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Investment, Uncertainty, and Irreversibility in Ghana

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Abstract

Panel data on Ghanaian manufacturing firms are used to test predictions from models of irreversible investment under uncertainty. Information on the entrepreneur's subjective probability distribution over future demand for the firm's products is used to construct the expected variance of demand, which is used as a measure of uncertainty. Empirical results support the prediction that firms wait to invest until the marginal revenue product of capital reaches a firm-specific hurdle level. Moreover, higher uncertainty raises the hurdle level that triggers investment, and uncertainty has a negative effect on investment levels that is greater for firms with more irreversible investment.

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SUMMARY

Private investment in Ghana has been extremely weak during 1992–96, averaging 4.1 percent of GDP. One contributing factor appears to be the uncertainties arising from persistently high inflation and the uneven nature of policy implementation in both macroeconomic and structural policies.

This paper analyzes the impact of uncertainty on the investment behavior of Ghanaian manufacturing firms by using panel data for the years 1994–95. Recent literature has focused on how uncertainty affects investment when capital expenditures are largely sunk or irreversible. The empirical analysis presented here explores the extent to which the investment-uncertainty relationship is affected by the degree of reversibility of a firm's capital expenditures. Manufacturing investment in Ghana is not completely irreversible, since markets exist for used capital goods. There is substantial variation across firms, both in involvement in the used capital goods market and in secondhand market discounts, indicating that firms face differing degrees of reversibility of their investment expenditures.

A firm-level measure of the expected variance in demand for the firm's products is constructed using survey data on the entrepreneur's subjective probability distribution over future demand. The advantage of this measure is that it is conditioned on the entrepreneur's information set. Therefore, no assumptions are made regarding which variables are in the entrepreneur's information set, as is necessary when observed trends in particular variables are used as uncertainty proxies.

The empirical results provide support for the prediction that firms wait to invest until the profitability of projects reaches a firm-specific hurdle level. Higher uncertainty raises the hurdle level that triggers investment, although there is only weak evidence that this effect is stronger for firms with more irreversible investment. Results indicate that uncertainty has a negative effect on investment levels and that the effect is significantly greater for firms with more irreversible investment.

I. Introduction

This paper analyzes the impact of uncertainty on the investment behavior of Ghanaian manufacturing firms using a panel data set for the years 1994–95. Recent literature has focused on how uncertainty affects investment when capital expenditures are largely sunk or irreversible. The empirical analysis presented here explores the extent to which the investment-uncertainty relationship is affected by the degree of reversibility of a firm's capital expenditures, an issue that has not received much attention in the few existing firm-level studies of investment under uncertainty. The objectives are to test some of the theory's predictions as well as to explore questions on which theory is not conclusive. In addition, the paper will test whether a firm-level uncertainty variable that measures the entrepreneur's perceptions of risk is significant in the model estimation.

Following the introduction of Ghana's Economic Recovery Program (ERP) in 1983, private investment was initially very weak, but improved to more consistent, although still modest levels during 1987–91, the second phase of the ERP. In 1992 private investment slumped in the wake of large slippages in fiscal and monetary policy. From 1993–95 the government had limited success in regaining control over public finances and restraining monetary growth. Private investment remained low in the face of uncertainties arising from persistently high inflation and the uneven nature of policy implementation in both macroeconomic and structural policies. For the period 1992–96, private investment averaged only 4.1 percent of GDP.

In analyzing private investment during 1983–91, a recent IMF occasional paper concludes that "the most important impact of polices on private investment behavior was through their effect on macroeconomic instability and uncertainty" (Hadjmichael *et.al*, 1996, p. 29). It is noted, however, that aspects of this uncertainty could not be captured adequately in the estimated aggregate investment equations. It is likely that the same conclusion would apply to the most recent period.

During 1994–95, an ongoing survey of a panel of Ghanaian manufacturing firms included questions to gather data on entrepreneur's perceptions of uncertainty in the context of a volatile macroeconomic environment. Firm owners reported their probability distribution over future demand for the firm's products. A variable representing the firm's uncertainty about future demand conditions is constructed from this probability distribution and used in the investment regressions.

In firm-level theoretical models of investment under uncertainty, investment depends on the expected value and conditional variance of the demand for the firm's product (or expected value and conditional variance of factor costs, capital costs or technology). The important point is that these variables are all subjective projections, conditional on information available to the firm. Empirical work on investment under uncertainty has largely focused on aggregate investment and employed uncertainty proxies such as the standard deviation of past changes in inflation, real exchanges rates, or the parallel premium (Ferderer, 1993; Huizinga, 1993). A few studies using firm or sector level data have also used these types of uncertainty proxies

(Ghosal and Loungani, 1996). For these to be valid proxies, however, one must assume that firms forecast future volatility based on past trends and that the aggregate volatility trends are part of their information set. In contrast, the uncertainty variable employed in this paper directly measures the entrepreneur's perceptions of risk, conditional on his/her information.

A number of recent models have characterized optimal investment behavior when investment is irreversible and demand follows a geometric Brownian motion. The firm allows the marginal revenue product of capital (MRPK) to fluctuate stochastically, and invests only when the MRPK hits an optimally derived trigger. It can be shown that the trigger is increasing in the standard deviation of the demand process. In this sense, greater uncertainty leads to less willingness to invest. However, average investment during a given period depends on how soon and how often the MRPK reaches the trigger. Although greater uncertainty raises the trigger, a more volatile process may hit the trigger more often. Thus the net effect on short run investment depends on the balance of these factors.

There is less consensus on the effect of irreversibility and uncertainty on long run average investment and the capital stock. Abel and Eberly (1995) show that since firms with irreversible investment face a higher user cost of capital, investment and the capital stock tend to be lower. However, when the irreversibility constraint binds the firm would like to sell capital but cannot, and this "hangover" effect tends to increase the average capital stock. In their model uncertainty adds to the ambiguity: whether uncertainty implies a lower capital stock under irreversibility depends on the parameters.

In light of these theoretical predictions and non-definitive results, I will consider three issues. First, can a method be developed to test the central prediction that investment is triggered only when the MRPK reaches a particular hurdle level. Second, does uncertainty increase the investment trigger, and is this effect larger for firms with more irreversible investment. Third, does uncertainty have a greater negative effect on the investment rate of firms with more irreversible investment.

Since the investment trigger is not observable, an indirect approach is used for testing the prediction that firms do not invest when the MRPK is below the trigger, and invest only when it reaches the trigger. In the data set, approximately half of the firms do not invest in a given year. Following from the theory, this information is exploited by assuming that when a firm invests, the measured MRPK is equal to the trigger. Using this a first-stage proxy for the trigger, I explore its determinants, including the effects of uncertainty variables. Using the coefficients from this estimation, a predicted trigger can be calculated for both investing and non-investing firms. A probit model is then used to test a model in which the firm invests when the MRPK is equal (or greater than) the predicted trigger value.

The paper is organized as follows: Section II provides background on macroeconomic and manufacturing sector developments in Ghana, Section III describes the characteristics of the sample, Section IV discusses literature and a particular model; Section V presents the econometric model; Section VI defines the variables; Section VII analyzes the results and Section VIII concludes.

