirms the intuition that the Dixitian entry/exit triggers move towards their Marshallian counterparts, making hysteresis less likely.

Secondly, consider the more complex effects of changing the **risk free interest rate, ρ**. This is not satisfactorily analysed by Dixit(1989,1992a) because the presence of two opposite effects is not noticed. Suppose that ρ quadruples to say $\rho= 0.10$, which gives **$\beta= 5$** and **$-\alpha= -4$**. This suggests that P_H and P_L contract towards their Marshallian values. However, Dixit(1989) describes his unreported numerical results for ρ as: "*Finally, as ρ increases, both triggers P_H and P_L rise....Thus investment is more reluctantly made and more easily abandoned.*"[22] This directly contradicts the findings above but the paradoxical answer is that both versions are correct. What happens is that the higher interest rate

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[20] See Dixit(1989), pp. 630-631.

[21] The α and β values are worked out using equation (A5), assuming $\mu= 0$.

[22] Dixit(1989), p.634.

Similarly, restarting operations at some future date incurs costs of rehiring labour, firing machinery up again, and re-establishing old markets. Assuming that firms always abandon is equivalent to stating that the sunk costs of suspension are large relative to the price of capital goods. With suspension allowed, the option value of waiting is not that of keeping the possibility of future operations alive but rather of being able to avoid all the shutdown and startup costs. If these are less than the cost of reinvesting from scratch, the option value of waiting to abandon is worth less than previously, meaning P_L is higher. Moreover, since the firm can shut down rather than abandon totally if circumstances turn sour, P_H will not have to be as high as previously to induce investment in the first place. Thus allowing only for abandonment widens the Dixitian gap by some unknown factor.

The combination of indivisibility and irreversibility in the face of uncertainty creates another channel for an option value. Namely, given the type of project decided upon, what size is the most appropriate ? If the scale is too large there will be the wastage of excess capacity, and if too small, a parallel plant with the contingent loss of economies of scale will be required. These option values are overlooked by Dixit, who assumes that the best way to make the product is known and that constant returns to scale mean this factor does not influence the size of the investment increment chosen.

This leads to the second extension of **non-constant returns to scale**. In reality, capacity additions are often lumpy, making increasing returns to scale (i.e. indivisibilities) a common feature of investment. Further sources of increasing returns include greater possibilities for specialisation, economies in research and development, lower unit advertising costs, and a larger customer base which by having stabler aggregate behaviour, allows fewer inventories to be held.

Indivisibilities mean that the marginal product of capital, F'(K) increases until some threshold level K^* is reached, where scale economies are at a maximum. The threshold price P(K) that generates new entry is obviously falling over the range [0,K*] because the marginal product of capital is positive, while its marginal cost is unchanged. Hence the entry trigger is lowest where scale economies are at a maximum. Crucially, P(K) does not serve as the threshold entry function when returns to scale are increasing. Supposing the contrary, then since $F'(K) \to 0$ as $K \to 0$, it must be the case that $P(K) \to \infty$. However, even starting at zero initial capital, there must exist some sufficiently high finite price to make it profitable to install a lump of capital. Thus for the increasing returns portion, there is a lower threshold function Q(X). Moreover, if $P \geq Q(X)$, then capacity is invested in a lump whereby the entire region of increasing returns is jumped, with new investment only stopping when the marginal product of capital falls below the entry price. If capital was not invested in such a lump, the firm would illogically be ignoring returns that exceed the trigger price. Hence scale economies cause: (i) A lower threshold entry price for investment levels up to where the indivisibilities are exhausted; (ii) Rather than investing incrementally, firms undertake a major jump to more than cross the increasing returns segment.

