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The Effects of Uncertainty on Investment under Risk Neutrality with Endogenous Information

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Using a Bayesian framework, this paper considers a risk-neutral firm which has to pick an investment project out of many that are available. It is shown that, if the firm is allowed to collect information, it will usually devote some time to information gathering before choosing. The main result is that, when uncertainty increases, the firm finds it profitable to delay investment decisions even further in order to collect more information. Thus increased uncertainty decreases the current level of investment even under risk neutrality. Another implication is that increased uncertainties cause an increase in the demand for liquid assets.

It is well known that in a world of risk-averse investors, an increase in uncertainty usually decreases the equilibrium level of investment. Much less attention has been paid to the possibility that there may be an additional channel through which increased uncertainty affects the current level of investment: For given costs of acquiring information, an increase in uncertainty about the relevant parameters makes it more profitable to spend more time and resources in acquiring information before making a particular investment decision. This element is particularly important when there are a range of possible investment projects out of which only a subset will ultimately be undertaken and when these projects, once started, cannot be reversed easily. In such circumstances it may pay the firm to increase its knowledge about the true relevant distribution before deciding to which project it wants to commit itself. If the costs of increasing its information are not prohibitive, a firm will find that it can improve its ex ante expected utility or expected returns by waiting for more

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information before investing. Consider, for example, Viner's (1931) celebrated case in which a different size plant minimizes average costs at different output levels. Suppose the firm considers adding a plant and has to decide what size plant to build. Once a decision is made it is difficult to reverse. Under such circumstances it will usually pay the firm to wait until its information about the future level of demand becomes reasonably accurate. Otherwise it runs the risk of building a plant whose capacity is too large or too small, and in either case its profits will be lower than if it had picked the right plant size for the level of demand which ultimately develops. If, as in most static uncertainty models, the level of information is given and cannot be altered, the firm will have to make the best decision it can based on this information, using whatever behavioral rule is appropriate to it (like maximization of expected utility or of expected profits, or some other criteria). However, if it also has the option of waiting and obtaining more information about the future level of demand, the firm may find it profitable to incur the necessary costs in order to get a more precise view about the distribution of demand, since this may ultimately improve its decision by enough to make it worthwhile. It is noteworthy that this will be true irrespective of whether the firm is risk averse or risk neutral, since more precise information can be used to increase expected profits as well as the expected utility of profits.

The main point of this paper is that increased uncertainty will cause a decrease in the current level of investment by making it more profitable to wait longer for more information before choosing an investment project. In particular, it is shown that this is true even if the firm is risk neutral—thus illustrating that the argument does not depend on risk aversion. This mechanism seems to be more explicit, at least in business parlance, than the much more widely discussed (by academic economists) effect of increased variance on investment through risk aversion.[1] Businessmen often talk about increased uncertainties in the economy which cause investors to sit on the sidelines and see how things are going to happen. This kind of expression strongly hints that investment projects are postponed until more accurate information becomes available, and it is what I try to capture with the model presented here.

In Section I the basic model of a firm with many investment opportunities is presented using a Bayesian learning framework.[2] The

[1] There is some evidence which suggests that, when confronted with actual decision making under uncertainty, people do not behave as if they were maximizing expected utility. See, e.g., Kahneman and Tversky (1973) and Kunreuther et al. (1978). If taken seriously, this evidence makes it even more important to develop alternative models to explain the effect of increased uncertainty on current investments.

[2] For some other applications of Bayesian learning to economic behavior under uncertainty, see Turnovsky (1969), Cyert and DeGroot (1974), Taylor (1975), and

optimal amount of information collection and the optimal investment project are derived for the case of normal distributions as a function of the parameters of the model. It is shown in Section II that the length of time devoted to information collection increases when the variance of the prior distribution of the expected rate of return increases. The implications for the demand for liquid assets are discussed as well. Section III shows that the main result of the paper derived in Section II manages to survive with a different distribution function of expected returns and a different parameterization of the gains achieved by making a correct investment choice. Some concluding comments follow in Section IV.

I. A Model of Investment Behavior in Which the Firm Collects Information prior to Deciding on an Investment Project

Consider a firm which can invest a given amount of resources in any one of a large number of investment projects. The return, r, on any investment project, d, is stochastic and depends on the value of a parameter, W, whose exact value is usually unknown to the firm when it decides which project to undertake. However, the firm has a prior distribution on the parameter W and can learn about its likely magnitude by observing the realizations, over time, of a certain random variable, x, whose distribution depends on the parameter W.