II. Background

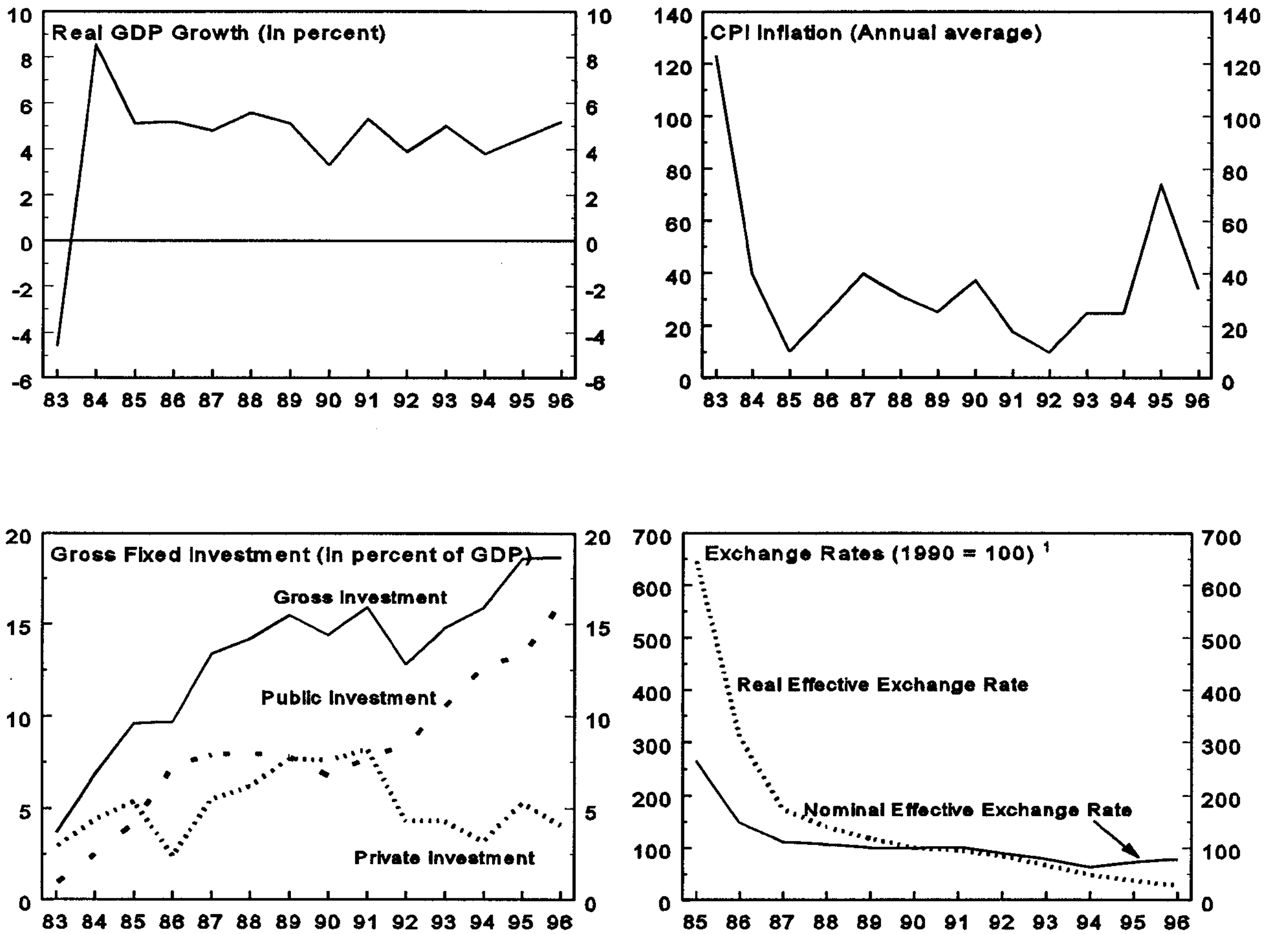
Since the beginning of the ERP in 1983, uncertainty has dampened private investment, although the nature of the uncertainties have changed over the period. During 1983–86 the credibility and sustainability of the reform was still in question. Uncertainty over whether the large changes in relative prices would persist may also have led investors to adopt a "wait-and-see" attitude. Although private investment rates improved during 1987–91, the very gradual nature of many of the structural and institutional reforms may have also led to some waiting behavior. Following the 1992 fiscal shock there has been a marked downturn in economic performance. The uncertainty created by macroeconomic instability, high inflation and some slippage in policy implementation have created an environment of uncertainty for investors.

One of the main determinants of the fiscal shock of 1992 was a large increase in wages and wage-related benefits for public sector employees, as the government faced a series of strikes in the run-up to multiparty elections. The resulting fiscal deficit was financed mainly by the banking system and inflationary pressures intensified. Private investment fell precipitously, to 4.3 percent of GDP. In 1993–94, the government had limited success in curbing the budget deficit. Although large divestiture receipts were used to finance the deficit in 1994, money supply growth accelerated due to increased central bank financing of the Ghana National Oil Corporation (GNPC). Broad money growth was well above targets in 1995, due to both an increasing overdraft at the central bank for the GNPC resulting from delays in the financial restructuring program, and larger than expected foreign exchange inflows. Some success in the fight against inflation was registered by mid-year, and the seasonally adjusted annualized inflation rate peaked at 120 percent in July. The annual average inflation rate for 1995 was 74 percent (Figure 1).

The weakness in private investment since 1992 has been an important policy concern, as reversing the poor investment record was considered key to the strategy for achieving the accelerated growth objectives. Although data on the sectoral composition of aggregate investment do not exist, it is likely that manufacturing investment is extremely low, given the stagnant growth in manufacturing sector value-added.

Structural reforms that have improved the environment for manufacturing have continued through the 1990's, including corporate tax reform in 1991 and the approval of a more liberal Investment Act in 1994. Capacity utilization rates have increased from the very low levels of the mid 1980's as access to imports has improved, and manufacturing has been freed from burdensome controls and regulations. However, the manufacturing sector has also had to cope with increased competition following trade liberalization, higher costs for imported inputs and capital goods as the real exchange rate depreciated, periods of high real interest rates and limited new lending from the troubled financial sector.

Figure 1
Ghana: Selected Economic Indicators
1983-96, Unless Otherwise Indicated



Source: International Monetary Fund, exchange rates from *Information Notice System*.
[1]Calculated using the offical exchange rate for the Cedi. An increase in the index indicates an appreciation.

The outcome has been that following an initial boom in the growth rate of manufacturing value-added during 1984–87, growth rates fell to an average of 3.1 percent during 1988–91, and have remained low at 2.7 percent during the period 1992–95. There have been large changes in the sectoral composition of GDP since the ERP: agriculture's share of GDP has fallen significantly and service's share has increased. The share of manufacturing in GDP, however, has remained essentially the same.

III. The Sample

The Ghana survey has collected panel data for the five years 1991–95 from a sample of approximately 200 manufacturing firms.[2] This paper, however, will use the 1994–95 data since the question on the subjective probability distribution of future demand was included only in the most recent surveys. The sample includes firms in eight sectors: bakeries, food manufacturing, furniture, garments, machinery, metalworking, wood products, and textiles. The size distribution ranges from micro firms with less than five workers to large scale enterprises with over 100 employees. The firms are located in four cities: Accra, Cape Coast, Kumasi and Takoradi. Some firms are wholly owned by private sector Ghanaians, others have some state or foreign ownership. Table 1 presents the age, size, sector and ownership distribution of the 1994–5 sample.

Table 2 shows that the fraction of firms undertaking any investment is low: 52 percent of firms invested in plant and equipment, 48 percent did not invest at all during 1994–95. While the proportion of firms investing increased from 49 percent in 1994 to 56 percent in 1995, the proportion had previously fallen from 54 percent in 1993. Large firms have a higher propensity to invest, but have a lower investment to capital ratio than small firms. The mean ratios of investment to capital and investment to value-added have increased slightly from the 1991–93 values.

Comparative analysis on manufacturing investment in Cameroon, Ghana, Kenya and Zimbabwe over the period 1991–93 has shown that the distributions of these investment variables are highly asymmetric, indicating that medians as well as means should be examined (Bigsten *et. al*, 1997). Table 3 shows, for example, that the mean profit rate of the Ghanaian firms was 421 percent, while the median was 68 percent.[3] While in the period 1991–93 Ghana

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[2] The first three rounds of the survey were part of the Regional Programme on Enterprise Development (RPED), organized by the World Bank. Rounds 4 and 5 are part of the Ghana Manufacturing Enterprise Survey (GMES), funded by the UK government, Department for International Development.

[3] Profit rates vary widely across size classes, and the mean and median rates decrease with firm size. Bigsten *et. al*, 1997 showed that although the coefficient on profit rates is significant in investment regressions, it is much smaller than the size of the effect found in results available for other countries.

Table 1. Sample Characteristics

Size	Percent	Age in 1994	Percent	Ownership	Percent	Sector	Percent
Micro <=5 employees	13	<= 5 years	18	Some foreign ownership	19	Bakery	9
Small 6-29	44	6-10 years	14	Wholly Ghanaian owned	78	Food Manufacturing	13
Medium 30-99	23	11-19 years	33	Some state ownership	3	Furniture	21
Large >=100	20	>= 20 years	35			Garment	20
						Machines	4
						Metal	21
						Textile	2
						Wood	10
Average	67		17				

Source: Author's calculations using Ghana Manufacturing Enterprise Survey data (GMES).

