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Investment, Uncertainty, and Irreversibility in Ghana

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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. [JEL D81, D92, C24]

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. Empirical methods for investigating the investment-uncertainty relationship are developed and applied to the example of Ghanaian manufacturing sector firms. 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 tests whether a firm-level uncertainty variable that measures the entrepreneur's perceptions of risk is significant in the model estimation.

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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 uncertainty 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 in Ghana during 1983–91, a recent IMF Occasional Paper concludes that "the most important impact of policies on private investment behavior was through their effect on macroeconomic instability and uncertainty" (Hadjimichael and others, 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 period after 1991.

During 1994–95, an ongoing survey of a panel of Ghanaian manufacturing firms included questions on entrepreneurs' 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 is 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), in addition to other factors. 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 exchange rates, or the parallel premium (Ferderer, 1993; and 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 or 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 the Abel and Eberly model, uncertainty adds to the ambiguity: whether or not uncertainty implies a lower capital stock under irreversibility depends on the parameters.

In light of these theoretical predictions and nondefinitive results, I consider three questions. 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 to test 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 the theory, this information is exploited by assuming that when a firm invests, the measured MRPK is equal to the trigger. Using this as 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 noninvesting firms. A probit model is then used to test a model in which the firm invests when the MRPK is equal to (or greater than) the predicted trigger value.

I. Background

Since the beginning of the ERP in Ghana in 1983, uncertainty has dampened private investment, although the nature of the uncertainties has 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 (mainly caused by a large increase in wages for public sector employees), there was a marked downturn in economic performance. The uncertainty created by macroeconomic instability, high inflation, and some slippage in policy implementation created an environment of uncertainty for investors.

The weakness in private investment since 1992 (see Figure 1) has been an important policy concern, as reversing the poor investment record was considered key to the strategy for achieving the accelerated growth objectives (Aryeetey, 1994). 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 improved the environment for manufacturing have continued through the 1990s, 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-1980s 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.

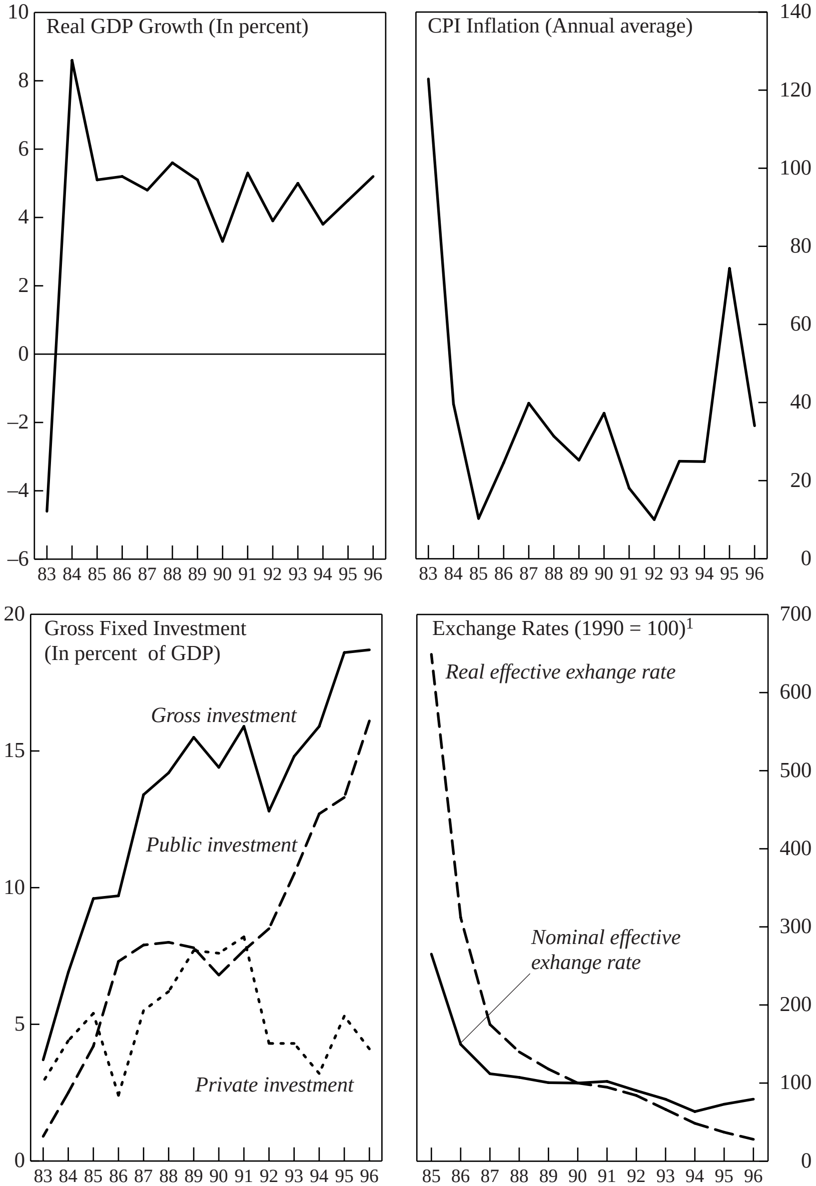
The outcome has been that, following an initial boom in the growth rate of manufacturing value added during 1984–87, growth rates fell to an average of 3.1 percent during 1988–91, and remained low at 2.7 percent during the period 1992–95. There have been large changes in the sectoral composition of GDP 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.