The rate of return r may have any stochastic distribution with expected value $y(W, d)$. This expected value depends in turn on the true value of the parameter W as well as on the project d, in the following manner:

$$y(W, d) = aW - b \mid W - d \mid , a > 0, b > 0. \tag{1}$$

Note that investment projects are indexed by the set of numbers which constitute the domain of the prior distribution function of W.

The firm is risk neutral. It is therefore interested only in the expected value of the rate of return. However, even that expected value is not known with certainty, because W is an unknown parameter. Using risk neutrality again, it follows that when the firm makes an investment choice it selects the project, d^*, which maximizes the expected value of y over the (currently believed in) distribution of W.

Townsend (1978). For a selective survey of recent developments in the application of Bayesian analysis to market equilibrium under uncertainty, see Prescott and Townsend (1980).

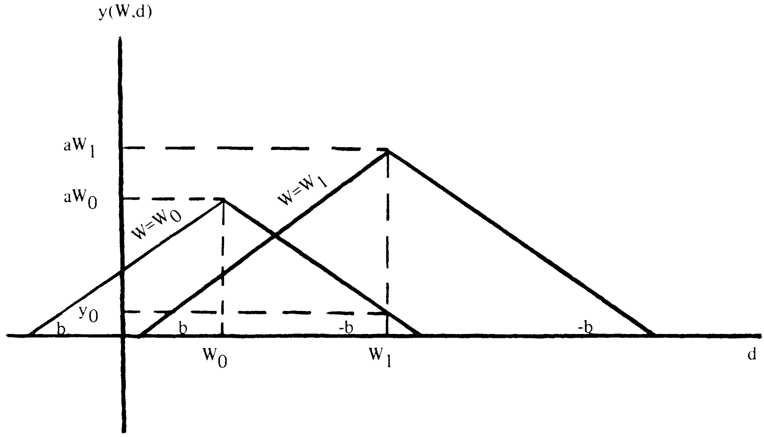

FIG. 1

That is, d^* is the investment project for which

$$\max_{d} \underset{W}{E}\, y(W, d) \tag{2}$$

is achieved.

The intuitive interpretation of the expected value in equation (1) is as follows: Expected return from project d is influenced by two elements. The first, aW, depends only on the true state of nature W. The second depends on the extent to which investment d is suited to the state of nature W and suggests that for any given value of $W = W_0$ there is an optimal investment decision which is $d = W_0$. Furthermore, as the project d deviates either up or down (as measured by $W - d$) from the optimal project, the expectation of the rate of return decreases linearly below its optimal value. This is illustrated in figure 1. As can be seen from the figure, when $W = W_0$ the optimal investment is the one indexed by W_0. Similarly, when $W = W_1$ the optimal investment is the one indexed by W_1. The maximum value of the expected value of the rate of return is higher for W_1 than for W_0 ($aW_1 > aW_0$). But this is beyond the control of the firm and depends on what W happens to be. As a matter of fact, if the firm is too optimistic and chooses project W_1 when the true value of the parameter is W_0, it will realize the expected return y_0 which is lower than aW_0.[3] Hence the firm may increase the expected return for high values of W by choosing high values of d, at the risk of obtaining low and suboptimal

[3] In more precise terms, this means the project indexed by W_1, which also happens to be the optimal project for the case $W = W_1$.

returns if W is actually low. For a risk-neutral firm, the balancing of these considerations is achieved through the maximization of the objective function in (2).

However, it is not necessary that the firm make a decision immediately. It may increase its knowledge about the parameter W, and thus increase the expected return in (2) by observing the realizations of a random variable x whose distribution is

$$x \sim N(W, p), \tag{3}$$

where W is the mean of x and p its precision.[4] By postponing the decision and observing realizations of the variable x, the firm may make a better investment decision and increase the expected value in (2). Observations on x are made through time. Assume that one observation is generated by the economy each period and denote the observation generated in period i by x_i. The observation x_i may be taken to reflect any macro- or microinformation deemed relevant by the firm for determining the relative profitability of different investment projects. It may include information about markets, competitors, existing or contemplated tax laws, and various other aspects of government behavior like macro and regulatory policies and production. More precisely, I shall assume that the firm has at its disposition a parametrically given mapping from each bit of information to values of the variable x. But this information becomes available at a cost which reflects the cost of collecting and evaluating the information *as well as the cost* of postponing the decision.[5] It is assumed that this is a fixed cost, c, per observation or per period.[6]

When the need to invest is first contemplated, the firm has some notion (based on the information available to it at that time) about the distribution of W. This notion will be formalized by assuming that, before any observations on x are made, the firm has a prior distribution on W which is normal with mean μ and precision τ. That is,

$$W \sim N(\mu, \tau). \tag{4}$$

When it decides to wait n periods and observe n values of x before it decides which investment to make, the firm bases its decision on the posterior distribution of W which incorporates both the prior beliefs

[4] The precision is the reciprocal of the variance.