Table 2. Investment Variables

Year	Proportion of Firms Investing	Investment/ Value-Added if Firms Invest	Investment/ Capital if Firms Invest	Investment/ Value-Added	Investment/ Capital
1994	0.49	0.212	0.318	0.105	0.141
1995	0.56	0.299	0.375	0.166	0.208
By Firm Size					
Small (1-29 employees)	0.41	0.183	0.44	0.08	0.172
Medium (30-99 employees)	0.60	0.360	0.37	0.22	0.214
Large (>= 100 employees)	0.75	0.49	0.16	0.37	0.113
Average, all firms 1994-5	0.52	0.314	0.348	0.164	0.171
Average for Cameroon, Ghana, Kenya, Zimbabwe 1991-3[1/]	0.535	0.211	0.239	0.113	0.128

Sources: Author's calculations using Ghana Manufacturing Enterprise Survey data (GMES); and [1/] from Bigsten *et. al*, (1997).

Table 3. Distribution of Key Variables

$I/K_{(-1)}$	M25	0	
	M50	0	
	M75	0.109	
	Mean	0.171	N = 321
I/V	M25	0	
	M50	0.004	
	M75	0.084	
	Mean	0.164	N = 340
C/K	M25	0.126	
	M50	0.680	
	M75	3.663	
	Mean	4.217	N = 333
$\Delta V/K_{(-1)}$	M25	-0.758	
	M50	-0.065	
	M75	0.425	
	Mean	-0.177	N = 302
K/V	M25	0.168	
	M50	0.653	
	M75	2.418	
	Mean	3.083	N = 344

Source: Author's calculations using Ghana Manufacturing Enterprise Survey data (GMES).November 6, 1997

Notes:
(1) Mi is the Ith the percentile, N is the number of observations.
(2) Variable definitions: $I/K_{(-1)}$ is investment to lagged capital, I/V is investment to value-added, C/K is the profit rate, $\Delta V/K_{(-1)}$ is the change in real valued-added deflated by lagged capital, and K/V is the ratio of capital to value-added.

was the only country of the four to experience positive mean growth in real value–added/capital, during 1994–95 Ghana's average growth in real value-added/capital turned negative.

IV. THEORY

The first two of this paper's empirical issues are motivated directly by recent theoretical models of irreversible investment under uncertainty. A number of models[4] have shown that the firm's optimal investment policy calls for inaction when the MRPK is below a trigger, and purchase of capital to prevent the MRPK from rising above the optimally derived trigger. The trigger is increasing in uncertainty, and is higher than the Jorgensonian user cost of capital. We will discuss a particular model below. Theory is more ambiguous regarding the third issue, the effect of irreversibility on the investment-uncertainty relationship.

A. Literature

A firm that cannot reverse its investment decisions faces a higher user cost of capital than a firm with perfectly reversible investment, and this leads to lower investment for firms with irreversible investment. More uncertainty in the returns to capital increase the user cost for the firm with irreversible investment, without affecting the user cost for firms with reversible investment. Abel and Eberly (1995) consider the opposing "hangover" effect—a firm which cannot disinvest will have more accumulated capital from times when demand was low, but the irreversibility constraint prevented it from reducing the capital stock. Although the user cost effect implies that increased uncertainty tends to lower irreversible investment, through the hangover effect increased uncertainty tends to increase the long run capital stock under irreversibility relative to that under reversibility . The net effect of uncertainty on the long run capital stock depends on the balance of these factors, and cannot be definitively signed. These findings are in contrast to the results of Dixit and Pindyck (1994). Focusing on a particular functional form, they calculate the expected long-run average change in the log of the capital stock and conclude that greater uncertainty leads to a lower long run average growth of the capital stock.

A further controversy within the irreversible investment literature concerns the role of imperfect competition (Caballero, 1991; Pindyck, 1993; Abel and Eberly, 1994). Caballero and Abel and Eberly have argued that in the limit of constant returns and an infinitely elastic demand curve, an increase in uncertainty will increase investment, even when that investment is irreversible. On the other hand, Pindyck maintains that these results on competitive investment are overturned when an industry equilibrium is considered.

Although most of the models in the literature make the simplifying assumption that investment is either completely reversible or completely irreversible, reality is likely to be somewhere in the middle. Some recent papers have begun to model the partial irreversibility resulting from a wedge between the purchase and sales price of capital (Abel and Eberly, 1994; Abel, Dixit,

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[4] For example, Bertola (1988), Bertola and Caballero (1994), Dixit and Pindyck (1994).

Eberly and Pindyck, 1996; Abel and Eberly, 1996). This wedge could arise because of transactions costs, installation costs, or the firm-specific nature of capital. There is significant variation in the wedge for Ghanaian manufacturing firms, and we will use this variable as proxy for the degree of irreversibility.

Abel and Eberly (1996) characterize the optimal investment policy for a firm purchasing capital at a higher price than it can be sold. The firm should purchase capital when the MRPK reaches an upper user cost trigger and sell capital when it reaches a lower trigger. The solution can be completely characterized in terms of the width of the range of inaction. They show that if the purchase price exceeds the sale price, the ratio of the upper to lower trigger is larger than the ratio of purchase to sale price of capital. In this sense, greater irreversibility widens the range where zero investment is optimal.

The theoretical models imply that uncertainty will have different effects for different types of firms, depending on how sunk their investment expenditures are, the degree of market power, and aspects of the firm's technology. Empirical evidence on the impact of uncertainty on firm-level investment, however, is quite scant. Working with a panel of U.S. manufacturing firms, Leahy and Whited (1996) obtain a measure of uncertainty from the variance of the firm's daily stock returns, arguing that this variance should reflect higher demand or factor price volatility. The authors then construct volatility forecasts, since an *ex ante* rather than an *ex post* measure of the volatility of asset returns is required. The results confirm that the uncertainty of expected asset values is negatively related to firm investment in reduced form panel regressions. Guiso and Parigi (1996) examine the significance of a firm-level uncertainty proxy on investment in a cross-section of Italian firms. They find the uncertainty effect is stronger for firms with more irreversible investment and those with substantial market power. Another study related to this paper's focus is the industry level examination by Caballero and Pindyck (1993). The study's objective is to test whether increased uncertainty increases the trigger that spurs irreversible investment. The maximal observed value of the MRPK within an industry is used as a proxy for the investment trigger, and the standard deviation of the MRPK as a proxy for uncertainty. The uncertainty proxy is found to be positively correlated with the trigger in cross-section regressions. The authors point out, however, that this method is not very conclusive since there is a positive correlation between the extreme values and the standard deviation of a series regardless of the validity of the model.

B. Determining the Investment Trigger Point

Since one issue of interest is how irreversibility influences the effect of uncertainty on investment, the most appropriate model to consider would include parameterization of the degree of reversibility. However, since the data set does not include adequate information on sale of capital, it would not be possible to test the predictions of a partial reversibility model along the lines of Abel and Eberly (1996). Therefore, to fix ideas, we will consider a model where investment is completely irreversible.

Appendix 1 presents a firm investment model, drawing on Bertola (1988). The key features are: (1) investment is irreversible; i.e. gross investment cannot be negative; (2) the production function is Cobb-Douglas; (3) the firm faces a constant elasticity demand function so that different degrees of market power can be studied; (4) uncertainty arises since a demand curve shifter, the wage rate[5], and productivity are stochastic. The objective function of the firm is to maximize the present discounted value of profits by choosing an optimal investment rule. All variables and parameters should have a firm subscript, which is omitted for convenience. The problem can be written so that reduced form operating profits are a function of K, the installed capital stock and Z, an index of business conditions. Z depends positively on the strength of demand and on productivity and negatively on the wage rate. Like its components, Z is stochastic and has a trend growth rate with a variance around that trend.

From the problem's first order conditions, it is clear that the firm's MRPK is also a function of K, the capital stock, and Z, the business conditions indicator. The MRPK is random and fluctuates as the firm experiences shocks to demand, input costs, and productivity. It can be shown that the optimal policy for the firm is to allow the MRPK to fluctuate randomly, and to undertake investment only when the MRPK reaches a certain trigger level. The condition can be written:

$$\frac{MRPK}{(r+\delta-\eta)}\,dK = \omega P\,dK \tag{1}$$

where $\omega = f(\eta,\sigma^2)$[6].

The left hand side is the discounted MRPK. This condition says that the firm waits to undertake an irreversible investment decision until the expected present value exceeds the cost of the investment by the multiple ω. Since the multiple is increasing in the variance of the business conditions indicator, higher uncertainty increases the investment trigger point.

The parameters of the problem are all implicitly indexed by the firm subscript i. Therefore the investment trigger levels are firm-specific, with heterogeneity due to firm-specific technology, costs of capital, growth and variance of demand, and sunk purchase price of capital.