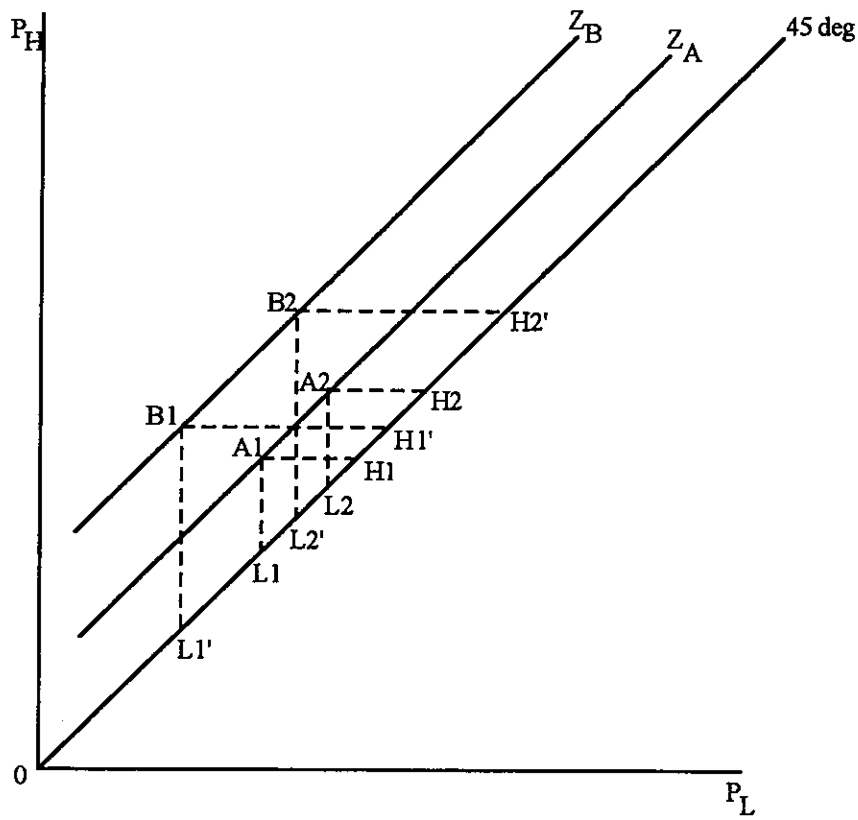
Thirdly, consider a **variable scale of output** so that a given amount of investment no longer yields a fixed amount of output. If output can be greatly reduced, (or put into inventory with no storage costs or decay), then the investment need never be abandoned, although there is likely to be some minimum feasible scale of operation beyond which there is a jump to zero output, (i.e. shutdown).[26] Output flexibility means that firms are more willing to invest, ($\Downarrow P_H$) because a downturn can be absorbed by reducing output rather than abandoning. Obviously, this also means that $P_L \Downarrow$.[27] With both triggers falling, the possibility of hysteresis is unaffected but the quantitative impact is unclear.

[26] Consider for instance Comalco's closure of an aluminium potline during the winter 1992 electricity crisis.

[27] The impact on the Dixitian gap of varying output is overstated here because while the variable costs of operating the capital stock will be reduced in proportion with output, firms still face fixed overheads and labour redundancy will have to be paid (i.e. $l > 0$). Furthermore, the firm loses specifically trained labour which it will not be able to reemploy when it subsequently wishes to increase output because of the duration effects of unemployment (i.e. deskilling) and the 'adverse' selection effect that the best labour units among those laid off will be reemployed by other firms.

also conditioned by the degree of sunk costs. If the two industries we have considered had greater sunk costs so that they lay on Z_B, the Dixitian gap increases to the range $L_2'H_1'$.

Diagram 2.3: The Dixitian Gap Under Aggregation[29]



Summarising, irreversible investment driven hysteresis will not necessarily appear to result in long periods of inertia broken by sudden outbursts of activity; observed behaviour will depend crucially on the degree of production and sunk cost differences between industries. This leaves us with the hypothesis that a major change in uncertainty or profits will have major effects, while a minor change might have minor effects, rather than no effects at all. The results of the econometric analysis that follows should be interpreted in this light.

3: AN ECONOMETRIC ANALYSIS OF INVESTMENT

3.1 Measuring Uncertainty

The theoretical arguments outlined in this thesis suggest two testable hypotheses regarding the effect of uncertainty on investment: (i) high certainty of a down/upturn causes dis/investment; (ii) following a period of such certainty, a return to uncertainty will result in hysteresis for as long as that uncertainty remains. Thus structural breaks in an investment equation might be removed by the addition of an uncertainty term.