II. The Sample

The Ghana survey collected panel data for the five years 1991–95 from a sample of approximately 200 manufacturing firms.[1] This paper, however, uses the 1994–95 data since the question on the subjective probability

[1] The first three rounds of the survey were part of the Regional Programme on Enterprise Development (RPED), organized by the World Bank (see Centre for the Study of African Economies, 1995). Rounds 4 and 5 are part of the Ghana Manufacturing Enterprise Survey (GMES), funded by the U.K. government, Department for International Development.

Figure 1. *Ghana: Selected Economic Indicators 1983–96, Unless Otherwise Indicated*



Sources: Real GDP growth, investment: staff estimates; CPI inflation: IFS; NEER, REER: Information Notice System.

[1] Calculated using the official exchange rate for the cedi. An increase in the index indicates an appreciation.

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 1994–95 sample.

Table 2 shows that the fraction of firms undertaking any investment is low: 52 percent of firms invested in plant and equipment, while 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 fallen in 1994 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 shows that the distributions of these investment variables are highly asymmetric, indicating that medians as well as means should be examined (Bigsten and others, 1997). Table 3 shows, for example, that the mean profit rate of the Ghanaian firms was 422 percent, while the median was 68 percent.[2] While in the period 1991–93 Ghana 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.

III. Theory

The first two empirical issues addressed in this paper are motivated directly by recent theoretical models of irreversible investment under uncertainty. A number of models[3] have shown that the firm's optimal investment policy calls for inaction when the MRPK is below a trigger level, 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

[2] Profit rates vary widely across size classes, and the mean and median rates decrease with firm size. Bigsten and others (1997) show 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.

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

Table 1. *Sample Characteristics*
(In percent)

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

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

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	0.441	0.082	0.172
Medium (30–99 employees)	0.60	0.360	0.373	0.224	0.214
Large (≥100 employees)	0.75	0.491	0.162	0.373	0.113
Average, all firms 1994–95	0.52	0.314	0.348	0.164	0.171
Average for Cameroon, Ghana, Kenya, Zimbabwe 1991–93	0.54	0.211	0.239	0.113	0.128

Sources: Author's calculations using Ghana Manufacturing Enterprise Survey data; and, for Cameroon, Ghana, Kenya, and Zimbabwe, 1991–93, from Bigsten and others (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.

Notes: M_i is the ith percentile, N is the number of observations. $I/K_{(-1)}$ 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 value added deflated by lagged capital, and K/V is the ratio of capital to value added.

a particular model below. Theory is more ambiguous regarding the third issue, the effect of irreversibility on the long-run investment-uncertainty relationship.

Literature

A firm that cannot reverse its investment decisions faces a higher user cost of capital than a firm with perfectly reversible investment. This leads to lower investment for firms with irreversible investment. More uncertainty in the returns to capital increases 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 that 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 argue 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 between. Some recent papers have begun to model the effective partial irreversibility resulting from a wedge between the purchase and sales price of capital (Abel and Eberly, 1994; Abel, Dixit, 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 a variable closely related to this wedge for Ghanaian manufacturing firms, and we will use this variable as a 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 that at which 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. Abel and Eberly show that if the purchase price exceeds the sale price, the ratio of the upper to lower trigger is larger than the ratio of the purchase price to the 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 United States 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 (1996). That 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.