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[5] The model can be generalized to include other flexible factors of production in addition to labor. If so, the price of all flexible factors is assumed to be stochastic.

[6] r is the firm discount rate, δ is the depreciation rate, η is the trend growth rate of the business conditions indicator, σ^2 is the variance of the business conditions indicator, and P is the purchase price of capital.

V. Econometric Method

Condition (1) above can be written as:

$$\text{(1')} \quad \text{Investment} > 0 \ \text{ if } \ \frac{MRPK}{P} \geq h$$
$$= 0 \quad \text{otherwise}$$[7]

where h is a function of both the user cost of capital and the uncertainty variables that determine the option value multiple ω.

Recall that the empirical analysis will address three issues: (i) is investment triggered when the MRPK[8] reaches a particular hurdle level; (ii) does uncertainty increase the investment trigger and is this effect larger for firms with more irreversible investment; (iii) does uncertainty have a greater negative effect on the investment of firms with more irreversible investment.

To address (i), the general idea is to generate predictions for the trigger h for all firms, and test if condition (1') is significant in predicting the decision to invest. The trigger is not directly observable. One way to obtain a first stage approximation for the trigger is to assume that the theory is correct, and that firms only invest when the MRPK hits the trigger. Thus, when a firm invests, a first stage proxy for the trigger is the measured MRPK. Using this a first-stage proxy for the trigger, I explore its determinants, including the effects of uncertainty variables. Question (ii) is addressed during this analysis.

At this stage then, we have no information on the trigger for firms that are not investing.[9] However, since there are data for all firms on the hypothesized determinants of the trigger, the firm-specific values for the determinants of the trigger and the coefficients from the regression on the MRPK for investing firms (the first stage proxy for the trigger) can be used to create a predicted trigger for both investing and non-investing firms.

Since the coefficients on the determinants of the trigger (proxied by the MRPK for investing

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[7] The model implies that investment should be positive whenever the MRPK/P is equal to the hurdle level, not greater than or equal to. The firm's purchase of capital should prevent the MRPK/P from exceeding the optimally derived trigger. Since the data are aggregated over a year, and measurement errors are present, we may assume that the condition preventing the MRPK from ever rising above the trigger will not always hold empirically. However, the fact that the probit specification does not strictly match the model condition is a weakness of the approach.

[8] Note that although the method discusses the trigger relative to the ratio MRPK/P, the empirical estimates will use only the firm's MRPK, since data on capital goods prices are not available.

[9] All that is known is that if the theory is correct, the measured MRPK is below the trigger.

firms) are estimated using observations on only those firms with positive investment, the selection bias resulting from non-random sampling must be corrected. Therefore the method used involves three steps: a reduced form probit model of decision to invest or not; a selection-bias corrected regression for the MRPK, which conditioned on positive investment is taken as an indication that the MRPK has reached, and is therefore equal to the firm's investment trigger; and a structural probit equation to test if the condition above is significant in predicting the decision to invest. This method follows Lee (1978) and Rosen and Willis (1979).

Question (ii) is explored by examining the sign of the uncertainty variables in the selection-bias corrected model for the MRPK for investing firms, and interacting these variables with the reversibility proxy. Issue (iii) is examined by estimating a non-structural equation for investment rates for firms with positive investment, using the same sample selection correction as for the trigger equation. The focus is again the sign of the uncertainty variable for firms with reversible and irreversible investment.

In more detail, the estimation procedure is as follows. In condition (1'), *h* is unobservable. What *h* should depend on, however, is known from the model.

(2) $$h = \gamma_0 + \gamma_1 U + \gamma_2 C + u_1$$

where *U*= uncertainty variables; *C*= cost of capital variables. A dummy variable INVDUM is constructed to equal 1 if the firm undertakes any investment, and 0 otherwise.

(3) Thus INVDUM=1 if: $MRPK/P \geq \gamma_0 + \gamma_1 U + \gamma_2 C + u_1$

This criterion can be written in form of a probit model. The firm invests if $I^* > 0$, where:

(4) $$I^* = \theta_0 + \theta_1 \left(\frac{MRPK}{P} - h\right)$$

Substituting equation (2) in (4) yields a reduced form probit model:

(5) $$I^* = \theta_0 + \theta_1 \left[\frac{MRPK}{P} - (\gamma_0 + \gamma_1 U + \gamma_2 C)\right] + \theta_1 u_1$$
$$\equiv W\pi - \epsilon$$

where $W = [U, C]$ and $-\epsilon = \theta_1 u_1$.

The theoretical model predicts that firms invest only when the MRPK/P reaches a critical trigger. The second step in the empirical method rests on the assumption that for firms that are investing, the observed MRPK/P when investing can be used as a first-stage approximation to the firm's investment trigger. Since the trigger should depend on uncertainty and the cost of capital we will estimate the following equation, conditional on the firm investing:

(6) $$\frac{MRPK}{P} = \alpha_0 + \alpha_1 U + \alpha_2 C + \alpha_3 O + \kappa_M \lambda + \eta_1$$

where U and C are defined above and O includes other variables expected to be correlated with the MRPK/P such as the capital-output and the capital-labor ratios. The selection bias induced by sampling only firms with positive investment is controlled for by the inclusion of λ, the inverse Mills ratio. λ is defined as $\phi(W\pi)/\Phi(W\pi)$ where Φ is the cumulative normal density and ϕ is its p.d.f.

The third step estimates a structural probit equation in order to test the economic restrictions of the model. From equation (4) we can write:

$$\text{(7)} \qquad \text{Prob (INVDUM=1)} = \text{Pr } [(\theta_0 + \theta_1(\frac{MRPK}{P} - \hat{h})) > \epsilon]$$

where $\epsilon = -\alpha_1\epsilon_1$. Consistent estimates of the trigger, h are derived from:

$$\text{(8)} \qquad \hat{h} = \hat{\alpha}_1 U + \hat{\alpha}_2 C$$

Note that these are predicted values of the trigger for all firms, even though implicit observations on h were only available conditional on positive investment. The approach uses a probit method to estimate a structural equation after substituting estimates of the endogenous variables in the equation. Lee (1979) showed that the resulting estimates of θ are consistent and derived the correct asymptotic covariance matrix. In this application θ_1 is expected to be positive and significant, which is a test of whether the firm waits to invest until the MRPK hits a trigger.

In order to address question (iii), an accelerator-style model supplemented with uncertainty variables will be estimated. It involves an equation for the investment level, in which variables are scaled by the firm's capital stock to account for firm size differences. Conditional on the firm investing, we will estimate:

$$\text{(9)} \qquad \frac{inv}{capital} = \beta_0 + \beta_1 U + \beta_2 C + \beta_3 Y + \kappa_i \lambda + \eta_2$$

where Y= the change in value-added over the capital stock and λ is the same inverse Mill's ratio as included in equation (6), which is necessary to account for the selection of only firms with positive investment.

VI. Variable Definitions

Estimated equations for the decision to invest, and the MRPK and the investment level, conditional on positive investment will be presented. Most of these equations control for industrial sector; controls for the type of ownership were found not to be significant. Firm age and size are included in all regressions. Age and size have been found to have a significant effect on firm investment decisions in other studies using pooled manufacturing data from a number of African countries (Bigsten *et. al*, 1997).

The dependent variable in the investment level equations is investment in plant and equipment in year *t*, divided by the value of plant and equipment in year *t-1*. The perpetual inventory method is used to create the capital stock series, using gross investment and a base year value for the replacement value of plant and equipment. The change in real value-added relative to the capital stock deflates both value-added and capital values by the CPI. Profits are defined as value-added less the wage bill (including allowances) less promotion and advertising expenditures less interest payments. The profit rate is profits relative to the capital stock.

A. Uncertainty Variable

Firm owners[10] were asked about their one-year and three-year ahead expectations of demand for their firm's products. However, rather than only asking for point estimates—what percentage demand change they expected—firms were asked to assign probabilities to a range of potential percentage changes in demand, so that the probabilities summed to 100 (see Appendix 2).[11] For example, a firm owner who was absolutely certain that next year's demand would be from 10–20 percent higher would place all 100 'points' in this range, while an owner who believed that there was equal likelihood that demand would either not change, decrease by 0–10 percent or decrease by 10–20 percent would put weights of 33.3 in each of these intervals. From these distributions it is possible to calculate an expected mean growth of demand as well as a subjective variance of expected demand growth.