Previous econometric analyses of investment have typically found no significant explanatory role for uncertainty. Ford & Poret(1990) made an unsuccessful attempt where they proxied uncertainty using

[29] This is adapted from Baldwin & Krugman(1989), p.643 and p.646. Z_i lies above the 45 degree line because $P_H > P_L$ everywhere due to sunk costs and the option value of waiting.

displaying a correlation coefficient of 0.905.[32] However, it is not identical and it has the advantages of: (i) using more information, (ii) it has a theoretical underpinning as a measure of **uncertainty**, and while it is clearly related to **confidence**, it is not a measure of confidence per se.

The postulated effect of uncertainty on investment is that when firms invest, they undertake an irreversible commitment from which they can recover very little if the investment turns out to be mistaken. Hence firms will disinvest only when extremely certain of a downturn, invest when extremely certain of an upturn, and sit tight when they do not hold strong beliefs about future events. Hysteresis might result as follows. Suppose firms feel some 'normal' level of uncertainty, as is the case for 1973:1-1974:3, and then some negative shock hits the economy which causes such high certainty of a future downturn that firms disinvest. Subsequently, the shock disappears and uncertainty returns to its former 'normal' interval, but the capital stock is left permanently at a lower level until a large positive shock arrives. Interestingly, following the negative shock of 1974:4, and with 'normal' defined as the 90% confidence interval, no positive shock to confidence in the interim has been large enough to spark a significant investment upturn until the 1993:4 survey.[33]

3.2 Estimation Of An Investment Model

The aim of investigating uncertainty's role in explaining investment means that rather than applying any one à priori theoretical construct to the problem, the data is allowed to speak for itself by applying a 'general to specific' modelling procedure. Economic theory suggests that the following variables may be of interest:

(1) Investment (ipox): net real business investment, with the 'net' being net of depreciation, which is assumed to be fixed at 1.8% of the existing capital stock per quarter.[34]

(2) Output (qpdx): real aggregate demand for private output. Measures of real GDP and real private output yielded very similar results. This variable captures the accelerator effect, where an increase in output requires an increase in the capital stock, given that some optimal capital-output ratio holds in the long run.

(3) Cost of capital: four possibilities were considered:[35]

(i) $\text{“cost1”} = \dfrac{\text{JTL - PPII} + \delta(1 - \text{TPD})}{1 - \text{TRC}}$

(ii) $\text{“cost2”} = \dfrac{\text{JTL - PPII} + \delta}{1 - \text{TRCE}}$

(iii) "cost1/wp" = cost1/wp

(iv) "cost2/wp" = cost2/wp

(4) Profits: although no one generally accepted theory has linked profits to investment, many empirical studies have found it to be significant. Reasons include its role as a proxy for economic activity and its retained earnings function where it provides liquidity to the firm. Two possible measures were considered;

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[32] For an example of tent's construction, consider the 1991:2 quarter: 'ups' = .17, 'sames' = .58, 'downs' = .25. Hence 'ent' = .8772 ⇒ 1/ent = 1.1399 ⇒ 'tent' = -0.1399. Full data is available on request from the author.

[33] This ignores the strong possibility that a cumulation of mildly positive quarters will spark significant investment. The 1993:4 result is outside the data period of this study which extends only to 1991:3.

[34] See Brooks & Gibbs(1991), p.11.

[35] JTL = trading bank lending interest rate, PPII = producers price index (inputs), d = capital scrapping rate calculated from Philpott(1991,1992), TPD = proportion of depreciation that is tax deductible, TRC = statutory company tax rate, TRCE = effective company tax rate, WP = hourly private sector real wage rate.