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 I presents a model of a firm's investment decision, drawing on Bertola (1988). The key features are: (1) investment is irreversible; that is, 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,[4] 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

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

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 as

$$\left[MRPK/(r+\delta-\eta)\right]dK = \omega PdK, \tag{1}$$

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

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 owing to firm-specific technology, costs of capital, growth and variance of demand, and purchase price of capital.

IV. Econometric Method

Condition (1) above can be written as

$$\begin{aligned} \text{Investment} &> 0 \quad \text{if } MRPK/P \geq h \\ &= 0 \quad \text{otherwise,} \end{aligned} \tag{1'}$$

[5]

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

[5] 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.

Recall that the empirical analysis will address three issues: (1) is investment triggered when the MRPK[6] reaches a particular hurdle level? (2) does uncertainty increase the investment trigger and is this effect larger for firms with more irreversible investment? and (3) does uncertainty have a greater negative effect on the investment of firms with more irreversible investment?

To address (1), 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 as a first-stage proxy for the trigger, I explore its determinants, including the effects of uncertainty variables. Question (2) is addressed during this analysis.

At this stage then, we have no information on the trigger for firms that are not investing.[7] 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 noninvesting firms.

Since the coefficients on the determinants of the trigger (proxied by the MRPK for investing firms) are estimated using observations on only those firms with positive investment, the selection bias resulting from nonrandom 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 Willis and Rosen (1979).

Question (2) is explored by examining the signs 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 (3) is examined by estimating a nonstructural equation for investment rates for firms with positive investment, using the same sample

[6] 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.

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

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.

$$h = \gamma_0 + \gamma_1 U + \gamma_2 C + u_1, \tag{2}$$

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

$$INVDUM = 1 \text{ if } MRPK/P \geq \gamma_0 + \gamma_1 U + \gamma_2 C + u_1. \tag{3}$$

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

$$I^* = \theta_0 + \theta_1 (MRPK/P - h). \tag{4}$$

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

$$I^* = \theta_0 + \theta_1 \left[MRPK/P - (\gamma_0 + \gamma_1 U + \gamma_2 C) \right] + \theta_1 u_1 \tag{5}$$

$$\equiv W\pi - \varepsilon,$$

where $W = [1, MRPK/P, U, C]$, $\pi = [(\theta_0 - \theta_1\gamma_0), \theta_1, -\theta_1\gamma_1, -\theta_1\gamma_2]$ and $-\varepsilon = \theta_1 u_1$.

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 estimate the following equation, conditional on the firm investing:

$$MRPK/P = \alpha_0 + \alpha_1 U + \alpha_2 C + \alpha_3 O + \kappa_M \lambda + \eta_1, \tag{6}$$

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.[8]

[8] We are using Heckman's two-step estimation method in order to control for selectivity bias. See Heckman (1979) and Maddala (1983) for further discussion.

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

$$\Pr(INVDUM = 1) = \Pr\left[\left(\theta_0 + \theta_1\left(MRPK/P - \hat{h}\right)\right) > \varepsilon\right], \tag{7}$$

where $\varepsilon = -\alpha_1\varepsilon_1$. Consistent estimates of the trigger, h, are derived from

$$\hat{h} = \hat{\alpha}_1 U + \hat{\alpha}_2 C. \tag{8}$$

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.

To address question (3), 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 differences in firm size. Conditional on the firm investing, we estimate

$$inv/capital = \beta_0 + \beta_1 U + \beta_2 C + \beta_3 Y + \kappa_i \lambda + \eta_2, \tag{9}$$

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.

V. Variable Definitions

Estimated equations for the decision to invest, and the MRPK and the investment level, conditional on positive investment are presented in Section VI. 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 and others, 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.

Uncertainty Variable

Firm owners[9] were asked about their one-year and three-year 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 II).[10] For example, a firm owner who was absolutely certain that next year's demand would be 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 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 $E_0 \sigma_{te}^2$ 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

$$E_0 X_t = \left(1 + E_0 d_{te}\right) S_0$$

$$E_0 \sigma_t^2 = E_0 \sigma_{te}^2 S_0^2.$$

Table 4 shows the frequency distribution of the coefficient of variation, $E_0 \sigma_t / E_0 X_t$. A large proportion of firms show very low subjective uncertainty, with a coefficient of variation in the range of 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

[9] 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.