Let $E_0 d_{te}$ and $E_0 \sigma^2_{te}$ represent the conditional mean and variance of future demand *t* years ahead, which can be calculated from the survey question. The conditional mean and variance that will be used in the regressions use these survey expectations to calculate the mean expected future *level* of demand and uncertainty by using the base year sales value, S_0. Thus the measure of the subjective expected mean and variance of demand are given by:

$$E_0 X_t = (1 + E_0 d_{te}) S_0$$
$$E_0 \sigma^2_t = E_0 \sigma^2_{te} S^2_0$$

[10] The objective was to interview the individual who made investment and production decisions. Firm owners were interviewed in the cases of sole proprietorships, partnerships and limited liability enterprises, and managing directors for larger corporations or multinational subsidiaries.

[11] The idea for the survey question and the variable comes from Guiso, Jappelli and Terlizzese (1992), who use a related measure to test for precautionary savings by households. More recently, Guiso and Parigi (1996) have also used such a measure to study investment in a cross-section of Italian firms.

Table 4 shows the frequency distribution of the coefficient of variation, $E_0\sigma_t/E_0X_t$. A large proportion of firms show very low subjective uncertainty, with a coefficient of variation in the range 0–1 percent. This reflects the proportion of firms who put nearly all their 100 points in a particular interval of expected demand changes. Still, since these are ranges, it does not indicate that the firm believes a particular percentage demand change will occur with certainty. For one year ahead demand expectations, the next largest fraction of firms had a coefficient of variation in the range 9–11 percent. The three year ahead expectations indicate that there was more uncertainty over this longer horizon, but only by a small amount. Both frequency distributions indicate that this measure of uncertainty exhibits substantial variation across the firms in the sample.

For use in the regressions both the expected mean demand growth and the subjective variance of expected demand are scaled by the previous period's capital stock in order to account for size and wealth differences across firms. Although interest centers on the uncertainty variable, it is also important to control for the expected mean demand growth. The growth rate of demand enters into the investment trigger condition in the investment under uncertainty model. Moreover, the estimated effects of the uncertainty variable would be biased if the expected mean demand growth is not controlled for.

The bottom panel of Table 4 displays one and three year ahead expected demand growth. Most firms are optimistic: the largest proportion expect demand growth of more than 30 percent.

B. Irreversibility Proxies

Guiso and Parigi (1996) and Pattillo (1997) classify firms as having more easily reversible investment if the firm either leased capital goods, bought used capital goods or sold capital. One weakness of this proxy is that it cannot distinguish firms with more irreversible investment from those that to date have optimally never chosen to lease, buy used or sell capital. In this paper, the irreversibility proxy used is the ratio of the real sales value of the capital stock to its real replacement value.[12] This measure approximates the discount value of capital goods in the second-hand market, with types of capital that sell at less of discount implying that the investment is more easily reversible. A dummy variable is constructed for use in the regressions. REV is set equal to 1 for firms with values of the sales/replacement value of the capital stock above the sample mean, and 0 otherwise.

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[12] However, all models in Section VII were also estimated using the other reversibility proxy (REV=1 if firms either bought used, leased, sold capital or bought their firms), and the results were similar.

Table 4. Frequency Distribution of the Coefficient of Variation of Future Demand and Expected Demand Growth

Interval (%)	One Year Ahead Frequency (%)	Three Years Ahead Frequency (%)
Coefficient of Variation		
0 - 1	18.8	21.1
1 - 3	1.9	2.6
3 - 5	1.3	2.6
5 - 7	5.2	3.9
7 - 9	14.9	3.9
9 - 11	17.5	13.2
11 - 13	9.1	13.2
13 - 15	8.4	11.8
15 - 17	3.9	1.3
17 - 19	3.2	3.9
19 - 21	0.6	5.3
21 - 23	1.3	1.3
23 - 25	10.4	10.5
Greater than 25	3.2	5.3
Mean	5.3	5.7
Expected Demand Growth		
Positive (%)		
More than 30	34.2	45.5
20 - 30	24.1	15.6
10 - 20	17.1	14.3
0 - 10	10.8	6.5
0	7.6	10.4
Negative (%)		
0 - 10	2.5	3.9
10 - 20	1.9	1.3
20 - 30	0.6	1.3
More than 30	1.3	1.3
Mean	2.6	2.5

Source: Author's calculations using Ghana Manufacturing Enterprise Survey data (GMES).

This measure of irreversibility is related to constructs used in the theoretical literature. Abel and Eberly (1996) model partial irreversibility as a wedge between the purchase and sale prices, motivated by Arrow's (1968) seminal discussion of irreversible investment. Partial irreversibility may also be related to the presence of industry-specific capital. When a firm attempts to sell capital goods because of poor market conditions it may find few buyers or low prices from other firms in the industry which face the same market conditions. The average ratio of sales to replacement value of the capital stock differs across manufacturing sectors in Ghana, but there is also substantial firm-level variation within a sector.

C. Marginal Revenue Product of Capital

For the estimation of the trigger equation for investing firms and the structural probit model of equation (7), we need a measure of the marginal revenue product of capital: $MRPK = K^{\beta}Z$. From Appendix 1 equation (A.4), Z can be solved for in terms of profits, K and β. K is defined as the value of the firm's plant and equipment. Since β is a function of the capital share and the inverse of the mark-up factor, we need proxies for these values. The capital share is derived by estimating a Cobb-Douglass production function. The inverse of the mark-up factor is calculated following Domowitz, Hubbard and Petersen (1987), who compute the firm's mark-up on unit prices. The price cost margin is : PCM = Value of sales - Payroll - Cost of Materials/ Value of sales; and $\mu = 1/PCM$.

VII. Results

A. Tobit Model

Before turning to the results from the method outlined above, some preliminary regressions will be discussed. A comparison could examine the effect of the uncertainty variable in OLS regressions of the investment rate for firms with positive investment. This would be a misspecification, however, since it would not allow for the selectivity in including only firms with positive investment. Preliminary discussion, therefore, will be based on the estimation of a Tobit investment model, shown in Table 5.

One problem in all the estimated equations is the difficulty of controlling for the firm's user cost of capital. Interest rates are not very relevant given that only approximately one-quarter of the firms obtain bank financing for their capital expenditures. If estimation were based on a longer panel, firm-specific costs of capital might be controlled for using a fixed-effects model. However, that method cannot be pursued in the current inquiry. The profit rate is included as a measure of internal liquidity, and its significance is interpreted as evidence that financing is important for investment decisions.

For the overall sample, the Tobit equation indicates that investment is positively related to the change in real value-added, the profit rate, the MRPK and the size of the firm, and negatively related to the age of the firm. The equations control for industrial sector (not reported).

Expected mean growth in demand for the firm's products is positively and significantly related to the investment rate, consistent with the model in which the firm faces a downward-sloping demand curve. The variance of expected demand is not significant, however, for the sample of all firms.

Column (2) considers the effect of reversibility on this relationship. When the reversibility indicator is interacted with the variance of expected demand, the results indicate that most of the negative effect of uncertainty comes from irreversibility. The coefficient on the variance of expected demand is the slope coefficient for firms with more irreversible investment (REV=0), and the sum of the coefficients on the variance and the interaction term is the slope coefficient for firms with more easily reversible investment (REV=1).[13] For firms with more irreversible investment the effect of uncertainty is negative and significant, while for firms with more easily reversible investment the value of the coefficient is close to zero, and a chi-squared test indicates that it is insignificant. Moreover, the t-statistic on the interaction term indicates that there is a significant difference between the slopes for firms with reversible investment and firms with irreversible investment.

Although these results are encouraging, the Tobit specification forces regressors to have the same effect on the probability of investing and on the investment level. Therefore it cannot be used to test the prediction that investment is triggered when the MRPK reaches a particular hurdle level. The restriction that regressors have the same effect on the probability of an observation being a non-limit observation and on the level of that variable is testable. Using a likelihood ratio statistic as in Greene (1997, pg. 970), this hypothesis is rejected at the 1 percent level.[14] This suggests that the sample selection model may be more appropriate.

B. Sample Selection Model

The first set of results do not make allowance for firms with differing ability to reverse their investment expenditures. Two issues can be explored: (i) is investment triggered when the MRPK reaches a hurdle level? (ii) does uncertainty increase the investment trigger? The empirical method involves three steps: a reduced form probit model of the decision to invest or not; a selection-bias corrected least-squares regression for the MRPK, which conditioned on positive investment is taken as indicating that the MRPK has reached the firm's investment trigger; and a structural probit equation to test if the firm is more likely to invest as the MRPK gets closer to the predicted trigger. The analysis will also consider the effect of uncertainty on the investment level, for firms with positive investment.