Table 3.1: ADF Unit Root Tests

	lag	ADF I(0)	ADF I(1)	variable	lag	ADF I(0)	ADF I(1)
log(ipox)	k=2	-2.7332 -1.4869	-6.0085* -6.0521*	4cvpc	k=4	-1.0094 -1.3021	-4.8531* -4.5751*
	k=4	-2.8271 -1.1864	-4.4056* -4.4222*		k=7	-0.8770 -1.3832	-5.0596* -4.2411*
	k=8	-2.0567 -0.2649	-4.1109* -4.1471*	4cv	k=0	-11.225* -11.229*	n/a
log(qpdx)	k=4	-2.3651 -1.3138	-3.4378# -3.4531*		k=4	-4.2451* -4.1898*	n/a
	k=9	-2.3651 -1.3138	-3.0598 -3.0611#	log(cost1)	k=4	-1.1755 -1.3992	-3.6590# -3.5870#
log(cost2/wp)	k=4	-2.7902 -0.8835	-4.9186* -4.9494*		k=8	-1.5717 -1.3959	-3.0471 -2.9671#
	k=9	-2.2563 -0.1163	-4.1495* -4.1312*	log(cost2)	k=4	-3.3919* -0.9828	-4.8241* -4.8558*
log(ocn/p)	k=4	-3.2372+ -3.2553#	n/a		k=9	-2.5240 -0.2495	-4.4967* -4.5424*
	k=9	-2.9032 -2.9239+	n/a		k=10	-2.5078 -0.2970	-3.9284* -3.9705*
tent	k=1	-4.0548* -4.0585*	n/a	qcu	k=2	-4.1161* -3.3462+	-5.1345* -5.1567*
	k=4	-5.4246* -5.4044*	n/a		k=4	-3.7637+ -2.8757+	-6.3182* -6.3478*
	k=5	-4.9940* -4.9731*	n/a		k=6	-3.0900 -2.3340	-5.5265* -5.5639*
YV	k=4	-2.9804 -2.5985+	-8.6514* -8.6973*	s-rate	k=2	-1.3007 -1.5889	-3.0910 -2.3813
	k=8	-1.9876 -1.7008	-5.0405* -5.0977*		k=4	-1.1269 -1.4237	-2.5187 -1.6627
	k=11	-2.1445 -2.0609	-4.1458* -4.2131*		k=6	-2.0060 -2.3123	-2.6825 -1.6452

The upper value for the ADF tests is for a unit root with a constant and trend, while the lower figure is for a constant and no trend. There are no cases of neither constant nor trend. Critical values are taken from MacKinnon(1991), p.275. A + indicates 10% significance, # is 5%, and * is 1%.

These results show that ipox, qpdx, cost2/wp and 4cvpc are I(1), while tent, 4cv and ocn/p are I(0). The results for YV are unclear, although one would expect it to be I(0) given that it is virtually a differenced version of qpdx. The lack of clarity concerning YV's stationarity means it will not be used in a cointegrating regression as was done by Driver & Moreton(1991). These conclusions accord with eyeball examinations of time series plots of the data. Note that ADF tests were carried out in preference to Phillips-Perron tests due to Schwert's(1989) finding that the nature of the ARIMA process underlying a series should be considered prior to testing for a unit root. When the MA component is large, he shows that neither the ADF nor PP tests perform particularly well but that the ADF test is better. Cursory examination suggested a non-negligible MA component in most of the series under consideration here.

Having determined which variables are I(1), it remains to test for cointegration. When two variables are I(1), it may be the case that a linear combination of these variables is stationary, I(0). Cointegration is tested for by applying the ADF test to the residuals of the cointegrating regression. A finding that these residuals are I(0) carries the implication that the two I(1) variables will not drift far apart over time. The cointegrating regression in this instance is;

$$\log(ipox_t) = \beta_0 + \beta_1 t + \beta_2 \log(qpdx_t) + u_t \qquad (25)$$

This gives a complete model involving both long run statics and short run dynamics. The number of lags and whether other (short run) variables should be included, is tested for by a 'general to specific' modelling approach. Note that the error correction term alters short run investment by the proportion ϕ whenever the capital-output ratio strays too far from its equilibrium value β_2 (in equation (25)).