[5] The cost of postponement may involve not only the loss involved in starting a profitable investment project later but also the risk that its profitability will be impaired in the meantime by the entry of competitors into similar projects.

[6] This cost is measured in units of expected return.

in (4) as well as the observations $x_1, \ldots, x_n$ obtained by waiting and incurring the necessary costs. The posterior distribution is given by[7]

$$W \sim N\left(\frac{\tau\mu + np\bar{x}}{\tau + np}, \tau + np\right), \tag{5}$$

where

$$\bar{x} = \left(\sum_{i=1}^{n} x_i\right) / n.$$

The optimal number of information-gathering periods before an investment decision is made can now be derived by noting that the firm chooses n so as to maximize the expected value in (2) (based on the posterior distribution of W) net of the costs of information collection which are nc. That is,

$$\max_n \,[\max_d \underset{W,n}{E}\, y(W, d) - nc], \tag{6}$$

where the n under the expectation operator designates the fact that it is computed using the posterior distribution of W after n periods have passed.

Substituting (1) into (2),

$$\max_d \underset{W}{E}\; y(W, d) = a \underset{W}{E}\; W + b \max_d \,(- \underset{W}{E} \mid W - d \mid), \tag{2a}$$

from which it follows that the expected value of return will be maximized if and only if $\underset{W}{E} \mid W - d \mid$ is minimized. According to DeGroot (1970, theorem 1, p. 232), this last expression is minimized when d equals the median of the distribution of W. Since W has a normal distribution, its median is equal to its mean. Hence, for a given distribution of W, the optimal investment strategy is $d^* = \underset{W,n}{E}\, W$. From (5) it also follows that the optimal investment after n periods (denoted d_n^*) is $d_n^* = \underset{W,n}{E}\, W$. The minimized value of $\underset{W,n}{E} \mid W - d \mid$ is given by[8]

$$\min_d \underset{W,n}{E} \mid W - D \mid = \left[\frac{2}{\pi(\tau + np)}\right]^{1/2} = \max_d \,(-\underset{W,n}{E} \mid W - d \mid). \tag{7}$$

Using (5), substituting (7) into (2a) and (2a) into (6), equation (6) becomes

$$\max_n \underset{W,n}{E}\; y \equiv \left\{a \,\frac{\tau\mu - np\bar{x}}{\tau + np} - b\left[\frac{2}{\pi(\tau + np)}\right]^{1/2} - nc\right\}. \tag{6a}$$

[7] This is a direct consequence of theorem 1 in DeGroot (1970, p. 167).

[8] The proof can be found in ibid., pp. 232–33, and is reproduced in my notation in the Appendix.

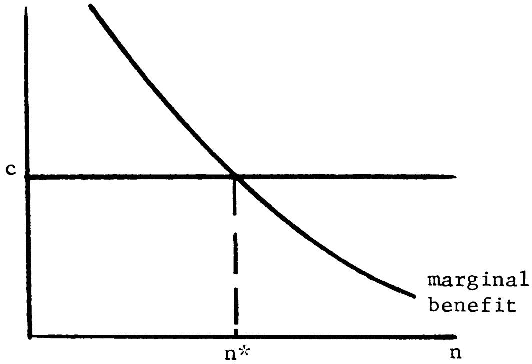

FIG. 2

If the firm must decide in advance how many periods it will wait, before making a decision, it must evaluate the probable value of $\bar{x}$ with the information available to it in period zero before any values of x have been observed. Since this information includes the prior distribution in (4), the best estimate, as of period zero, of $\bar{x}$ is the prior mean μ. In that case the first term on the right-hand side of (6a) becomes $a\mu$, which does not depend on n, and the maximization problem in (6a) becomes[9]

$$\max_n \underset{n}{E}\, y = \left(a\mu - \left\{b\left[\frac{2}{\pi(\tau + np)}\right]^{1/2} + nc\right\}\right). \tag{6b}$$