[10] 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. *Frequency Distribution of the Coefficient of Variation of Future Demand and Expected Demand Growth*

Coefficient of Variation		
Interval (percent)	1-year-ahead frequency (percent)	3-year-ahead frequency (percent)
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
>25	3.2	5.3
Mean	10.4	11.1
Expected Demand Growth		
	Frequency (percent)	Frequency (percent)
Positive (percent)		
>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 (percent)		
0–10	2.5	3.9
10–20	1.9	1.3
20–30	0.6	1.3
>30	1.3	1.3
Mean	20.7	21.8

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

change will occur with certainty. For one-year demand expectations, the next largest fraction of firms had a coefficient of variation in the range of 9–11 percent, followed by 7–9 percent. A relatively high percentage of firms also had a coefficient of variation in the 23–25 percent range. This illustrates that a significant proportion of firms seem quite uncertain about future demand since they distribute their points across a large number of different intervals. The three-year 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, to account for size and wealth differences across firms. This is an attempt to control for differences in risk aversion across entrepreneurs, by assuming it will be reflected in the sensitivity of investment to uncertainty. I assume that absolute risk aversion is decreasing in wealth and account for the dependence by rescaling the uncertainty term by the capital stock as a proxy for the entrepreneur's wealth. 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 expected demand growth. Most firms are optimistic: the largest proportion expect demand growth of more than 30 percent.

Irreversibility Proxies

Guiso and Parigi (1996) and Pattillo (forthcoming) classify firms as having more easily reversible investment if the firm 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 capital, buy used capital, 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.[11] This measure approximates the discount value of capital goods in the second-hand market. Types of capital that sell a smaller discount imply that the investment is more easily reversible. A dummy variable is constructed for use in the regressions. *REV* is set equal to one for firms with sales/replacement value of the capital stock above the sample mean, and zero otherwise.[12]

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

[12] The variable was converted to a dummy variable since its distribution contained some extreme values that could bias the results given that the estimation methods used do not completely control for heteroscedasticity.

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 offered by other firms in the industry that 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.

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 I, equation (A4), 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 markup factor, we need proxies for these values. The capital share is derived by estimating a Cobb-Douglas production function. The inverse of the markup factor is calculated following Domowitz, Hubbard, and Petersen (1987), who compute the firm's markup on unit prices. The markup is defined as the price cost margin, equal to the value of sales, less payroll, less cost of materials divided by the value of sales.

VI. Results

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-fourth 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.

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	–0.001
	(0.41)	(0.37)
Expected mean demand growth	0.003	0.003
	(2.12)	(4.28)
Variance of expected demand (β6)	–0.002	–0.005
	(0.34)	(2.68)
Variance* reversibility (β7)		0.005
		(2.21)
MRPK	0.032	0.099
	(2.32)	(5.34)
Number of observations	154	139
Ln (likelihood)	–97.85	–85.22
χ^2 test of restriction: β6 + β7 = 0		0.001(1), p=0.96

Source: Authors' estimates using Ghana Manufacturing Enterprise Survey data.
Notes: Figures in parentheses are the absolute value of the *t*-statistics. The coefficients are the marginal effects, evaluated at the mean of all observations.

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). The firm's expected mean growth in product demand 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) of Table 5 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 χ^2 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.

It should be noted, however, that there are potential difficulties inherent in using a Tobit procedure with survey data. First, if the distribution of the errors is non-normal, the Tobit estimates will be biased. Second, the presence of heteroscedasticity can lead to inconsistent estimates of the conditional mean, unlike in the standard regression case.

Although these results are encouraging (subject to the potential problems noted), 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 nonlimit observation and on the level of that variable is testable. Using a likelihood ratio statistic as in Greene (1997, p. 970), this hypothesis is rejected at the 1 percent level.[14] This suggests that the sample selection model may be more appropriate.

Sample Selection Model

The first set of results does not make allowance for firms with differing abilities to reverse their investment expenditures. The first two issues can be explored here: (1) is investment triggered when the MRPK reaches a hurdle level? and (2) does uncertainty increase the investment trigger? The empirical method involves three steps: a reduced-form probit model of the decision

[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 χ^2 value is 27.7.

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 whether 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 of which control for industrial sector. The reduced-form 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) of Table 6 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 noninvesting 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. As shown in column (3) of Table 6, 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) of Table 6 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) of Table 6 confirms that "waiting" for the MRPK to reach or exceed the investment trigger has the most powerful effect on the decision to invest. 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. 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) of Table 6 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 are determinants of the decision to invest, but they do not influence the investment level, conditional on positive investment. While higher expected mean demand growth does 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.