Prior to estimating equation (28), its usefulness in overcoming the well-known lack of power of the cointegrating regression ADF test needs to be outlined. This lack of power means that the null of no cointegration is not rejected often enough. Kremers et al(1992) consider what they describe as the frequent case where the ADF test is on the margins of accepting/rejecting the null of no cointegration but the coefficient on the error correction term in the corresponding dynamic model (28) is highly significant, and thus supports cointegration strongly. This is clearly the case here. Kremers et al argue that the relatively greater power of an ECM-based t test is supported by both empirical and Monte Carlo evidence. Thus they recommend carrying out a t test on the ECM term, (using the DF critical values rather than the standard t distribution), to either back up or override the ADF test in cases where cointegration is marginally rejected.

Equation (28) is estimated for the two separate cases where uncertainty is included and excluded, by applying OLS to quarterly undeseasonalised data spanning 1965:2-1991:3. Whether or not a particular variable is differenced depends on the unit root tests conducted earlier.[36]

Model (i) No Uncertainty: $\overline{R}^2 = .7345$; log AIC = -4.8962

$$\Delta\log(ipox_t) = \underset{(t=10.72)^*}{1.7619}\Delta_4\log(qpdx_t) + \underset{(t=3.39)^*}{.2060}\Delta_4\log(ipox_{t-1}) - \underset{(t=-6.46)^*}{.4613}[\log(ipox_{t-4}) - \log(qpdx_{t-4})]$$

Model (ii) Uncertainty Included: $\overline{R}^2 = .7580$; log AIC = -4.9450

$$\Delta\log(ipox_t) = \underset{(t=9.41)^*}{1.620}\Delta_4\log(qpdx_t) + \underset{(t=1.71)^+}{.114}\Delta_4\log(ipox_{t-1}) + \underset{(t=2.43)^\#}{.099}\sum_{i=3}^{5} tent_{t-i} - \underset{(t=-6.92)^*}{.504}[\log(ipox_{t-4}) - \log(qpdx_{t-4})]$$

All the signs accord with economic theory and are significant at a reasonable level of confidence. Lags are chosen on the basis of minimising the AIC. The restriction that the constant equals zero is easily accepted by a t test, meaning there is no autonomous investment. The inclusion of uncertainty improves the $\overline{R}^2$ and lowers the AIC, suggesting that uncertainty lagged three to five quarters plays a significant role in explaining investment. Further dynamic effects are captured by the significant presence of the lagged dependent variable. Since the uncertainty measure (tent) includes some negative terms, logs cannot be taken and no precise quantitative interpretation can be placed upon the coefficient. The relationships in models (i) and (ii) of the output and uncertainty measures with investment are illustrated in Diagram 3.1.

[36] The two equations that follow have very similar explanatory power to Rae(1991), who uses different data and finds significance for different explanatory variables. Here, the $\overline{R}^2$ values are .7345 and .7580, whereas Rae's value for plant and machinery investment is .7560.

An interesting aspect to both equations is the strong negative significance of the error correction terms.[37] This suggests a large change in short run investment whenever the capital-output ratio strays away from its normal level. Furthermore, according to the work of Kremers et al(1992), the high t values strongly imply that output and investment are cointegrated.

One issue dogging the specification that includes uncertainty is that of multicollinearity. Diagram 3.1 shows that investment, output and (lagged) uncertainty tend to move in the same fashion over time. Thus the apparently strong effect of the output term on investment could be swamping that of uncertainty to some degree. This can be seen from the simple regressions;

$$\Delta_4 \log(ipox_t) = .0558 + .3904 \sum_{i=3}^{5} tent_{t-i} \; ; \; \overline{R^2} = .3924 \qquad (29)$$
$$\quad (t{=}4.05) \quad (t{=}7.28)$$

$$\Delta_4 \log(qpdx_t) = .0298 + .1534 \sum_{i=3}^{5} tent_{t-i} \; ; \; \overline{R^2} = .4319 \qquad (30)$$
$$\quad (t{=}6.24) \quad (t{=}8.26)$$

