NO NEWS CAN BE GOOD NEWS: IRREVERSIBLE INVESTMENT AND STRATEGIC INTERACTION

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Abstract: This paper introduces an aggregate demand externality into a model of irreversible investment. The central result of the paper establishes the mechanism in which increases in uncertainty can lead to sub-optimal recessions. These inefficient outcomes occur even if agents are allowed to coordinate to the best possible equilibria. The result is driven by the external effects of firms' investment decisions. The "no news can be good news" section draws an analogy between increases in uncertainty and improvements in the quality of information, with the conclusion that an improvement in information may also lead to a sub-optimal recession. **Keywords**: *Irreversible investment, aggregate demand externalities. JEL D92, E22, E32.*

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1. INTRODUCTION

Can an increase in uncertainty cause large sub-optimal fluctuations in output? Can more precise information about future economic variables make risk-neutral firms worse off? These are the two main questions that this paper attempts to answer.

Our analysis takes place in an uncertain environment where firms must choose a level of irreversible investment. The literature on this problem is well developed, with the fairly robust result that either an increase in uncertainty or an increase in the quality of information to arrive in the future will cause firms to become more prudent and postpone some investment.[1] In this literature, abstracting from the effects of imperfect competition, the decreased investment by the firms is efficient; even when there are many such firms, a social planner would not choose a different level of investment. Our extension is to add a pecuniary externality so that the profits of one firm add to the demand for the products of all firms.[2] The addition of this externality in the irreversible investment problem yields both sub-optimal business cycles and the striking result that an improvement in the quality of information to arrive in the future can cause all firms to be made worse off.[3]

The first feature of the model is the existence of sub-optimal movements in output when uncertainty varies in the economy. Casual evidence indicates that periods of recession are related with increases in uncertainty about the future.[4] Firms wonder when the recession will end or how big the 'recovery' will be. The answer to these questions about the future will affect their optimal policies. This connection has been analyzed in many models. Only recently, however, have models linked specific market imperfections with investment and uncertainty.[5] In addition, recent empirical evidence emphasizing the effect of uncertainty on business cycles has renewed the need for further theoretical work.[6] One relatively unexplored connection has been through irreversible investment. Bernanke (1983a) gives an example where the slow arrival of information about a single

[1] A sample of the papers in this area most related to our work is Arrow and Fischer (1974), Henry (1974), Cukierman (1980), Bernanke (1983a), Pindyck (1988), Bertola (1989), Dixit (1989), Dixit (1992) and Leahy (1993). For a caveat to the results presented in these papers see Caballero (1991), and for a good survey of this literature see Pindyck (1991).

[2] This idea is taken from the literature on aggregate demand externalities in macroeconomics. Good references include Diamond (1982), Shleifer (1986), Blanchard and Kiyotaki (1987), Cooper and John (1988), Shleifer and Vishny (1988) and Murphy, Shleifer and Vishny (1989).

[3] In a different framework, Caplin and Leahy (1993) present a model with costly investment and information externalities.

[4] See Romer(1990).

[5] See Stiglitz and Weiss (1981), Bernanke (1983b) and Mankiw (1986).

[6] For example, Bernanke (1983b) and Romer (1990).

uncertain event can, by itself, cause irreversible investment to move in cycles. However, the cycles induced in his model are 'optimal'. The model presented here shows how the cycles induced by the increased uncertainty are in general *sub-optimal.* The reasoning is intuitive. Suppose a firm is planning to undertake a specific irreversible investment project. Before making the investment, there is an increase in uncertainty in the economy which increases the variance of profits for the investment project. We can think of this uncertainty in many different ways: input costs, demand, technological, but what is important is that the project be irreversible and postponable. Then, the firm may decide to postpone investment until some (or all) of the uncertainty is resolved. When the firm postpones its investment today, it causes a reduction in demand which adversely affects other firms. Although its cautiousness is privately optimal, it has negative external effects. The net effect will be to reduce overall output, which can be socially sub-optimal. This is the main mechanism which we use throughout the paper.

The second feature of the model illustrates another interpretation for the mechanism described above. Instead of an increase in uncertainty, we can think of an uncertain project which *cannot* be postponed long enough for the uncertainty to be resolved. That is, the 'window of opportunity' of the project does not include the resolution of the uncertain event. A risk-neutral firm facing such a project would elect to undertake the project if its expected present value was greater than its cost. Now, consider an improvement in information which occurs within the 'window'. The firm will receive some signal about the resolution of uncertainty and this signal will be revealed before the final investment decision needs to be made. Now, the mechanism works exactly as above: a firm may decide to be cautious and wait for information, investing only if 'good news' is received. This caution, while privately optimal, has adverse affects on other firms which may lead to a net negative effect for the whole economy. We call this the "no news can be good news" result.

The paper is organized as follows: in section 2 we present the setup and solution of the model under certainty. This section repeats the analysis of earlier work. In section 3 we introduce uncertainty and develop the first result about sub-optimal business cycles, making explicit the mechanism explained above. Section 4 studies imperfect information, and we give our example of "no news can be good news". Section 5 concludes and an Appendix gives proofs of the propositions stated in the text.

2. CERTAINTY

2.1 Setup

For the purpose of examining irreversible investment in an economy with aggregate demand externalities, we construct a model along the lines of Shleifer and Vishny (1988). The world lasts for two periods. There is a single representative consumer who inelastically supplies N units of labor in each period, owns all claims to profits in the economy, and maximizes

$$U = exp\Big\{\int_0^1 ln(x_{i1})\ di\Big\} + exp\Big\{\int_0^1 ln(x_{i2})\ di\Big\} \tag{2.1}$$

Consumption (x_{it}) is chosen along a continuum of sectors indexed by i on the unit interval. Equation (2.1) is a time- separable Cobb-Douglas utility function for a continuum of goods, where each good has the same share. This formulation implies identical within-period consumption shares across sectors and unit elastic demand for all goods. In this economy, there is no storage, so all output must be consumed in the period it is produced. Define y_{it} as the expenditure in each sector, then the budget constraint in each period is equal to

$$\int_0^1 p_{it}x_{it} = \int_0^1 y_{it} = Y_t = \Pi_t + W_t \tag{2.2}$$

where Y_t is aggregate income (expenditure), Π_t represents aggregate profits by all firms and W_t represents total wages. Since consumption shares are identical across sectors and we normalize on the unit interval, expenditure in each sector, y_{it}, will be equal to Y_t.

We use wage as the numeraire and posit that each sector possesses a competitive fringe of firms with access to CRS technology: $q_t = n_t$, where q_t and n_t represent production and labor. Thus, the competitive fringe can produce at a marginal cost of 1. Following Shleifer and Vishny (1988), we also have a single 'monopoly' firm in each sector. These monopoly firms have access to two possible technologies. The first technology is free; the firm is 'endowed' with it in the first period. This technology yields the production function

$$q_{it} = \lambda_0 n_{it} \tag{2.3}$$

where $\lambda_0 > 1$. Thus, the monopoly firm can costlessly use a CRS technology superior to the competitive fringe. We will refer to this production function as 'low' technology. Monopoly firms will also be able to improve upon this production function by paying a fixed cost. We call this production function 'high' technology. For now, we will ignore this option and solve for aggregate income and profits as if only the low technology were possible.