Table 6 presents the estimates. All estimates control for industrial sector. The reduced form

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[13] Note that reported coefficients are the marginal effects evaluated at the mean for all observations.

[14] The likelihood ratio statistic (LRS) is computed using $\lambda = -2*$[Tobit model log likelihood-(Probit model log likelihood+Truncated regression log likelihood)]. The LRS = 86.1, while at the 1 percent level the critical chi-squared value is 27.7.

probit results show that faster growth rates of value-added, higher profitability, and higher MRPK increase the probability of investing. Larger firms are more likely to invest and older firms less likely. The expectation of higher mean demand growth is not significant in the decision to invest. High variance of expected demand, however, does lower the probability of investing. The model correctly predicts 68 percent of the observations.

Next I assume that for firms with positive investment the MRPK has reached the investment trigger, implying that the MRPK of investing firms can be used as a first-stage proxy for the trigger. The profit rate is included in this selection model since as the average realized return on capital, it is related to the firm's cost of capital. Column (2) shows how the expected mean and variance of demand and the profit rate affect the firm-specific hurdle level of the MRPK that triggers investment. In addition, the regression controls for two other variables correlated with the MRPK, the firm's output/capital and capital/labor ratios. The output/capital ratio proves highly significant and quantitatively important. Many of the other variables are not significant. The results do indicate, however, that the variance of expected demand has a positive and significant effect on the hurdle level of the MRPK for firms with positive investment. This result is interpreted as support for the prediction that high levels of uncertainty increase the investment trigger.

To support the interpretation that the MRPK for investing firms can be viewed as a preliminary proxy for the investment trigger, the MRPK equation is also estimated using the full sample of investing and non-investing firms. This would not represent the investment trigger and there is no clear prediction on the effect of uncertainty. For firms that are not investing, the MRPK is not equal to the trigger. The MRPK depends on variables such as the output/capital ratio and the capital/labor ratio, while the investment trigger depends on uncertainty. the As shown in Column (3), the uncertainty proxy is insignificant in the overall sample.

The next step is to estimate the structural probit equation (7) that follows from the irreversible investment model. A variable representing the investment trigger for all firms is required. As indicated in equation (8), the coefficients from column (2) and the firm values for the determinants of the trigger can be used to create a predicted trigger for firms with positive and zero investment. The structural probit equation tests whether the deviation of a firm's MRPK from the predicted trigger is a significant determinant of the decision to invest. Column (4) confirms that the most powerful effect on the decision to invest is the "waiting" for the MRPK to reach or exceed the investment trigger. The trigger has been constructed as a function of the firm-level measure of uncertainty. The growth rate of value-added and profitability are also found to have a positive and significant impact on the decision to invest. In order to account for the use of predicted values as regressors, the standard errors are corrected using the method of Murphy and Topel (1985).

Finally, column (5) presents the estimates of equation (9), the investment rate, conditioned on positive investment. The model includes the same selection-bias correction as used in the trigger equation. Growth of value-added and profitability are positively related to the investment level. Firm size and age were determinants of the decision to invest, but they do not influence the investment level, conditional on positive investment. While higher expected mean demand growth did not affect the probability of investing, it does have a positive and significant effect on investment levels. The variance of expected demand, or the uncertainty proxy, has a negative and significant effect on the investment level.

C. Sample Selection Model with Consideration of Irreversibility

Next we turn to examination of the following issues: (i) do the results still indicate that firms invest when the MRPK reaches a hurdle level when different degrees of reversibility are accounted for; (ii) does uncertainty increase the investment trigger to a greater extent for firms with irreversible investment; and (iii) does uncertainty have a larger negative effect on the investment levels of firms with more irreversible investment. The method followed is the same as that above.

In Table 7, the reduced form probit model provides strong evidence that for the decision to invest, uncertainty is a greater deterrent for firms with irreversible investment than for firms with more easily reversible investment. For firms with more irreversible investment the effect of uncertainty is negative and significant, while the coefficient is insignificantly different from zero for firms with more easily reversible investment. There is a significant difference between the slopes for firms with reversible investment and firms with irreversible investment.

Column (2) again examines the effect of the expected mean and variance of expected demand and the profit rate on the hurdle level of the MRPK that triggers investment. The impact of reversibility on the relationship between uncertainty and the investment trigger is not completely clear cut. Higher uncertainty increases the investment trigger for firms with both irreversible and reversible investment, but the difference in the coefficients is not statistically significant. However, I cannot reject that the coefficient on uncertainty for firms with more reversible investment is insignificantly different from zero. It seems that uncertainty increases the MRPK that triggers investment, but there is only weak evidence that this effect is stronger for firms with more irreversible investment.

The form of the structural probit model in column (3) is the same as the one in Table 6. The predicted trigger ($\hat{h}$) is different, however, since the degree of reversibility was controlled for in both the reduced form probit and the equation for the MRPK of investing firms. Is there still support for the prediction that investment is triggered when the MRPK reaches a firm-specific hurdle level? Accounting for the degree of reversibility when predicting the trigger strengthens the results—the size of the coefficient on the deviation between the MRPK and the trigger is much larger and has increased in significance.

Turning to the final issue, recall that the theoretical models did not yield clear cut results on how reversibility influenced the investment-uncertainty relationship. Selection-bias corrected estimates of the investment rate are shown in column (4). The estimates indicate that for this sample of Ghanaian manufacturing firms, uncertainty has a greater negative effect on investment rates for firms with more irreversible investment. While the coefficient for firms with more easily reversible investment is still negative, it is much smaller, and there is a significant difference in the coefficients for firms with irreversible and reversible investment.

Several different variants of the above specification were estimated in order to assess the robustness of the results. First, a variable representing total firm debt was added to the probit equations for the decision to invest and the investment level regressions. Highly leveraged firms may face higher borrowing costs which would effect their cost of capital and investment decisions. The results were qualitatively the same and debt was significant in the investment level, but not the probability of investment equations. Second, two different variants of the uncertainty measure were calculated. In one, the conditional variance from the survey questions is combined with base year value-added, rather than sales, to calculate the expected variance of demand. In another the variance of expected demand is scaled by output, rather than the capital stock. In both cases the results were broadly similar. Third, identification by excluding age and size from the investment rate equation, rather than the MRPK, was tried and also did not significantly effect the results. Finally, an alternative reversibility proxy was used, in which REV=1 if the firm either bought used capital, leased capital, or sold capital during 1991–95. The results in Table 8 illustrate that the only significant change in the results is in the reduced form probit model of the decision to invest. There is no longer a significant difference between uncertainty's effect for firms with reversible investment and firms with irreversible investment.

Although the results are generally supportive of the hypotheses, there is scope for improvement in the analysis. First, an alternative to the probit method could be found in order to satisfy the model prediction that capital is purchased to prevent the MRPK from rising above the optimally derived trigger . Second, when a longer panel becomes available it will be important to control for firm-specific effects such as the entrepreneur's risk aversion, managerial ability, or firm costs of capital. Finally, although it has been argued that the selection model is appropriate, the selection bias terms were not significant. The reduced form model should be extended to further explore the selection mechanism.

VIII. Conclusion

Firm level panel data are extremely useful for exploring the effect of uncertainty on investment. Theoretical models show that firms that cannot easily reverse investment decisions wait to invest until the MRPK reaches a specific hurdle level. The hurdle level is an increasing function of uncertainty. Although one would expect uncertainty to increase the trigger to a greater extent for firms with more irreversible investment, there are no theoretical predictions on this issue. There is also some controversy in the theoretical literature on the impact of uncertainty and irreversibility on average investment levels. Firm level data can be used to test these issues. In addition, the Ghanaian manufacturing firm data set included information on the entrepreneur's subjective probability distribution over future demand for the firm's products. From this data it was possible to construct a direct measure of the firm owners' perceptions of uncertainty, conditional on his/her information. This facilitated estimating the impact of the variance of expected demand, while also controlling for the expected mean demand growth.

The empirical results provide support for the prediction that firms wait to invest until the MRPK reaches a firm-specific hurdle level. It is also found that greater uncertainty leads to an increase in a first-stage proxy for the investment trigger, although there is only weak evidence that this effect is stronger for firms with more irreversible investment. The results indicate that uncertainty has a negative effect on investment levels and that the effect is significantly greater for firms with more irreversible investment.