A major issue that could invalidate all the results to date is that of simultaneity between investment and output. One might expect not only a causal link running from output to investment, but also one from investment to output, given that investment is a component of output. If this is so, then the estimated coefficients will be biased. If output turns out not to be exogenous, then estimating an unbiased investment equation requires the instrumental variables method. One would expect a sizeable difference in the coefficient estimates if exogeneity is violated. Using output lagged one quarter (i.e. $\Delta_4\log(qpdx_{t-1})$) as an instrument for current output yields;[38]

$$\Delta_4 \log(ipox_t) = \underset{(t=3.99)}{1.1144}\Delta_4 \log(qpdx_{t-1}) + \underset{(t=3.54)}{.2637}\Delta_4 \log(ipox_{t-1}) + \underset{(t=2.78)}{.0974}\sum_{i=3}^{5} tent_{t-i}$$
$$- \underset{(t=-6.13)}{.4509}[\log(ipox_{t-4}) - \log(qpdx_{t-4})] \; ; \; \overline{R^2} = .7148 \qquad (31)$$

The only major change between this and the OLS estimation is a reduction in the size and significance of the output coefficient. The other coefficients change little, as is the case with the explanatory power of the equation. This suggests simultaneity is not a major issue although it is likely to bias the coefficient on output upwards to some extent in the OLS estimation.

A more explicit measure of output's exogeneity is the Hausman Specification Test. The test statistic comes from the intuition that if exogeneity is not the case, then output will be correlated with the error term, implying the coefficient on output (β_1) is inconsistent. To get a consistent estimator under endogeneity, the instrumental variable method is used. Hausman's test statistic compares the estimator that is consistent and efficient under H_0 but is not consistent under H_1, with the IV-derived estimator that is consistent under both H_0 and H_1, but is not efficient under H_0;

$$m = \hat{q}'[\hat{V}(\hat{q})]^{-1}\hat{q} \sim \chi^2(k), \text{ where } \hat{q} = \hat{\beta}_1 - \hat{\beta}_0, \; \hat{V}(\hat{q}) = \hat{V}(\hat{\beta}_1) - \hat{V}(\hat{\beta}_0) \qquad (32)$$

Here, using $\Delta_4\log(qpdx_{t-1})$ as the instrument for $\Delta_4\log(qpdx_t)$, we get;

model (i): $m = 0.3795 < \chi^2(4) = 9.49$

[37] Estimating an error correction model with D_4 transformations assumes that any seasonality is constant over time.

[38] This is a viable instrument because current investment can in no way cause past output.

3.4 Structural Break Tests

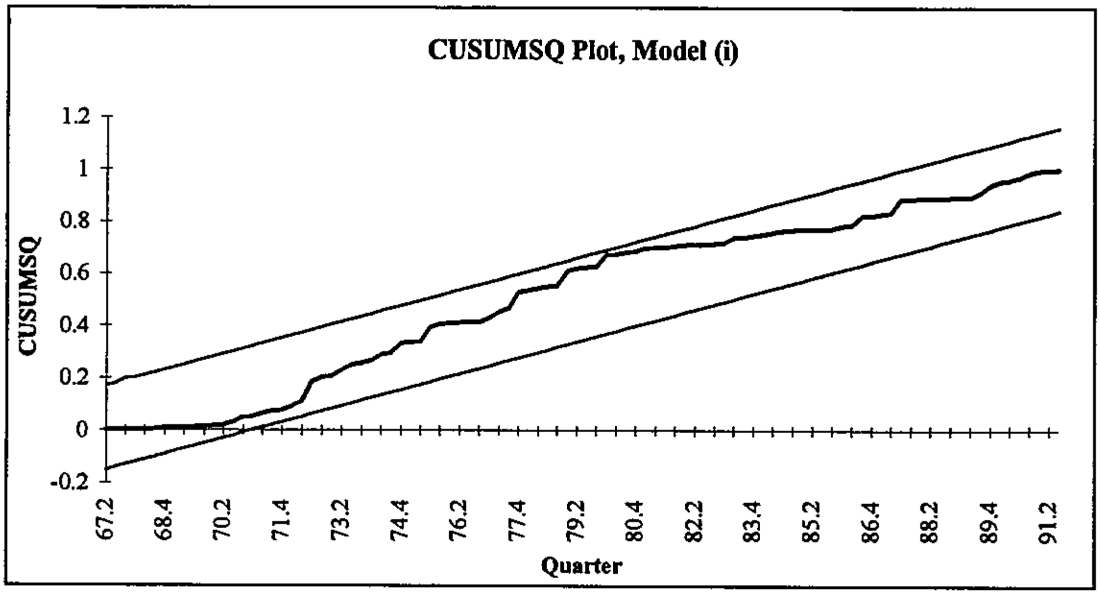
(1) *Chow Test*;