We assume Bertrand competition, so monopoly firms cannot set a price above 1 because they would lose all of the market to the competitive fringe. Also, since demand is unit elastic, monopoly firms have no incentive to lower their price below 1. Hence, the price in each sector is 1 and the monopoly firms capture all of the market. Since the only cost of production is labor and there is no uncertainty, profits of each (monopoly) firm using low technology are

$$\pi_{it}^{L} = q_{it} - \frac{q_{it}}{\lambda_0} = a_0 q_{it} \tag{2.4}$$

where $a_0 \equiv (\lambda_0 - 1)/\lambda_0$ and the superscript L refers to the low technology. Since supply equals demand in each sector, we can substitute $y_{it} = q_{it}$. Aggregating profits across all sectors, we can now solve for aggregate income,

$$Y_t = \int_0^1 \pi_{it}^{L} di + W_t = a_0 Y_t + W_t \quad \Rightarrow \quad Y_t = \frac{W_t}{1 - a_0} \tag{2.5}$$

Since we are using the wage as the numeraire, $W_t = N$. In future equations we will refer to this constant level of wages simply as N. Given this aggregate income we can write aggregate profits as:

$$\Pi_t = \frac{a_0 N}{1 - a_0} \tag{2.6}$$

Since there is a continuum of firms on the unit interval all using the same technology, our normalization gives that aggregate profits are the same as individual profits. For convenience, we will drop the i subscripts in all future equations.

Next, we allow firms to pay a cost and adopt the 'high' technology. They can adopt this technology in either of the two periods, however, once adopted, the decision cannot be reversed. This new technology improves the production function to $y_t = \lambda_1 n_t$, with $\lambda_1 > \lambda_0$. To obtain this technological jump, the firm must pay a cost in each remaining period[7] equal to $\overline{I}$. This cost represents the fixed cost of purchasing intermediate goods for production. For simplicity, we assume that an equal amount of intermediate goods must be purchased from each sector. A firm paying this cost adds to the demand of all firms by an amount equal to $\overline{I}$. Thus, to an individual firm, this cost will directly reduce profits, however, for the entire economy, this loss in profits will be offset by

[7] The usual assumption is that a fixed cost is paid once when the project is undertaken. We assume that a cost is paid each period the technology is used only for analytical convenience.

an increase in demand. Total demand in the economy, which must be met by gross production, now includes consumption demand and demand for intermediate goods. We use the term 'invest' to refer to a firm which adopts the high technology.

Firms which decide to invest will have one-period profits equal to

$$\pi_t^H = q_t - \frac{q_t}{\lambda_1} - \overline{I} = a_1 q_t - \overline{I} \tag{2.7}$$

where $a_1 \equiv (\lambda_1 - 1)/\lambda_1$ and the superscript H refers to the high technology. Firms which elect not to invest have one-period profits as in (2.4). The introduction of the demand for intermediate goods, driven by the fixed cost, drives a wedge between income, Y_t, and gross production, Q_t. Gross production, Q_t, must be equal to *total* supply and *total* demand in the economy. This will encompass demand from both the representative consumer (for consumption) and firms (for intermediate goods). Note again that our normalization gives that gross production, Q_t, is equal to production in each sector, q_t. Aggregate income, Y_t, will always be identically equal to wages plus profits and will be the budget constraint for the representative consumer. We can also think of Y_t as net output.[8] Formally, we now have that $Q_t = Y_t + \mu_t I = \Pi_t + N + \mu_t I$, where μ_t represents the fraction of monopoly firms using the high technology at time t. Therefore, gross production is equal to

$$Q_t = \mu_t(a_1 Q_t - \overline{I}) + (1-\mu_t)a_0 Q_t + N + \mu_t \overline{I} \quad \Rightarrow \quad Q_t = \frac{N}{1 - \mu_t a_1 - (1-\mu_t)a_0} \tag{2.8}$$

Notice that $\overline{I}$ does not appear in the expression for gross production. Q_t is a function of only N and μ_t; all that matters is the total amount of labor and the sectors in which it is employed. We can now solve (2.4), (2.7) and (2.8) for profits in terms of only N and $\overline{I}$. Firms which invest have one- period profits equal to

$$\pi_t^H = \frac{a_1 N}{1 - \mu_t a_1 - (1-\mu_t)a_0} - \overline{I} \tag{2.9}$$

Firms which elect not to invest have one-period profits equal to

$$\pi_t^L = \frac{a_0 N}{1 - \mu_t a_1 - (1-\mu_t)a_0} \tag{2.10}$$

The nature of the externality can be studied by examining equations (2.9) and (2.10). In both equations, only the denominator is a function of μ_t. We interpret the inverse

[8] Throughout the text we refer to Q_t as output or gross production. Some readers may be confused by this, since Q_t includes a component of intermediate goods, which would not be included in an output calculation. In our context, however, the purchase of intermediate goods can be thought of as investment which depreciates after only one period. Therefore, Q_t represents gross output and Y_t represents net output.

of the denominator as the 'multiplier'. We see that when a firm decides to invest, it reduces the denominator, thus increasing the multiplier and increasing profits in both equations. Thus, there will always be a positive externality associated with investment in the high technology.

2.2 Equilibrium

In this section, we look at the equilibria in the economy. We want to investigate the conditions necessary to induce investment by all firms and also to see if this economy can experience coordination failure. The setup gives us a two-period simultaneous game of complete information. We will solve backwards and restrict ourselves to symmetric subgame-perfect Nash equilibria (SSPNE).

Second period

Consider a firm in the *second period* which did not invest in the first period. Second-period profits, if the firm invests, are

$$\pi_2^H = \frac{a_1 N}{1 - \mu_2 a_1 - (1 - \mu_2) a_0} - \overline{I} \tag{2.11}$$

Second-period profits if the firm forgoes the investment are

$$\pi_2^L = \frac{a_0 N}{1 - \mu_2 a_1 - (1 - \mu_2) a_0} \tag{2.12}$$

Firms take as given the decisions of other firms, represented by μ_2, the fraction of firms which use the high technology in the second period. Note that this fraction includes firms which invested in the first period (since investment is irreversible) and firms which invest concurrently in the second period. Therefore, the condition for investing is, invest if

$$\pi_2^H - \pi_2^L = \frac{(a_1 - a_0) N}{1 - \mu_2 a_1 - (1 - \mu_2) a_0} - \overline{I} > 0 \tag{2.13}$$

Since this condition is an increasing function of μ_2, there is a possibility of multiple equilibria. Why is this so? Since a_1 is greater than a_0, the numerator in the first term of equation (2.13) is strictly positive. This represents the extra production made by the high technology. This amount is greater when a higher fraction of other firms invest, because the higher 'average' technology implies a higher aggregate gross production for the whole economy. This entire first term is a strictly increasing function of μ_2. The second term in (2.13) is constant and equal to $\overline{I}$. When more firms invest, the first term rises and the entire expression increases. We could have that (2.13) holds for

$\mu_2 = 1$ but does not hold for $\mu_2 = 0$, so that both 'everyone invests' and 'everyone forgoes' are equilibria in the second period. This multiplicity is a very simple kind of coordination failure; if everyone invests then demand is high and investing is optimal, if everyone forgoes then demand is low and foregoing is optimal. It occurs because an individual firm, when considering its own profits, looks upon $\overline{I}$ as a *cost* which reduces profits, but for the entire economy, this cost is *exactly* offset by an increase in demand for intermediate goods. Thus, Q, aggregate demand and output, is unaffected by $\overline{I}$, the level of the fixed cost. This drives a wedge between privately optimal and socially optimal decisions and gives rise to a possible case of coordination failure.