Table 5. Tobit Investment Functions

	$Investment/Capital_{(-1)}$ (1)	$Investment/Capital_{(-1)}$ (2)
Constant	0.903	-0.122
	(4.20)	(1.73)
Δ Value-added/$capital_{(-1)}$	0.014	0.008
	(2.01)	(1.87)
Profit $rate_{(-1)}$	0.017	0.017
	(2.70)	(2.76)
Ln (size)	0.001	0.035
	(0.06)	(1.82)
Firm age	-0.001	-7.9e-04
	(0.41)	(0.37)
Expected mean Demand growth	0.003	0.003
	(2.12)	(4.28)
Variance of Expected demand	-0.002	-0.005
	(0.34)	(2.68)
Variance* reversibility		0.005
		(2.21)
MRPK	0.032	0.09
	(2.32)	(5.34)
N	154	139
Ln (likelihood)	-97.85	-85.22
χ^2 test of restriction: $\beta6 + \beta7=0$		0.001(1),p=0.96

Source: Authors' estimates using GMES data.

Notes:
(1) The figures in parentheses are the absolute value of the t-statistics.
(2) The coefficients are the marginal effects, evaluated at the mean of all observations.

Table 6. Investment under Uncertainty Model

	Reduced form Probit INVDUM=1 if any investment, 0 otherwise	MRPK= trigger Selection Model	MRPK for all firms	Structural Probit INVDUM=1 if any investment otherwise	Investment/ $Capital_{(-1)}$ Selection Model
	(1)	(2)	(3)	(4)	(5)
Constant	1.18 (0.06)	-1.34 (1.21)	-1.11 (1.27)	0.008 (0.05)	1.81 (5.81)
Δ Value-added/ $Capital_{(-1)}$	0.028 (2.89)			0.04 (2.65)	0.025 (2.27)
Profit $rate_{(-1)}$	0.024 (2.89)	-0.006 (0.35)	-0.14 (1.88)	0.053 (3.11)	0.045 (3.55)
Ln (size)	0.061 (1.72)			0.045 (1.04)	0.009 (0.23)
Firm age	-0.007 (1.78)			-0.002 (0.49)	-0.001 (0.28)
MRPK	0.05 (2.52)				
Expected mean Demand growth	9.14e-04 (1.04)	-0.003 (0.87)	3.0e-04 (0.63)		0.008 (3.02)
Variance of Expected demand	-0.002 (2.54)	0.007 (2.09)	-0.001 (0.91)		-0.002 (1.94)
Output/capital		0.176 (7.96)	0.426 (3.04)		
Capital/employment		2.48e-04 (0.09)	3.7e-04 (0.37)		
Lambda		0.003 (0.03)			
MRPK - $\hat{h}$				0.099 (2.14)	
N	226	116	227	163	94
Ln (likelihood)	-141.1			-92.8	
% correctly predicted	68%			64%	
Adjusted R^2		0.54	0.52		0.29
F(DF)		14.8 (15,100)	27.7 (14,212)		5.3 (14,79)

Source: Authors' estimates using GMES data.

Notes:
(1)The figures in parentheses are the absolute value of the t-statistics.
(2) The standard errors in column (4) have been corrected following Murphy and Topel (1985).

Table 7. Investment under Uncertainty Model with Irreversibility

	Reduced form Probit INVDUM=1 if any investment, 0 otherwise	MRPK= trigger Selection Model	Structural Probit INVDUM=1 if any investment otherwise	Investment/ $Capital_{(-1)}$ Selection Model
	(1)	(2)	(3)	(4)
Constant	1.06	-1.22	0.099	1.52
	(0.06)	(0.54)	(0.59)	(4.63)
Δ Value-added/ $Capital_{(-1)}$	0.036		0.028	0.352
	(2.58)		(1.69)	(2.61)
Profit $rate_{(-1)}$	0.03	0.022	0.024	0.024
	(2.71)	(1.34)	(1.6)	(1.64)
Ln (size)	0.075		0.047	0.015
	(1.95)		(1.09)	(0.37)
Firm age	-0.004		3.7e-04	0.002
	(0.85)		(0.07)	(0.47)
MRPK	0.067			
	(2.39)			
Expected mean Demand growth	0.009	-7.5e-04		0.004
	(1.08)	(2.50)		(3.08)
Variance of Expected demand	-0.005	0.002		-0.002
	(2.51)	(6.2)		(1.96)
Variance* Reversibility	0.004	0.003		0.001
	(1.67)	(0.80)		(2.07)
Output/capital		0.098		
		(2.91)		
Capital/employment		1.6e-04		
		(0.74)		
Lambda		0.002		0.008
		(0.03)		(0.06)
(MRPK- $\hat{h}$)			0.154	
			(3.15)	
N	197	96	149	83
Ln (likelihood)	-119.57		-85.78	
% correctly predicted	64%		65%	
Adjusted R^2		0.51		0.38
F(DF)		12.02 (14,81)		6.05 (15,67)
χ^2 test of restriction: $\beta7 + \beta8=0$	1.68,p=0.002	0.63,p=0.43		6.65 ,p=0.01

Source: Authors' estimates using GMES data.

Notes:

(1) The figures in parentheses are the absolute value of the t-statistics.

(2) The standard errors in column (3) have been corrected following Murphy and Topel (1985).

Table 8. Investment under Uncertainty Model with Irreversibility Using Alternative Reversibility Proxy 1/

	Reduced form Probit INVDUM=1 if any investment, 0 otherwise (1)	MRPK= trigger Selection Model (2)	Structural Probit INVDUM=1 if any investment otherwise (3)	Investment/ $Capital_{(-1)}$ Selection Model (4)
Constant	1.17	-0.72	-0.027	1.72
	(0.06)	(0.69)	(0.18)	(5.08)
Δ Value-added/ $Capital_{(-1)}$	0.031		0.028	0.26
	(2.80)		(2.11)	(1.76)
Profit $rate_{(-1)}$	0.024	0.003	0.032	0.031
	(2.65)	(0.18)	(2.34)	(2.4)
Ln (size)	0.06		0.067	0.022
	(1.71)		(1.62)	(0.48)
Firm age	-0.003		-0.002	-0.002
	(0.47)		(0.47)	(0.40)
MRPK	0.048			
	(2.39)			
Expected mean Demand growth	0.009	-6.3e-04		0.002
	(1.048)	(0.15)		(1.48)
Variance of Expected demand	-0.002	0.008		-0.002
	(2.65)	(2.43)		(2.49)
Variance* Reversibility	0.001	-0.008		0.001
	(1.2)	(1.32)		(2.06)
Output/capital		0.18		
		(8.18)		
Capital/employment		-5.6e-04		
		(0.19)		
Lambda		0.002		0.073
		(0.31)		(0.45)
(MRPK- $\hat{h}$)			0.121	
			(3.17)	
N	226	116	153	94
Ln (likelihood)	-140.37		-95.33	
% correctly predicted	67%		61%	
Adjusted R^2		0.54		0.25
F(DF)		16.2 (14,101)		4.48 (15,78)
χ^2 test of restriction: $\beta 7 + \beta 8 = 0$	1.56(1),p=0.21	0.31(1),p=0.99		6.49 (1),p=0.01

Source: Authors' estimates using GMES data.

Notes:

(1) The figures in parentheses are the absolute values of the t-statistics.

(2) The standard errors in column (3) have been corrected following Murphy and Topel (1985).

1/ Using REV=1 if firms either bought used capital, leased capital, or sold capital.

THE MODEL

The production function is Cobb–Douglas:

(1) $$Q_t = [K_t^{\alpha} (AL_t)^{1-\alpha}] ,$$

The firm faces a constant elasticity demand function:

(2) $$B_t = D_t Q_t^{\mu-1}$$

where B_t is the product price, Q_t is output, and μ is the inverse of the markup factor, which indexes the firm's monopoly power. Monopoly power increases as μ goes to zero; μ equals 1 for a perfectly competitive firm. D_t influences position of demand curve; if μ equals 1, then D_t equals B_t which is the market price that the firm takes as given. L is labor, a perfectly flexible production factor that can be rented at the rate w_t. A_t is a technological progress indicator.