At a 95% confidence level, we reject the null of parameter stability for sample splits at;
model (i): 1980:1 - 1985:1, 1987:1 - 1988:2
model (ii): 1972:1 - 1973:1, 1974:3, 1975:1-2, 1978:1 - 1985:3, 1986:1 - 1987:1
Model (ii) has a larger number of possible structural breaks but three important caveats make this result highly questionable. Firstly, the test is conditional on variance equality between the two sub-samples. The Goldfeld-Quandt tests clearly show that this is not met. Secondly, the Chow test is only capable of testing for one structural break, that being the date at which the researcher chooses to make the sub-sample split. This is an obvious drawback for a period that saw two oil shocks, and multiple other exogenous shocks to business certainty. Thirdly, the pretesting issue is a concern in much recent literature. By looking at the data prior to deciding the break at which to apply the Chow test, the critical values against which the test statistic are compared are implicitly biased upwards. Thus there is a tendency to reject the null hypothesis of no structural change too easily.

(2) *CUSUM/CUSUMSQ Test*;

The CUSUM test considers the cumulative sum of recursive residuals and the CUSUMSQ test looks at the squared values of such residuals. When a model is misspecified, many of the recursive residuals will have the same sign meaning the CUSUM moves away from zero. Similarly, a structural break might be indicated by a secular change in the plots post-break. Diagram 3.2 shows the CUSUMSQ plots for our two models together with 10% confidence bounds. Both the following plots fall entirely within the 10% confidence bounds, although model (i) goes very close to breaking the upper bound for 1980:1-1980:3 and the lower bound for 1970:4 - 1971:1. In comparison, model (ii) which allows for uncertainty, does not come particularly close to the bounds at any point. Although this analysis may seem rather imprecise, it is in the spirit of Harvey's(1990) suggestion that these plots are best thought of as data analytic techniques rather than formal tests of significance.[41]

Diagram 3.2: CUSUMSQ Plots For Models (i) and (ii)



[41] Harvey(1990), p.155.

the two models perform very similarly. However, despite model (i) being fractionally better in terms of these overall measurements, the proportion of forecast errors due to bias is 35% lower in the model which includes uncertainty. Thus this model specification is more likely to accurately represent the true model. Examination of the predicted values for each quarter shows that model (ii) performs better in picking up the late 1993 investment surge, but is considerably too strong in its prediction for 1993:1. The observed value for that quarter appears to be something of an outlier, and one suspects that model (ii) would perform considerably better if it were to be excluded. Model (ii)'s ex post simulation performance is better in every respect than that of model (i).

4: CONCLUSIONS

Almost all other studies of investment have failed to find any explanatory importance for uncertainty. Given the theory developed in this paper, and the findings of the econometric investigation, it is contended that rather than uncertainty not having any such importance, other studies have simply failed to treat it in a satisfactory manner. This study derives an original "transformed entropy" measure from business opinion data and finds that when it is lagged three to five quarters, such uncertainty is significant at a 5% level. Moreover, multicollinearity is likely to have biased the coefficient downwards.

The most interesting implication arising from the theory of irreversible investment is its ability to explain structural breaks in investment via hysteresis. Although not explicitly linking their findings to this literature, Driver & Moreton(1991,1992) analysed the U.K. manufacturing sector and found that an investment equation which would otherwise display a structural break has it removed by the addition of uncertainty.[43] This study does not find such an apparently clearcut result but it does present a series of findings that, on balance, tend to support rather than contradict the hysteresis hypothesis. Namely: (1) Although acceptable for both models, the CUSUMSQ plot for model (ii) displays a lesser degree of misspecification; (2) This possibility is given strong support by Harvey's recursive residuals t test which shows that the structural breaks and/or functional misspecification suffered by model (i) are removed by model (ii); (3) Ramsey's RESET test suggests (at a 10% level) functional misspecification for model (i) but not model (ii); (4) In model (ii), the sum of lagged uncertainty terms is significant and of the sign expected.