For the remainder of the paper, we want to restrict attention to projects which are always profitable in the certain world even if no other firm has invested. That is, we assume

ASSUMPTION A :

$$\frac{(a_1 - a_0)N}{1 - a_0} - \overline{I} > 0$$

Note that Assumption A implies that (2.13) holds for all $\mu_2 \in [0,1]$. Under this assumption, the only equilibrium in the second period has all firms investing and $\mu_2 = 1$.

First period

The firm has two options in the first period: first, it can invest in the high technology and thus commit itself to this technology in the second period or, second, it can use the low technology in the first period and retain the option of investing in the second period. The solution to the second-period subgame indicated that firms which retain the option of investing will *always* choose to exercise this option and invest in the second period. This is assured by Assumption A. Therefore, second-period profits are the same regardless of the first-period decision and the first-period problem must consider only the difference in first-period profits. Thus, the decision rule is, invest if

$$\pi_1^H - \pi_1^L = \frac{(a_1 - a_0)N}{1 - \mu_1 a_1 - (1 - \mu_1)a_0} - \overline{I} > 0 \tag{2.14}$$

By Assumption A, (2.14) holds for all $\mu_1 \in [0,1]$. Therefore, the only SSPNE for the whole game has all firms investing in the first period. Thus, the equilibrium of this economy is very simple under certainty; Assumption A ensures that no coordination failure can occur. The equilibria become more interesting in the next section when we introduce uncertainty about $\overline{I}$ in the second period and investigate its effects upon first-period investment.

3. UNCERTAINTY

3.1 Setup

We begin with the model presented in the previous section, where firms are planning to undertake a profitable irreversible investment project with fixed costs I to be paid by purchasing intermediate inputs in each period. We are now interested in the following question: if there is an increase in uncertainty about profits tomorrow, what happens to investment, output and welfare today? Our model provides a simple framework in which to analyze this question. We can think of an increase in uncertainty in many ways. For the purpose of exposition, it is simplest to model uncertainty entering through the fixed cost, I. At time 1, the fixed cost is equal to $\overline{I}$. At time 2, after the investment decision has been made but before production, fixed cost rises or falls by an amount equal to ϵ. Each of these outcomes occurs with probability $\frac{1}{2}$. We denote the 'good' realization as I_g, where $I_g = \overline{I} - \epsilon$ and the 'bad' realization as I_b, where $I_b = \overline{I} + \epsilon$. Firms are told the *level* of ϵ at time 0.[9] In addition, before the investment decision in period 2, they receive a public signal about how the uncertainty will be resolved. We will call this signal Z and denote Z_g as the 'good' signal and Z_b and the 'bad' signal. In this section we will assume that the signal is perfectly informative in the sense that the true state is fully revealed; e.g., after observing Z_g firms know that the future level of the fixed cost is I_g with probability one. The complete timing of the game is as follows:

Learn the value of ϵ

$$\overbrace{\textit{Invest} \qquad\qquad\qquad \textit{Wait}}^{\text{First-period decision}}$$

First-period production

Receive signal about future state

Second-period decision

$$\overbrace{\textit{Invest} \quad \textit{Forgo}}^{\text{if waited}} \quad \overbrace{\textit{No Decision}}^{\text{if invested}}$$

True cost revealed

Second-period production

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[9] This section uses a very simple type of uncertainty, however, this is only for purpose of exposition. For the mechanism in this paper to work, all that is needed is that increases in uncertainty reduce investment. The negative sign of the uncertainty-investment relationship is a main focus of the irreversible investment literature. We refer the reader to the references cited in the introduction.

3.2 Equilibrium

We can now study the equilibria of this game for given levels of ϵ. Then, by varying ϵ, we can study the effect of changing uncertainty.[10] The introduction of uncertainty will give us two results: first, for some values of ϵ there will be a multiplicity of pareto-rankable equilibria even when Assumption A is satisfied. Despite Assumption A, the structure of the game changes and multiplicity becomes possible. Second, for a range of ϵ there will be a unique equilibrium that is pareto inefficient. This type of equilibrium cannot exist under certainty even if Assumption A does not hold.

As before, we solve backwards, beginning in the second period.

Second Period

Recall that the perfectly informative public signal is received before the investment decision in the second period. Therefore, from the perspective of firms after the signal has been received, firms face a one-period simultaneous game of complete information. Consider the problem of the firm which waited in the first period. There are two possible signals:

(*i*) $Z = Z_g$, *'Good News'*

The firm's decision is to invest if the value of investing is positive, that is, if

$$\pi_2^H - \pi_2^L = \frac{(a_1 - a_0)N}{1 - \mu_2 a_1 - (1 - \mu_2)a_0} - (\bar{I} - \epsilon) > 0 \tag{3.1}$$

By Assumption A, (3.1) holds for all μ_2 when $\epsilon = 0$. Since ϵ enters (3.1) positively, (3.1) always holds. Thus, if the good signal is received, investing is the only equilibrium and $\mu_2 = 1$.

(*ii*) $Z = Z_b$, *'Bad News'*

The firm should invest if

$$\pi_2^H - \pi_2^L = \frac{(a_1 - a_0)N}{1 - \mu_2 a_1 - (1 - \mu_2)a_0} - (\bar{I} + \epsilon) > 0 \tag{3.2}$$

Assumption A tells us that this condition holds for all μ_2 if $\epsilon = 0$. Also, we can see that (3.2) is decreasing in ϵ. Since we are restricting ourselves to SSPNE, we can graph (3.2) against ϵ for both $\mu_2 = 0$ and $\mu_2 = 1$ to solve for the possible equilibria.

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[10] Note that for any single game, the level of ϵ is *fixed*. When we vary ϵ, we are considering different games.

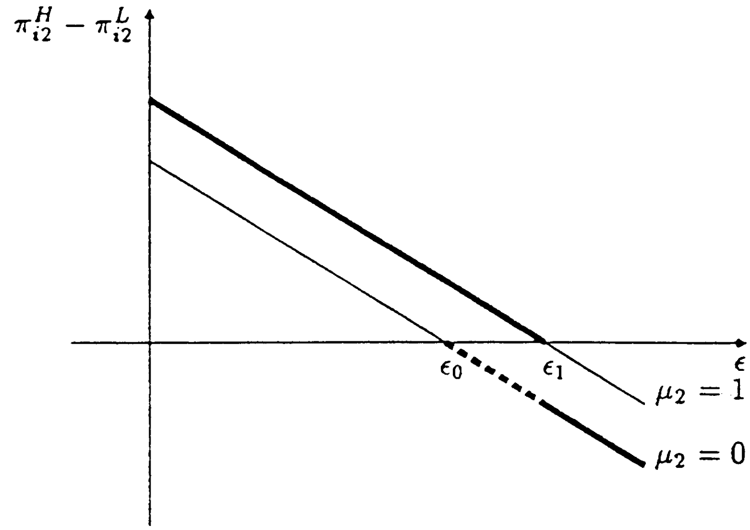

Figure 1

The shaded lines of Figure 1 represent the possible equilibria in the second period. For now we will assume that when there are two possible equilibria, the firms always coordinate to the highest possible equilibrium. The dashed line in Figure 1 represents an equilibrium *not* selected by our criterion. We will show later that relaxing this assumption does not affect our results. Under this equilibrium selection rule, for all levels of $\epsilon \leq \epsilon_1$, the equilibrium is that all firms invest in the second period after receiving the bad signal, i.e., $\mu_2 = 1$. They receive 'bad news', but not bad enough to turn the initially profitable project unprofitable. For $\epsilon > \epsilon_1$, the project is unprofitable for all firms even if all firms invest, therefore the only equilibrium has all firms foregoing the project, i.e., $\mu_2 = 0$.