The first- and second-order conditions for the maximization of (6b) are[10]

$$\left(\frac{2}{\pi}\right)^{1/2} \frac{bp}{2(\tau + np)^{3/2}} - c = 0 \tag{8}$$

and

$$-\left(\frac{2}{\pi}\right)^{1/2} \frac{3}{4} \frac{bp^2}{(\tau + np)^{5/2}} < 0, \tag{9}$$

respectively. The first term on the left-hand side of (8) measures the positive marginal contribution of an increase in n to expected return. The second term, c, measures the marginal cost of such an increase. As can be seen from (9), the marginal benefit of an additional observation decreases monotonically. Hence it will pay the firm to increase n up to the point at which the marginal benefit equals the marginal cost of an additional observation. This is illustrated graphically in figure 2.

[9] The subscript W under the expectation operator is deleted for simplicity.
[10] Assuming an interior maximum exists.

Suppose alternatively that the firm decides on the number of observation-gathering periods sequentially. That is, after the observation of period j has come through, it evaluates anew whether to continue waiting for information or to make a decision immediately. Let μ_j be the posterior mean of W after j periods. In period j the best guess about the mean μ_{j+1} after the jth observation has come through is still μ_j. Hence the value of μ_j is irrelevant for deciding whether to wait or to choose an investment project immediately. The only consideration will again be whether the marginal benefit in figure 2 is larger or smaller than the marginal cost of information. Hence the optimal number of observations is still n^*.

II. The Effect of Increased Uncertainty on Investment Decisions and the Demand for Liquid Assets

Solving for n^* from (8),

$$n^* = \frac{b^{2/3}}{(2\pi p c^2)^{1/3}} - \frac{\tau}{p}. \tag{10}$$

As we just saw, this will be the optimal number of periods that the firm will wait before making a decision—both when it decides in advance how many periods to wait as well as when it is free to evaluate anew after each period whether to terminate waiting and make an investment decision or to wait for the next period's information.[11]

Suppose now that some external events increase the uncertainty about the true value of the parameter W. That is, the precision τ in the prior distribution of W decreases. It is immediately apparent from (10) that this will cause an increase in n^*. This leads to the central implication of this paper, which is summarized in what follows.

Proposition 1

Even under risk neutrality, an increase in the variance of the relevant stochastic variable decreases the quantity of current investment.

It is noteworthy that this is not necessarily a permanent decrease. That is, an increase in uncertainty concerning W may cause only a postponement and not a cancellation of investment plans. However, if many potential investors perceive increased uncertainty simultaneously, this postponement may cause an investment slump and a retardation in the rate of growth of the economy. This is compounded

[11] This is not true for any distribution. It holds for any distribution like the normal for which some indices of dispersion depend only on the number of observations taken and not on the values of those observations. For more details, see DeGroot (1970, pp. 284–85 and theorem 1 in particular).

by the fact that, if τ is very small, the expected value of the rate of return in (6b) may be so low that, even after gathering the optimal amount of information, the firm may find it unprofitable to make any investment.[12] In such a case, it will not even bother to collect the necessary information and will drop permanently the set of investments considered.

Intuitively, when the precision τ decreases (uncertainty about W increases), it becomes more difficult for the firm to locate the right type of investment. The chances increase that it will make the wrong investment whatever it may decide currently. As a result, it becomes relatively more profitable to collect more information before reaching a decision. Therefore, investment decisions will be postponed in order to sharpen the precision of the forecast for the parameter W. In more extreme cases, an increase in τ may depress expected profits so much that the whole string of projects will be dropped.

This suggests that even under risk neutrality in the Von Neumann–Morgenstern sense more uncertainty is detrimental to investment. Periods of political instability usually have a negative impact on investments. The model developed here suggests a possible reason: Investors sit on the sidelines waiting to see how things will develop. In terms of the model, they find it more profitable to observe how matters evolve, and decide only later which of the irreversible projects to undertake.

The model also has interesting implications for the demand for liquid assets in periods of increased uncertainty. Since irreversible investment projects of the kind considered here are postponed or canceled altogether in such periods, the demand for readily reversible liquid investment increases. Potential investors do not want to commit themselves to any particular project for a period of time. As a result, their demand for liquid assets like short-term Treasury bills and time deposits increases. Such a phenomenon was actually observed during the period of accelerated inflation which followed the 1973–74 oil embargo.[13] Contrary to conventional economic wisdom, which predicts that in periods of higher inflation (and inflationary expectations)

[12] This will be the case if $\underset{n}{E}\, y$ in (6b) is negative or, more generally, if it is lower than the cost of capital to the firm.