Define the operating profits function:

(3) $$\Pi(K_t, w_t, D_t) = \max_{L_t} B_t Q_t - w_t L_t$$

s.t. (1) and (2) above. Operating profits can be written in reduced form as:

(4) $$\Pi(K_t, w_t, D_t) = \frac{1}{1+\beta} K_t^{1+\beta} Z_t$$

where:

$$\beta = \frac{\mu - 1}{1 - (1-\alpha)\mu} , \quad -1 < \beta < 0$$

The business condition parameter Z_t can be written:

$$Z_t = f(\alpha, \ \mu, \beta; D_t, w_t, A_t)$$

Z_t depends positively on the strength of demand and on productivity, and negatively on the cost of factors other than capital.
Z_t is stochastic: constant mean growth rate η and variance σ^2:

Firm's Dynamic investment problem:

(6)

$$V^*(K_t,\ Z_t) = \underset{\{x(\tau)\}}{Max}\ E_t \int_t^{\infty} e^{-r(\tau-t)} \left[\frac{1}{1+\beta} K_\tau^{1+\beta}\ Z_\tau\, d\tau\ -\ P_\tau\, dX_\tau \right]$$

subject to $dK_\tau = -\delta K_\tau\, d\tau + dX_\tau$

and to $dX_t \geq 0$.

It can be shown that the solution is:

Firm invests when:

(7')

$$\frac{(K^{\beta} Z)}{(r+\delta-\eta)}\, dK = \frac{\gamma}{\gamma-1} P\, dK$$

where $\frac{\gamma}{\gamma-1} = f(\eta, \sigma^2)$

SUBJECTIVE PROBABILITY DISTRIBUTION QUESTION FROM SURVEY

This question tries to ascertain by how much **you** expect the output of your firm to change, in terms of volume of products? This is done with the help of the table below.

The table specifies various ranges by which output may change. This is shown in the first column, for example, an increase in output of 20–30 percent, a decrease in output by more than 30 percent, etc.

Now we need you to estimate the likelihood of each expected change in output occurring on a scale of 0–100.

100 means that there is a 100 percent chance that the specified growth rate will occur, 10 means that there is a 10 percent chance that the specified growth rate will occur, 0 means that there is a 0 percent chance that the specified growth rate will occur, etc., for each of the categories. Remember there are nine categories and your total points should add up to 100.

On the basis....

		1 by what % do you expect your product output to grow next year? (in % terms)	2 by what % do you expect your average product output to grow in the next 3 years? (in % terms)
INCREASE:	**more than 30%** *(a great deal higher)*		
	20 to 30% *(a lot higher)*		
	10 to 20% ***(moderately higher)***		
	0 to 10% *(a little higher)*		
NO CHANGE			
DECREASE:	**0 to 10%** ***(a little lower)***		
	10 to 20% *(moderately lower)*		
	20 to 30% *(a lot lower)*		
	more than 30% *(a great deal lower)*		
TOTAL POINTS (Should add to 100)		**100**	**100**

REFERENCES

Abel, Andrew and Janice Eberly, 1994, "A Unified Model of Investment under Uncertainty," *American Economic Review* 84(5), pp. 1369–84.

Abel, Andrew and Janice Eberly, 1995, "The Effects of Irreversibility and Uncertainty on Capital Accumulation," *NBER Working Paper* No. 5363.

Abel, Andrew and Janice Eberly, 1996, "Optimal Investment with Costly Reversibility," *Review of Economic Studies* 63, pp. 581–93.

Abel, Andrew, Avinash Dixit, Janice Eberly and Robert Pindyck (1996). "Options, The Value of Capital, and Investment," *Quarterly Journal of Economics* 111(3), pp. 753–777.

Arrow, Kenneth, 1968, "Optimal Capital Policy with Irreversible Investment," in J.N. Wolfe (ed.) *Value, Capital and Growth, Papers in Honour of Sir John Hicks* (Chicago: Aldine Publishing Company), pp. 1–19.

Aryeetey, Ernest, 1994, "Private Investment Under Uncertainty in Ghana," *World Development* 22(8), pp. 1211–1221.

Bertola, Giuseppe, 1988, "Adjustment Costs and Dynamic Factor Demands: Investment and Employment Under Uncertainty," Ph.D. dissertation, Massachusetts Institute of Technology.

Bertola, Giuseppe and Ricardo Caballero, 1994, "Irreversibility and Aggregate Investment," *Review of Economic Studies* 61, pp. 223–246.

Bigsten, Arne, Francis Teal, Anders Isaksson, Mans Soderbom, Bernard Gauthier, Michel Sylvain, Jan Gunning, Remco Oosetendorp, Abena Oduro, Albert Zeufack, Paul Collier, Stefan Dercon, Cathy Pattillo, 1997, "Investment in Africa's Manufacturing Sector in Cameroon, Ghana Kenya and Zimbabwe: An International Comparative Panel Data Analysis" (mimeo).

Caballero, Ricardo, 1991, "On the Sign of the Investment–Uncertainty Relationship," *American Economic Review* 81(1), pp. 279–288.

Caballero, Ricardo and Robert Pindyck, 1992, "Uncertainty, Investment and Industry Revolution," *NBER Working Paper* No. 4160.

Centre for the Study of African Economies, University of Oxford and the Department of Economics, University of Ghana, 1995, "The Regional Program on Enterprise Development: The Ghanaian Manufacturing Sector 1991–1993, Findings of Waves 1 to 3, Final Report.

Dixit, Avinash and Robert Pindyck, 1994, *Investment Under Uncertainty* (New Jersey: Princeton University Press).

Greene, William H., 1997, *Econometric Analysis*, Upper Saddle River (New Jersey: Prentice-Hall Inc.)

Ferderer, J. Peter, 1993, "The Impact of Uncertainty on Aggregate Investment Spending: An Empirical Analysis," *Journal of Money, Credit and Banking*, 25(1), pp. 30–48.

Ghosal, Vivek and Prakash Loungani, 1996, "Product Market Competition and the Impact of Price Uncertainty on Investment: Some Evidence from U.S. Manufacturing Industries" *International Finance Discussion Papers*, Board of Governors of the Federal Reserve System.

Guiso, Luigi, T. Japelli and D. Terlizzese, 1992, "Earnings Uncertainty and Precautionary Saving," *Journal of Monetary Economics*, 30, pp. 307–37.

Guiso, Luigi and Giuseppe Parigi, 1996, "Investment and Demand Uncertainty: Evidence from a Cross-Section of Italian Firms" (mimeo).

Hadjimichael, Michael, Michael Nowak, Robert Sarer and Amor Tahari, 1996, *Adjustment for Growth: The African Experience*, IMF Occasional Paper No. 143 (Washington: International Monetary Fund).

Hartman, R., 1976, "Factor Demand with Output Price Uncertainty," *The American Economic Review*, 66, pp. 675–81.

Huizinga, John, 1993, "Inflation Uncertainty, Relative Price Uncertainty and Investment in U.S. Manufacturing," *Journal of Money, Credit and Banking*, 25(3), pp. 521–549.

Leahy, John and Toni Whited, 1996, "The Effect of Uncertainty on Investment: Some Stylized Facts," *Journal of Money, Credit and Banking*, 28(1), pp. 64–83.

Lee, Lung-Fei, 1978, "Unionism and Wave Rates: A Simultaneous Equations Model with Qualitative and Limited Dependent Variables," *International Economic Review*, 19(2), pp. 415–433.

Lee, Lung-Fei, 1979, "Identification and Estimation in Binary Choice Models with Limited (Censored) Dependent Variables," *Econometrica* 47, pp. 977–976.

Murphy, Kevin and Robert Topel, 1985, "Estimation and Inference in Two-Step Econometric Models," *Journal of Business and Economic Statistics*, 3(4), pp. 370–379.

Pattillo, Catherine, 1997, "The Impact of Uncertainty on the Investment Behavior of Ghanaian Manufacturing Sector Firms," in P. Collier and C. Pattillo, eds., *Risk and Agencies of Restraint: Reducing the Risk of African Investment* (London: MacMillian Press).

Pindyck, Robert, 1988, "Irreversible Investment, Capacity Choice and the Value of the Firm," *American Economic Review* 7, pp. 969–985.

Pindyck, Robert, 1993, "A Note on Competitive Investment Under Uncertainty," *American Economic Review* 83(1), pp. 273–277.

Rosen, Sherwin and Robert J. Willis, 1979, "Education and Self-Selection," *Journal of Political Economy*, 87(5) pt.2, pp. s7–s36.

White, H., 1978, "A Heteroscedasticity Consistent Covariance Matrix and a Direct Test for Heteroscedasticity," *Econometrica*, pp. 817–38.

World Bank, 1990, "Ghana: Towards a Dynamic Investment Response," Western Africa Department, Industry and Energy Operations Division, Report No. 8911-GH.