First Period

Given the solution to the second-period subgames, firms can solve for their optimal policies in the first period and for the whole game. Recall that the level of ϵ is revealed before the first-period decision. Therefore, we have two possibilities:

(i) $\epsilon \leq \epsilon_1$

For these values of ϵ, all firms will always invest in the second period, regardless of the signal. Therefore, firms must only decide whether to invest in the first period or in the second period. The only difference between these two policies is whether or not the firm is invested in the high technology *during* the first period. They will invest if

$$\pi_1^H - \pi_1^L = \frac{(a_1 - a_0)N}{1 - \mu_1 a_1 - (1 - \mu_1)a_0} - \overline{I} > 0 \tag{3.3}$$

which is implied by Assumption A. The intuition behind this result is straightforward:

since investing is always profitable, firms will never postpone it. The unique SSPNE has all firms investing in the first period.

(*ii*) $\epsilon > \epsilon_1$

In this case a firm which invests in the first period runs the risk of being trapped in an unprofitable investment in the second period. A firm which decides to wait until the second period, when information is better, forgoes strictly positive profits (from Assumption A) from investing in the first period. The firm's optimal decision must come from balancing these two factors; so the firm decides to wait only when the expected value of its loss is greater than the foregone first-period profits. The expected present value of profits for a firm which invests in the first period is

$$V^H(\mu_1) = \left(\frac{a_1 N}{1-\mu_1 a_1-(1-\mu_1)a_0} - \overline{I}\right) + \frac{1}{2}\left(\frac{a_1 N}{1-a_1} - I_g\right)$$

$$+\frac{1}{2}\left(\frac{a_1 N}{1-\mu_1 a_1-(1-\mu_1)a_0} - I_b\right) \tag{3.4}$$

Where $V^H(\mu_1)$ represents the expected present value of a firm which invests in the high technology in the first period and μ_1 is the fraction of sectors investing. From the perspective of an individual firm, μ_1 is taken as given. Note that, in the second period, μ_2 is replaced by its equilibrium values. The first term is the certain profit in the first period. Although $\overline{I}$ is known, this term is still a function of μ_1. The second term is the expected value of profit earned in the second period if the good state occurs. In the good state, we know that all firms will have received good news, and all will have invested. Therefore, we replace μ_2 with 1. The third term is the expected value of profit earned if the bad state occurs. In the bad state, all firms will have received bad news, and no new firms will invest. Of course, all firms which invested in the first period must maintain the high technology. Therefore, we replace μ_2 with μ_1. Since firm i invested in the first period, it has no second-period decision, but merely waits to see the realization of the state and of the value of μ_2. For convenience, we restrict our attention to cases where firms cannot make negative profits. That is, we restrict parameter values so that even in the bad state firms have positive profits.[11] This total must be compared with the present value of profits for a firm which waits in the first period.

$$V^L(\mu_1) = \left(\frac{a_0 N}{1-\mu_1 a_1-(1-\mu_1)a_0} - \overline{I}\right) + \frac{1}{2}\left(\frac{a_1 N}{1-a_1} - I_g\right)$$

[11] This assumption does not drive any of the results. We make it in order to avoid problems of bankruptcy.

$$+\frac{1}{2}\left(\frac{a_0 N}{1-\mu_1 a_1-(1-\mu_1)a_0}\right) \tag{3.5}$$

Where $V^L(\mu_1)$ represents the present value of the firm which 'waits' and keeps the low technology for the first period and μ_1 is the fraction of sectors investing. The terms in (3.5) have analogous interpretations as in (3.4). In this case, however, the firm has a second-period decision, which is reflected by the different technology used in the second and third terms of (3.5). Thus, the decision rule for the firm is: invest in the first period if

$$V^H(\mu_1)-V^L(\mu_1)=\frac{(a_1-a_0)N}{1-\mu_1 a_1-(1-\mu_1)a_0}-\overline{I}$$

$$+\frac{1}{2}\left(\frac{(a_1-a_0)N}{1-\mu_1 a_1-(1-\mu_1)a_0}-I_b\right)>0 \tag{3.6}$$

We see here an illustration of the "bad news" principle from option theory. (3.6) can be interpreted as saying "invest when the present value is greater than the cost plus the option value". The option value is affected only through the bad news, or I_b. I_g does *not* appear in equation (3.6). The SSPNE of the game will occur when (3.6) holds for $\mu_1 = 1$ and when (3.6) does not hold for $\mu_1 = 0$. From inspection we can see that multiple equilibria are possible. Figure 2 shows the possible equilibria graphically.

Each line in this graph represents the expected value of profits for a different investment decision with different levels of μ_1, taking second-period equilibria as given. Thus $V^H(1)$ represents the expected value of profits if a firm invests in the first period and $\mu_1 = 1$ (all other firms also invest), $V^H(0)$ if a firm invests and $\mu_1 = 0$, $V^L(1)$ if a firm waits and $\mu_1 = 1$, and $V^L(0)$ if a firm waits and $\mu_1 = 0$. Only $V^H(1)$ ('everyone invests today') and $V^L(0)$ ('everyone waits today') can be SSPNE. $V^H(1)$ is a SSPNE when $V^H(1) \geq V^L(1)$ and $V^L(0)$ is a SSPNE when $V^L(0) \geq V^H(0)$. The possible equilibria are shaded in the figure. Section 3.3 will discuss specific equilibria and their welfare properties. For now, we give a general description of the graph.

For $\epsilon < \epsilon_1$, investing is always better than not investing; even in the bad state. Thus, firms will always want to invest as early as possible; $V^H(1)$ is the highest line in the graph and the unique SSPNE.[12] At $\epsilon = \epsilon_1$, it is no longer an equilibrium in the second period for firms to invest if they receive bad news. Backing up to the first

[12] Recall that earlier in this section we stated that allowing firms to coordinate to the best possible equilibrium in the second period would not affect our results. From Figure 1, we see that second period coordination failure can only occur for a range of $\epsilon < \epsilon_1$. The only thing that could change in Figure 2 is that ϵ_2 can be less than ϵ_1. That is, the range where multiple equilibria exist can start at some point before ϵ_1.