[13] The sum total of time and savings deposits at banking and nonbanking thrift institutions continued to increase through 1973 and 1974. The rate of growth was slightly lower than in subsequent years (10.6 percent in 1974 and 11.5 percent in 1975, compared with a number somewhere between 12 percent and 13 percent for 1976 and 1977) (U.S. Federal Reserve, July 1975 and September 1978). Without the increase in demand for liquid assets caused by the increased uncertainties in the economy, this financial aggregate would probably have decreased or increased at a much lower rate because of the sharp drop in real rates of interest on time deposits—which actually became negative.

the demand for fixed-interest time deposits should decrease, the quantity of time deposits increased. This is explainable in terms of the negative effect of increased uncertainty, during that period, on the tendency to make irreversible decisions. The argument here was developed in terms of a firm. However, a similar argument may be applied to a consumer who considers making some long-term commitment like buying a house, a car, or some other consumer durable.[14] His demand for liquid assets will also increase, at least temporarily.

It is useful to contrast the mechanism through which increased uncertainty increases the demand for liquid assets here with the mechanism through which it increases the demand for money in Tobin's (1958) now classic article. Tobin shows, within the context of a two-asset model (money and a consol), that an increase in the variance of return on the consol increases the demand for money, provided the individual is risk averse. I show that, even if individuals are risk neutral, an increase in uncertainty will increase their demand for liquid assets while they wait longer in order to increase their information about the true state of the economy.

An interesting implication of (10) is that a decrease in the informational content of the observations which takes the form of a decrease in the precision p has in general an ambiguous effect on n^*. This can be understood intuitively as follows: On the one hand, a decrease in precision makes it less profitable to wait for information, since the informational content of each observation is smaller. On the other hand, it now takes more time to achieve the same level of information as before. The ultimate effect on the number of waiting periods therefore depends on the relative strength of those two effects. The larger the loss that is caused by a wrong decision as measured by the size of b, the more likely it is that the second effect will dominate.

III. Another Example

An important question is, How general is the result that a decrease in τ leads to an increase in the time spent on information gathering

[14] It is noteworthy that the demand for consumer durables which increased steadily from 1970 to 1973 actually decreased by 7.6 percent between 1973 and 1974 and did not change at all between 1974 and 1975. (By contrast, the sum total of other consumption expenditures increased slightly during each of those 2 years.) A similar picture emerges with respect to fixed investment spending, which decreased by 7.9 percent between 1973 and 1974 and by another 13.7 percent between 1974 and 1975 before resuming an upward course (U.S. Department of Commerce July 1977, p. 18). At least part of those decreases is explainable in terms of the increased uncertainties caused by the oil embargo. In addition, some evidence presented in Wachtel (1977) suggests that increased uncertainty reduces households' borrowings, thus increasing excess demand for liquid assets.

before an investment decision is reached? More precisely, does it hold for other distributions of W and x and for other parameterizations of the losses in expected return caused by deviations of actual from optimal investment projects? I do not believe this question can be answered in general within the Bayesian framework used here.[15] However, it may be of some interest to note that the same result manages to survive in at least another class of cases. This is illustrated briefly below by introducing the following alterations in the model of Section I.

a) The rate of return r still has a stochastic distribution with expected value $y(W, d)$. However, its particular form is now

$$y(W, d) = aW - b(W - d)^2, a > 0, b > 0, \tag{1a}$$

instead of equation (1). The difference is that the loss in expected return increases with the square of the deviation of the actual from the optimal project instead of being a linear function of this deviation.

b) Instead of being distributed normally, the observations x have a Poisson distribution with mean W. That is, (3) is replaced by

$$x \sim P(W). \tag{3a}$$

c) Instead of being normal, as in (4), the prior distribution of W is

$$W \sim \text{gamma with parameters } \alpha \text{ and } \beta. \tag{4a}$$

The other elements of the problem remain essentially the same. For a given sample of observations $x_1, \ldots, x_n$, the decision d_n^* which maximizes the expected value of $y(W, d)$ over the distribution of W is the same as the decision for which

$$\min_{d} \underset{W,n}{E} (W - d)^2 \tag{11}$$

is attained, where the expected value is over the posterior distribution of W after n observations on x have been secured.[16] It is demonstrated in DeGroot (1970, p. 229) that the minimized value of the expression in (11) is

$$\frac{\alpha}{\beta(\beta + n)}. \tag{11a}$$

If the firm chooses n so as to maximize the expected value of return net of costs of observation, the problem in (6a) becomes

$$\max_{n} \left[a\mu_n - b\frac{\alpha}{\beta(\beta + n)} - nc\right]. \tag{6c}$$

[15] For one thing, conjugate distributions are known only for some subsets of the set of all distributions. See DeGroot (1970, chap. 9).