Hence notwithstanding the possibility of serious aggregation problems, due to the industry specificity of investment and abandonment trigger points, some support is found for the hypotheses derived from the theory of irreversible investment. In particular, this study finds uncertainty to play a significant role in explaining investment, whereas no such role is found for the cost of capital. Moreover, the possibility of hysteresis is suggested by how adding uncertainty removes functional misspecification and/or structural breaks from what was otherwise a well-specified equation.

5: APPENDIX

Note 1

Starting in the idle state 0, the expected net present value of following optimal policies is $V_0(P)$. The change dP in P is random with $E[dP] = \mu P dt$ and $var[dP] = \sigma^2 P^2 dt$. The condition for an idle firm to stay idle is that its expected gain from waiting to invest is at least as large as the opportunity cost of actually investing;

---

[43] Their finding is however based on the problematical Chow test statistic and their sample size of 37 observations is far shorter than is generally recommended for cointegration analysis of any great power.

$$V_1(P) = A_1 P^{-\alpha} + B_1 P^{\beta} + \left[\frac{P}{\rho-\mu} - \frac{w}{\rho}\right] \qquad \text{(A7)}$$

The extra term in (A7) is the expected net present value of keeping the project active forever. The real value of initial revenue P falls by the discount rate every period, offset by the trend growth rate μ. Initial operating costs w are also discounted. If the extra term is negative, a firm only stays active if its operating loss is exceeded by the value of the option to abandon, which is hence the remainder of (A7). Similarly, for an idle firm, which has no operating profit/loss, $V_0(P)$ is the value of the option to become active (i.e. invest), as shown by (A6).

If the current price P is very low, then there is only a very small probability of it rising to P_H, the price that induces investment by an idle firm. Since P is to the power of $-\alpha$, as $P \to 0$, $P^{-\alpha} \to \infty$, => $V_0(P) \to \infty$, which is obviously nonsense. Thus we assume that $A_0 = 0$. Conversely for (A7), if P is very high, then there is very little chance that it will fall to P_L, the price that induces abandonment. Thus the option of abandoning is nearly worthless in this case, which requires $B_1 = 0$. Hence (A6) and (A7) become;

Idle state: $$V_0(P) = BP^{\beta} \qquad \text{(A8)}$$

Active state: $$V_1(P) = AP^{-\alpha} + \left[\frac{P}{\rho-\mu} - \frac{w}{\rho}\right] \qquad \text{(A9)}$$

Note 2

(14) $$\Rightarrow \frac{P_H}{\rho-\mu} - \frac{w}{\rho} = BP_H^{\beta} + k$$

(16) $$\Rightarrow \beta B P_H^{\beta-1} = \frac{1}{\rho-\mu}$$

$$\Rightarrow BP_H^{\beta} = \frac{1}{\rho-\mu}$$

$$\Rightarrow BP_H^{\beta} = \frac{P_H}{\beta(\rho-\mu)}$$

into (14) $$\Rightarrow \frac{P_H}{\rho-\mu} - \frac{w}{\rho} = \frac{P_H}{\beta(\rho-\mu)} + k$$

$$\Rightarrow P_H = \frac{\rho-\mu}{\rho} \cdot \frac{b}{b-1} (W_H) \qquad \text{where } W_H = w + \rho k$$

Note 3

The rationale for the entropy measure comes from the work of Garner(1962), who begins with the premise that the uncertainty about an outcome occurring depends on the number of possible outcomes. A measure to capture such uncertainty thus has to be monotonically related to the number of possible outcomes and must also ensure that each successive event adds the same amount of uncertainty. For instance, if n is the number of possible outcomes, then the uncertainty U about specific outcome x cannot be adequately captured by U(x) = n. One need only consider a dice throw, where one roll has 6

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