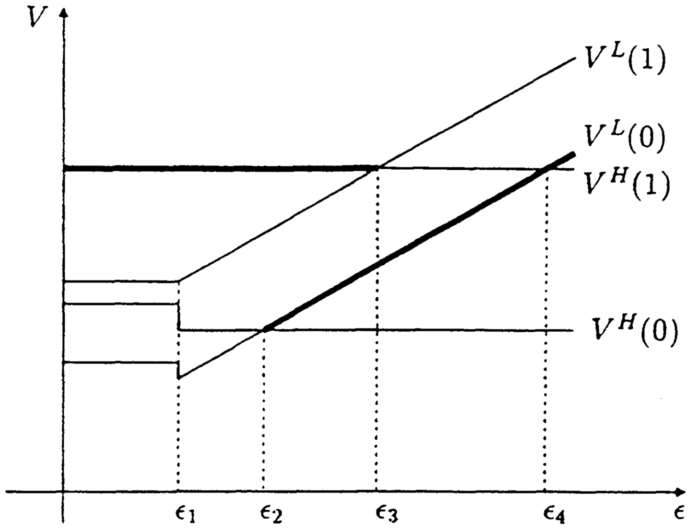

Figure 2

period, this causes a discontinuous drop in the $V^L(0)$ and $V^H(0)$ loci; since all other firms will now forego investment if they receive bad news ($\mu_1 = 0$). This causes the loss of a positive spillover. The $V^H(1)$ and $V^L(1)$ loci are unaffected because all other firms have already committed to high-technology forever ($\mu_1 = 1$). Also beginning at $\epsilon = \epsilon_1$, the $V^L(0)$ and $V^L(1)$ loci begin to slope upwards. These two are now less affected by 'bad news' than by 'good news' since they do not have to pay the cost if they don't invest. In the following section, we establish the location and importance of the specific points of intersection drawn in the figure.

3.3 Welfare

Now we turn to the welfare properties of the above equilibria. To begin, we can see that, in equilibrium, utility is exactly equal to income in every period.[13] Thus, total utility in each period is $Y_t = \Pi_t + N$. Since N is constant, we can equate total welfare with the present value of profits plus a constant. This relationship is very important: now, when we analyze welfare, we need concern ourselves only with the present value of aggregate profits. Therefore, the lines in Figure 2 represent welfare as well as profits. Note also that the consumer only cares about *expected* profit; uncertainty about profits does not matter. The next proposition establishes the existence and welfare properties for a range with multiple equilibria.

PROPOSITION 1: *There exists some $\epsilon_3 > \epsilon_2 \geq \epsilon_1$, so that in the range $\epsilon \in [\epsilon_2, \epsilon_3]$,*

[13] As demand for every good is equal to income in that period $exp\left\{\int_0^1 ln(x_{it})\ di\right\} = exp\left\{\int_0^1 ln(Y_t)\ di\right\} = Y_t$. Of course, this is only true because our market structure ensures that all prices are the same.

two equilibria exist and can be pareto-ranked.

PROOF: see appendix.

This result shows that the multiplicity of equilibria can be created and destroyed through changes in the level of uncertainty. The intuition is as follows. At $\epsilon = \epsilon_1$, firms which waited in the first period begin to forego the project entirely if they receive bad news. This causes the $V^L(0)$ and $V^L(1)$ lines to slope upwards, because as ϵ rises beyond this point, a firm which waited in the first period and then chose to invest only if they received the good news will reap the benefits of investing in the good state but reduce its exposure to the bad state. The proposition states that in the range $[\epsilon_2, \epsilon_3]$ there exists the possibility of coordination failures. There are two equilibria in this range. This is represented by both $V^H(1) > V^L(1)$ ("all firms investing") and $V^L(0) > V^H(0)$ ("all firms waiting") for this range in Figure 2. Moreover, the latter is pareto dominated by the former because $V^H(1) > V^L(0)$ when both are equilibria. If firms are unable to coordinate to the best of the two equilibria, an increase in uncertainty from some value of ϵ lower than ϵ_2 to a value between ϵ_2 and ϵ_3 will cause a decrease in welfare. This result gives a dynamic interpretation to a story told about coordination failure. Here, it is the desire to wait for uncertainty to be resolved which causes the possibility of a sub-optimal outcome. A firm which sees the possibility of, say, a war or an oil shock may believe that other firms will react by postponing investment until the outcome has been determined. Given this reaction, the firm also finds it optimal to wait. However, if all firms invested, the individual firm would find it optimal to invest as well. Even though the latter option is superior to the former from a social point of view, both are possible equilibria in the economy.

The previous result can be strengthened in the sense that a similar result can be obtained *even if we allow firms to coordinate to the best possible equilibrium.* This is captured in the next proposition.

PROPOSITION 2: *There exists some $\epsilon_4 > \epsilon_3$, so that in the range $\epsilon \in (\epsilon_3, \epsilon_4)$, there exists a unique equilibrium which is pareto inferior to the outcome a social planner could achieve.*

PROOF: see appendix.

According to Proposition 2, an increase in uncertainty from some value of ϵ lower than ϵ_3 to a value in the range (ϵ_3, ϵ_4) will imply a decrease in aggregate welfare even if firms coordinate to the best possible equilibria. The result is due to the fact that when firms decide to wait they do not take into account the external effects which their decision has on other firms. From the perspective of a social planner it is optimal not to postpone the investment decision. In the diagram this is shown by the fact that $V^H(1) > V^L(0)$ for $\epsilon \in (\epsilon_3, \epsilon_4)$. However, $V^H(1) < V^L(1)$ for this range, so the socially optimal outcome is not an equilibrium of the game.

It is helpful to think of the firms in this economy as playing several different games. For $\epsilon < \epsilon_2$, the firms play a 'pareto-optimal' game, where the only SSPNE is pareto optimal. For $\epsilon_2 < \epsilon < \epsilon_3$, the firms play a 'coordination' game, with two possible SSPNE, one of which is pareto optimal. For $\epsilon_3 < \epsilon < \epsilon_4$, the firms play a 'prisoner's-dilemma' game, with one possible SSPNE which is pareto inferior to the best possible outcome. For $\epsilon > \epsilon_4$, we are back to the 'pareto-optimal' game again. Changes in ϵ can simply be thought of as changing the nature of the game.[14]

In this section we have attempted to show that even risk-neutral firms can be adversely affected by an increase in uncertainty about future costs. Optimal responses on the part of individual firms can turn out to be socially sub-optimal. This result is interesting when contrasted with previous work on the irreversible investment problem. Several authors have found that an increase in uncertainty decreases investment; however, their results still lead to first-best final outcomes.[15] In this model, the addition of pecuniary externalities yields the result that an increase in uncertainty can lead to a second-best, pareto-inferior, reduction in investment. The key force driving this result is the desire for firms in a decentralized economy to wait for information about key variables. In trying to understand business cycles, this effect can be an important one. Note that the lower welfare we found in the above example *always* means lower gross production (output). Since gross production, Q, depends only on the allocation of labor to different sectors and does *not* depend on $\overline{I}$, any increase in uncertainty which causes investment to be postponed or foregone will reduce gross production. Although we are really concerned with welfare, we may actually only observe gross production, and the mechanism described in this section can help to explain why increases in uncertainty might make measures of production decrease.

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[14] We are grateful to Greg Mankiw for this interpretation.

[15] See survey in Pindyck (1991).