[16] This posterior distribution is also gamma with parameters $\alpha + \Sigma_{i=1}^{n} x_i$ and $\beta + n$ (see DeGroot [1970], p. 164, theorem 1).

If the firm has to choose n before any observation is taken, $\mu_n = (\alpha/\beta)$ for any n,[17] and the first- and second-order conditions for the maximization of (6c) become

$$\frac{b\alpha}{\beta(\beta + n)^2} - c = 0 \tag{12a}$$

and

$$-\frac{2b\alpha}{\beta(\beta + n)^3} < 0, \tag{12b}$$

respectively. The first and second terms on the left-hand side of (12a) are, respectively, the marginal benefit and cost of an additional observation as seen from the vantage point of period zero. Intuitively, (12a) and (12b) imply (as was the case with fig. 2) that the number of waiting periods should be extended up to the point at which the marginal benefit and the marginal cost are equal. Suppose, alternatively, that in each period the firm may reconsider whether to continue waiting or to make an immediate investment decision. In particular, suppose that it has to decide that after n periods, when the posterior mean of W is μ_n. Since from the vantage point of period n this mean is not expected to change between periods n and $n + 1$, the firm will continue waiting if and only if the left-hand side of (12a) is positive and will make a decision when it first becomes zero or negative. It follows that in this case too there will be no difference between the optimal number of waiting periods, n^*, with and without sequential decision making. Solving for n^* from (12a),

$$n^* = \left(\frac{b\alpha}{c\beta}\right)^{1/2} - \beta = \beta\left[\left(\frac{b}{c\beta}\right)^{1/2} \sigma_W - 1\right] \tag{13}$$

where σ_W is the standard error of the prior distribution of W. It can be seen from (13) that an increase in σ_W, whether caused by an increase in α or a decrease in β, causes an increase in n^*.[18] That is, we find again that the higher the uncertainty about the location of W as measured by the prior variance of W, the longer will the economic agent wait before finally making a decision that is not easily reversed.

IV. Concluding Comments

This paper has illustrated that, even when investors are risk neutral, increased uncertainty deters economic activity by making it more

[17] From the vantage point of period zero, before any observations on x become available, the expected value of W for any stage of the sampling process is the same as the prior mean of W, which is α/β.

[18] Note that the variance of W is α/β^2.

profitable to wait until more information becomes available. This implies that ambiguous and sometimes contradictory statements by government officials with respect to planned economic policies will have adverse effects on investments as well as on the acquisition of consumer durables. On the other hand, stable economic policies will be growth promoting because they shorten the period of information gathering before investment decisions are reached.

However, it is in the nature of the democratic process that before new policies are adopted they are often debated openly or semi-openly within the government as well as outside it. To the extent that those contemplated policies are relevant for the choice of investment projects, this debate causes, by increasing uncertainty, a postponement of investment and a retardation in growth. There is, therefore, a trade-off between the democratic discussion of issues and the number of investment projects undertaken within a period of time.

Appendix

Derivation of Equation (7)

From (5), $d_n^* = \underset{W,n}{E} W = (\tau\mu + np\bar{x})/(\tau + np)$. Substituting this last expression into $\underset{W,n}{E} |W - d|$, we obtain

$$\underset{W,n}{E} |W - d| = \underset{W,n}{E} |Y|, \tag{A1}$$

where $Y \equiv W - (\tau\mu + np\bar{x})/(\tau + np)$ and is therefore a normal random variable with mean zero and (from [5]) precision $\tau + np$. According to DeGroot (1970, equation 7, p. 233), the expected value of the absolute value of Y is given by

$$\underset{W,n}{E} |Y| = \left(\frac{2}{\pi p_Y}\right)^{1/2}, \tag{A2}$$

where p_Y is the precision of Y. Equation (7) in the text follows by applying (A2) to the explicit form of Y above.

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