4. IMPERFECT INFORMATION

4.1 Setup

The previous section showed how changes in the level of uncertainty can have adverse affects on the economy. This section is a slightly different application of the same mechanism. The main idea is that better future information can have very similar effects to an increase in uncertainty. In fact, the relationship between these two concepts is very straightforward in our model. An individual firm facing an uncertain irreversible investment decision may choose to postpone some of its investment. Postponement occurs so the firm can wait for the resolution of uncertainty, but most projects cannot be postponed indefinitely. If the uncertainty is about some event which falls *outside* of the window for undertaking the project, then firms' have no incentive to wait. They do not wait because they cannot learn anything which would help them make a better decision. Suppose, however, that they receive some signal about the resolution of future uncertainty, and that this signal comes before they need to make their final decision. We could imagine that elections might be an important source of uncertainty, but if the elections are far off, political polls might be the only signal of future election results which falls within the window of an investment project. Similarly, firms might be concerned about a possible policy change from the government, but only postpone their project if they thought the policy change would 'leak' at an early date. More generally, any information which comes out in advance of the uncertainty resolution might induce firms to wait and, thus, cause other firms to be made worse off.

To capture these effects, we reduce the informative content of the second-period signal. Then, by varying the accuracy of this signal, we can more carefully examine the effects of different qualities of information. Consider that all firms now receive a public signal Z_g or Z_b, but these signals do not reveal the future states perfectly. Instead, we can represent the information structure as

$$\Pr(I_g|Z_g) = p \qquad \Pr(I_b|Z_g) = 1 - p$$
$$\Pr(I_g|Z_b) = 1 - p \qquad \Pr(I_b|Z_b) = p$$

therefore p represents the probability that I will be equal to I_g in the second period given that the signal received is Z_g. Before first-period decisions are made, firms are informed of ϵ, the level of uncertainty, and of p, the quality of information.[16] By

[16] Note that given the symmetry of our information structure with respect to each of the two states, the probability of getting each of the signals is $\frac{1}{2}$.

restricting ourselves to $p \in [\frac{1}{2}, 1]$, we can still speak of 'good' and 'bad' news. If $p = \frac{1}{2}$, then the signal is completely noninformative. We call this the 'no news' case. If $p = 1$, then the signal is completely informative and we have the model of the previous section. In this section we will fix some $\overline{\epsilon} \in (\epsilon_3, \overline{I}]$ and determine the effects of changing p.[17]

4.2 Equilibrium

As we did in previous sections we solve backwards and restrict to symmetric subgame perfect Nash equilibria.

Second Period

Consider the decision of a firm which waited in the first period. There are two possible signals:

(*i*) $Z = Z_g$, *'Good News'*

A risk-neutral firm should invest if the expected value of investing is positive. That is, if

$$\frac{(a_1 - a_0)N}{1 - \mu_2 a_1 - (1 - \mu_2)a_0} - \left(pI_g + (1-p)I_b\right) > 0 \tag{4.1}$$

We can rewrite (4.1) as

$$\frac{(a_1 - a_0)N}{1 - \mu_2 a_1 - (1 - \mu_2)a_0} - (\overline{I} - \epsilon^*) > 0 \tag{4.2}$$

where $\epsilon^* \equiv (2p - 1)\overline{\epsilon}$. This substitution establishes the link between this section and the previous one. In fact, the two problems are analogous. If $p = \frac{1}{2}$, then $\epsilon^* = 0$, and Assumption A implies that (4.2) holds for all μ_2. Since the firm does not receive useful information in the second period, it will not wait to undertake a project with a positive expected value. Then, since $p > \frac{1}{2}$, and ϵ^* is a positive function of p, (4.2) holds for all $p \in [\frac{1}{2}, 1]$.

(*ii*) $Z = Z_b$, *'Bad News'*

The relevant investment condition is

$$\frac{(a_1 - a_0)N}{1 - \mu_2 a_1 - (1 - \mu_2)a_0} - (\overline{I} + \epsilon^*) > 0 \tag{4.3}$$

[17] We restrict to values of $\epsilon > \epsilon_3$ so there is some value for p which induces firms to wait. Otherwise the problem is uninteresting. Recall that ϵ_3 is the lowest level of uncertainty for which the unique equilibrium is sub-optimal.

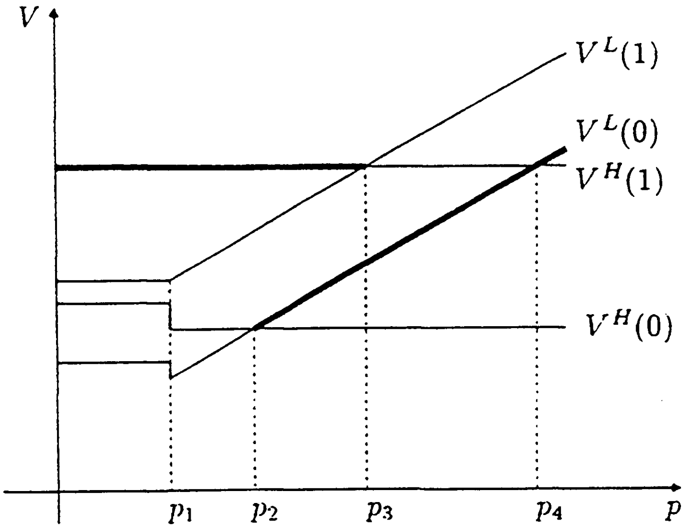

Figure 3

where once again we have $\epsilon^* \equiv (2p-1)\bar{\epsilon}$. Because we can make this substitution, this problem is equivalent to the 'bad news' second-period problem of the previous section. We can refer to Figure 1 for the possible equilibria. Under our second-period equilibrium selection rule, when $\epsilon^* \leq \epsilon_1$, the chosen equilibrium has all firms investing after receiving bad news. The bad news is not bad enough to make the project have negative expected value. If $\epsilon^* > \epsilon_1$, then all firms which wait in the first period will choose to forgo the project if they receive bad news. The critical value for p is $p_1 = (\epsilon_1 + \bar{\epsilon})/2\bar{\epsilon}$.

First Period

Since the equivalence of the problem is established, we will not write first-period equations again. The equilibria are shown graphically in Figure 3.

Once again, we graph the four loci $V^H(1), V^H(0), V^L(1), V^L(0)$. The only possible SSPNE of the game occur when $V^H(1) > V^L(1)$ or when $V^L(0) > V^H(0)$. We have shaded the equilibria in the diagram. The only difference between Figure 3 and Figure 2 of the previous section is the use of p instead of ϵ on the x-axis. The analogy between the two sections is illustrated by these identical diagrams. We can model an improvement in the quality of information the same way as an *increase* in a uncertainty. They are equivalent in the sense that they both have the same effect on the optimal policies of firms; both induce firms to 'wait and see'. This result is intuitive. The higher is p, the more information that a firm expects to receive *before* it needs to make a final decision about the project. While a firm might wait for the results of a very reliable political poll, it is less likely to wait for the results of an unreliable poll. This model is set up so that the two have a linear relationship. Thus, the equilibria shaded in Figure 2, with critical values p_1, p_2, p_3, and p_4, have the same properties as the equilibria of Section 3. Proposition 3 in the next section states this result formally.

4.3 Welfare

PROPOSITION 3 : *(No News Can Be Good News) There exists some p_1, p_2, p_3, p_4; $\frac{1}{2} < p_1 < p_2 < p_3 < p_4 \leq 1$, such that*

i) for $p \in [p_2, p_3]$, two equilibria exist and can be pareto-ranked.

ii) for $p \in (p_3, p_4)$, there exists an unique equilibrium which is pareto inferior to an outcome a social planner could achieve.

PROOF: see appendix.

Proposition 3 is the imperfect information analogue of Propositions 1 and 2 of the previous section. These results attempt to show that the optimal response of deciding to wait for information about future events can have large social costs; large enough to offset whatever gains are made from waiting. The benefit of better information is that firms make fewer mistakes. Suboptimal equilibria can arise if the costs (not internalized by individual firms) exceed the benefits (internalized by individual firms). The waiting can be induced either through an increase in uncertainty about the future or through an increase in the quality of information which will arrive at some future date. We usually think of information as being a good thing for a Bayesian decision maker, however, if information arrives through time, decision makers, through optimal 'caution', may destroy an otherwise superior equilibrium. Thus, *ex ante*, they would prefer not to have that information arrive at all. In this specific case, if $p = \frac{1}{2}$ then firms have 'no news' and decide to invest. However, if $p \in (p_3, p_4)$, then firms all decide to 'wait and see', thus reducing first-period output and overall welfare. The increase in the quality of future information has exactly the same effect as an increase in future uncertainty. In this case, no news is good news.

What we have attempted to do in Sections 3 and 4 is to provide a framework to analyze the consequences that 'cautious' behavior by firms facing irreversible investment has on the fluctuations in an economy. We can also interpret the implications of these results for output and for the 'bunching' of investments. First, consider that output, which may be all that we actually observe, is measured in this economy by the quantity Q. Since Q is an increasing function of μ, any event which causes firms to be more cautious will unambiguously reduce output. In addition, we would also expect investment decisions to be bunched around times of important public signals. In fact, casual empiricism suggests that government announcements of important leading indicators are often followed by busy economic activity, especially in financial markets. (Since the purchase and sale of securities have some transactions costs, they are only partially reversible.) While there are no obvious policy implications to be drawn from this observation, it can perhaps help us to understand why bunching occurs and why it might have adverse affects.

5 CONCLUSION

This paper has attempted to illustrate a new avenue for the effects of uncertainty and information on the macroeconomy. In Section 2 we set up a simple general equilibrium model with monopoly firms facing finite-window irreversible investments. The results of this section showed how the addition of pecuniary aggregate demand externalities can cause multiple equilibria. Section 3 added uncertainty about costs to this framework and found that changes in the uncertainty can, by itself, create and destroy multiple equilibria. In addition, even risk-neutral firms can be made worse off by an increase in uncertainty which causes a prisoner's dilemma-like drop in output. Section 4 reduced the informative content of the public signal received by firms. This enabled us to show the equivalence between uncertainty and *future* information and to achieve the paradoxical result that, sometimes, no news is good news.

The model presented in this paper is very special. We do believe, however, that the effects described here are an important component of real world experience. To illustrate our intuition, we have a parable.

Suppose you are a firm contemplating a discrete irreversible investment. You have a one year window to make the investment, and it is now, say, August 1. After studying the problem carefully, you determine that the optimal policy is to invest immediately. The next morning you hear on the radio that a large dispute has erupted within OPEC; one member nation has invaded another. Expert commentators believe that one of two things will happen: either OPEC will break up and oil prices will fall or a large-scale war will erupt in the Middle East and oil prices will rise. They assign a 50 percent probability to each. The deadline for the invading country to withdraw is January 15 of the following year. After learning this, you reoptimize and discover that it would now be better to wait until after the deadline to make your decision. Then, you will invest if oil prices fall and not invest if oil prices rise. Your prudence is privately optimal, but it has unintended effects on other firms. Because you chose to wait, you adversely affected the profits of other firms. In addition, many of these firms have also chosen to postpone investment, and this has adverse effects on your own profits.

Suppose now you are considering yet another irreversible investment, but this one has only a five month window. Your analysis on August 1 indicated that you should invest immediately. Since you are risk-neutral, and the new uncertainty will not be resolved until after your 'window' is closed, your investment plans for this project do not change. However, later that same afternoon, the United Nations announces a peace conference on November 15. You believe that information revealed at the conference will provide a signal about the result on January 15. You estimate the precision of this signal to be, say, 75 percent. After hearing this, you reoptimize and discover that it is now better to wait until after the conference to make your decision; investing only if the signal is good. Once again, your decision has adverse affects on other firms, and their decisions have adverse affects on you.

This is the type of story that we are trying to tell with this paper. The model presented here makes no claims to be universal, or to be a complete description of the causes of business-cycles. Our aim is to illustrate the interaction that uncertainty and information can have with investment in a world with pecuniary externalities between firms.The approach taken by us suggests several extensions. First, the presentation here forces a static structure onto a dynamic problem. In future work, we hope to make the investment problem a dynamic one; with an evolving technology and information structure. Second, the introduction of risk aversion on the part of firms would make the model more realistic and enable a more careful analysis of the welfare effects of increasing uncertainty. Third, in future work we plan to link the actions of firms with the signal received in the economy. Certainly a decision to wait should send a signal to other firms about the future path of technology and output. We believe that the results from this paper will carry through to these more complex models, and perhaps allow for a framework rich enough for some quantitative results.

6. APPENDIX

Proof of Proposition 1.

First we show that 'all firms waiting' is an equilibrium for values of ϵ greater than some $\epsilon_2 \geq \epsilon_1$. We should look at the difference $V^H(0) - V^L(0)$; when this difference is negative, there will be a SSPNE in which all firms wait in the first period.

For $\epsilon \leq \epsilon_1$ this difference is constant and equal to

$$V^H(0) - V^L(0) = \frac{(a_1 - a_0)N}{1 - a_0} - \overline{I} \qquad (A.1)$$

which is positive by Assumption A.

For $\epsilon > \epsilon_1$ this difference is a decreasing function of ϵ equal to

$$V^H(0) - V^L(0) = \left(\frac{(a_1 - a_0)N}{1 - a_0} - \overline{I}\right) + \frac{1}{2}\left(\frac{(a_1 - a_0)N}{1 - a_0} - (\overline{I} + \epsilon)\right) \qquad (A.2)$$

Notice that as soon as ϵ becomes greater that ϵ_1, the value of investing 'jumps' down from $(A.1)$ to $(A.2)$. The amount of this jump can be calculated by looking at the second term of $(A.2)$ evaluated at ϵ_1. This term is negative by definition of ϵ_1. The jump is due to the loss of the positive spillover from projects which become privately unprofitable at $\epsilon = \epsilon_1$. Since $(A.2)$ is decreasing in ϵ, there will some value for $\epsilon \geq \epsilon_1$, say ϵ_2, such that the above expression becomes negative (if the jump at ϵ_1 is large enough then it might be the case that $\epsilon_2 = \epsilon_1$). Thus, 'all firms wait' is a SSPNE for $\epsilon \in [\epsilon_2, \overline{I}]$.

The next step is to find the largest ϵ such that 'all firms investing' is an equilibrium. We need to show first that the difference $V^H(1) - V^L(1)$ is positive at $\epsilon \leq \epsilon_1$ and then that it is decreasing in ϵ.

For $\epsilon \leq \epsilon_1$ this difference is constant and equal to

$$V^H(1) - V^L(1) = \frac{(a_1 - a_0)N}{1 - a_1} - \overline{I} \qquad (A.3)$$

which is always positive by Assumption A.

For $\epsilon > \epsilon_1$ this difference is

$$V^H(1) - V^L(1) = \left(\frac{(a_1 - a_0)N}{1 - a_1} - \overline{I}\right) + \frac{1}{2}\left(\frac{(a_1 - a_0)N}{1 - a_1} - (\overline{I} + \epsilon)\right) \qquad (A.4)$$

Notice that the second term of $(A.4)$ is zero for $\epsilon = \epsilon_1$. This is by definition of ϵ_1. Then, as ϵ rises above ϵ_1, $(A.4)$ falls. Thus, $(A.4)$ is equivalent to $(A.3)$ at $\epsilon = \epsilon_1$, and does not jump as in the previous example. This is because all firms are already committed to the investment forever, and no positive spillover is lost. Note also that $(A.4)$ is decreasing in ϵ. Let ϵ_3 be the value such that $V^H(1) - V^L(1) = 0$. Then 'all firms invest' is a SSPNE for $\epsilon \in [0, \epsilon_3]$.

Next we must show that these two ranges intersect for some values of ϵ; that is, we must show that $\epsilon_2 < \epsilon_3$. We accomplish this by examination of $(A.2)$ and $(A.4)$. The only difference between these two expressions is in the denominators. Since $a_1 > a_0$, $(A.4)$ is always greater than $(A.2)$ and therefore it will be zero only for a higher ϵ. Therefore $\epsilon_3 > \epsilon_2$. This proves the first claim of the proposition, that there exists a range for ϵ, $[\epsilon_2, \epsilon_3]$, such that two equilibria exist.

The second claim of the proposition is that the two equilibria can be pareto-ranked. We need to show that $V^H(1) > V^L(0)$ for all this range or, in other words, that the equilibrium where all firms invest implies a higher level of profits than the one in which all firms wait. This difference is equal to

$$V^H(1) - V^L(0) = \left(\frac{a_1 N}{1 - a_1} - \frac{a_0 N}{1 - a_0} - \overline{I}\right) + \frac{1}{2}\left(\frac{a_1 N}{1 - a_1} - \frac{a_0 N}{1 - a_0} - (\overline{I} + \epsilon)\right) \qquad (A.5)$$

This expression is decreasing in ϵ and, moreover, it becomes negative for a value of ϵ higher than ϵ_3. This means that for all values of $\epsilon < \epsilon_3$, $(A.5)$ will be positive. This establishes the second part of Proposition 1: for all values of ϵ for which there exist two equilibria, the SSPNE in which all firms invest pareto-dominates the SSPNE in which all firms wait.

PROOF OF PROPOSITION 2.

Proposition 2 claims that the equilibrium of the model in the range (ϵ_3, ϵ_4) is unique and inefficient. The uniqueness result follows directly from the previous proof. Recall that $V^H(1)$, 'all firms invest', is a SSPNE for $\epsilon \in [0, \epsilon_3]$ and $V^L(0)$, 'all firms wait', is a SSPNE for $\epsilon \in [\epsilon_2, \overline{I}]$. Therefore, for all $\epsilon > \epsilon_3$, $V^L(0)$ is a unique SSPNE. To establish the inefficiency of the unique SSPNE, we return again to equation $(A.5)$ of the previous proof. We showed earlier that this expression is positive for ϵ_3, thus establishing that the unique SSPNE is inefficient at this point. Next we note that this expression is decreasing in ϵ. Define ϵ_4 as the value of ϵ for which $(A.5)$ is equal to zero. Therefore, in the range (ϵ_3, ϵ_4), $V^H(1) > V^L(0)$, and the unique SSPNE is inefficient.

PROOF OF PROPOSITION 3.

Proposition 3 is proven by establishing the equivalence between uncertainty, measured by ϵ, and the quality of information that will be received in the future, measured by p. This equivalence is shown in equations (4.1) and (4.2). Now, all equilibrium conditions for the case of imperfect information, $p < 1$, can be rewritten in terms of the conditions for the case of a perfectly informative signal, $p = 1$, by doing the transformation $\epsilon^* \equiv (2p-1)\bar{\epsilon}$, where $\bar{\epsilon}$ has been fixed at a level higher than ϵ_3. Given this transformation we can find, according to Propositions 1 and 2, values $\epsilon_1, \epsilon_2, \epsilon_3$ and ϵ_4 for ϵ^* that satisfy the properties proven above. We can then solve for the values p_1, p_2, p_3, p_4 which define the equilibria for the 'imperfect information' case and will satisfy the properties stated in Proposition 3.

7. BIBLIOGRAPHY

ARROW, KENNETH AND ANTHONY FISCHER. "Environmental Preservation, Uncertainty, and Irreversibility", *Quarterly Journal of Economics*, May 1974.

BERNANKE, BEN S. "Irreversibility, Uncertainty, and Cyclical Investment", *Quarterly Journal of Economics*, February 1983a.

————————, "Nonmonetary Effects of the Financial Crisis in the Propagation of the Great Depression", *American Economic Review*, June 1983b.

BERTOLA, GUISEPPE. "Irreversible Investment", Unpublished Manuscript, Princeton University, 1989.

BLANCHARD, OLIVIER J. AND NOBUHIRO KIYOTAKI. "Monopolistic Competition and the Effects of Aggregate Demand", *American Economic Review*, September 1987.

CABALLERO, RICARDO J. "On the Sign of the Investment- Uncertainty Relationship", *American Economic Review*, March 1991.

CAPLIN, ANDREW AND JOHN LEAHY. "Sectoral Shocks, Learning and Aggregate Fluctuations", *Review of Economic Studies*, October 1993.

COOPER, RUSSELL W. AND ANDREW JOHN. "Coordinating Coordination Failures in a Keynesian Model", *Quarterly Journal of Economics*, August 1988.

CUKIERMAN, ALEX. "The Effects of Uncertainty on Investment under Risk Neutrality with Endogenous Information", *Journal of Political Economy*, June 1980.

DIAMOND, PETER. "Aggregate Demand Management in Search Equilibrium", *Journal of Political Economy*, October 1982.

DIXIT, AVINASH. "Entry and Exit Decisions under Uncertainty", *Journal of Political Economy*, June 1989.

————————. "Investment and Hysteresis", *Journal of Economic Perspectives*, Winter 1992

HENRY, CLAUDE. "Investment Decisions under Uncertainty: the 'Irreversibility Effect'", *American Economic Review*, December 1974.

LEAHY, JOHN., "Investment in Competitive Equilibrium: the Optimality of Myopic Behavior", *Quarterly Journal of Economics*, November 1993.

MANKIW, N.GREGORY. "The Allocation of Credit and Financial Collapse", *Quarterly Journal of Economics*, August 1986.

MURPHY, KEVIN M., ANDREI SHLEIFER AND ROBERT W. VISHNY. "Industrialization and the Big Push", *Journal of Political Economy*, October 1989.

PINDYCK, ROBERT S. "Irreversible Investment, Capacity Choice, and the Value of the Firm", *American Economic Review*, December 1988.

————————. "Irreversibility, Uncertainty, and Investment", *Journal of Economic Literature*, September 1991.

ROMER, CHRISTINE. "The Great Crash and the Onset of the Depression", *Quarterly Journal of Economics*, August 1990.

SHLEIFER, ANDREI. "Implementation Cycles", *Journal of Political Economy*, December 1986.

——————, AND ROBERT W. VISHNY., "The Efficiency of Investment in the Presence of Aggregate Demand Spillovers", *Journal of Political Economy*, December 1988.

STIGLITZ, JOSEPH E. AND ANDREW WEISS. "Credit Rationing in Markets with Imperfect Information", *American Economic Review*, June 1981.