Sample Selection Model with Consideration of Irreversibility

Next I examine the following questions: (1) do the results still indicate that firms invest when the MRPK reaches a hurdle level when different degrees of reversibility are accounted for? (2) does uncertainty increase the investment trigger to a greater extent for firms with irreversible investment? and (3) 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 coefficients for firms with reversible investment and firms with irreversible investment.

Column (2) of Table 7 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

Table 6. *Investment Under Uncertainty Model*

	Reduced-form probit *INVDUM* = 1 if any investment, 0 otherwise (1)	*MRPK* = trigger selection model (2)	*MRPK* for all firms (3)	Structural probit *INVDUM* = 1 if any investment, 0 otherwise (4)	Investment/ capital$_{(-1)}$ selection model (5)
Constant	1.183	–1.341	–1.111	0.008	1.811
	(0.06)	(1.21)	(1.27)	(0.05)	(5.81)
Δ Value added/ capital$_{(-1)}$	0.028			0.040	0.025
	(2.89)			(2.65)	(2.27)
Profit rate$_{(-1)}$	0.024	–0.006	–0.141	0.053	0.045
	(2.89)	(0.35)	(1.88)	(3.11)	(3.55)
Ln (size)	0.061			0.045	0.009
	(1.72)			(1.04)	(0.23)
Firm age	–0.007			–0.002	–0.001
	(1.78)			(0.49)	(0.28)
MRPK	0.050				
	(2.52)				

Expected mean demand growth	0.001 (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		2.4e-04 (0.09)	3.7e-04 (0.37)		
Lambda		0.003 (0.03)			
$MRPK - \hat{h}$				0.099 (2.14)	
Number of observations	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-test (degrees of freedom)		14.8 (15, 100)	27.7 (14, 212)		5.3 (14, 79)

Source: Authors' estimates using Ghana Manufacturing Enterprise Survey data.

Notes: The figures in parentheses are the absolute value of the *t*-statistics. 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 (1)	*MRPK* = trigger selection model (2)	Structural probit *INVDUM* = 1 if any investment, 0 otherwise (3)	Investment/capital$_{(-1)}$ selection model (4)
Constant	1.061 (0.06)	–1.222 (0.54)	0.099 (0.59)	1.520 (4.63)
Δ Value added/ capital$_{(-1)}$	0.036 (2.58)		0.028 (1.69)	0.352 (2.61)
Profit rate$_{(-1)}$	0.030 (2.71)	0.022 (1.34)	0.024 (1.6)	0.024 (1.64)
Ln (size)	0.075 (1.95)		0.047 (1.09)	0.015 (0.37)
Firm age	–0.004 (0.85)		3.7e-04 (0.07)	0.002 (0.47)
MRPK	0.067 (2.39)			
Expected mean demand growth	0.009 (1.08)	–0.001 (2.50)		0.004 (3.08)
Variance of expected demand (β7)	–0.005 (2.51)	0.002 (6.2)		–0.002 (1.96)
Variance* Reversibility (β8)	0.004 (1.67)	0.003 (0.80)		0.001 (2.07)
Output/capital		0.098 (2.91)		
Capital/employment		1.6e-04 (0.74)		
Lambda		0.002 (0.03)		0.008 (0.06)
MRPK – $\hat{h}$			0.154 (3.15)	
Number of observations	197	96	149	83
Ln (likelihood)	–119.57		–85.78	
% correctly predicted	64		65	
Adjusted R^2		0.51		0.38
F-test (degrees of freedom)		12.02 (14, 81)		6.05 (15, 67)
χ^2 test of restriction: β7 + β8 = 0	1.68, $p = 0.002$	0.63, $p = 0.43$		6.65, $p = 0.01$

Source: Authors' estimates using Ghana Manufacturing Enterprise Survey data.

Notes: The figures in parentheses are the absolute value of the *t*-statistics, except for the *F*-test, where they are the degrees of freedom. The standard errors in column (3) have been corrected following Murphy and Topel (1985).

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) of Table 7 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) of Table 7. 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 variants of the above specification were estimated 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 affect 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 was combined with base year value added, rather than sales, to calculate the expected variance of demand. In the other, the variance of expected demand was 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 affect 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. Table 8 illustrates that the

Table 8. *Investment Under Uncertainty Model with Irreversibility Using Alternative Reversibility Proxy*

	Reduced-form probit *INVDUM* = 1 if any investment, 0 otherwise (1)	*MRPK* = trigger selection model (2)	Structural probit *INVDUM* = 1 if any investment, 0 otherwise (3)	Investment/ capital$_{(-1)}$ selection model (4)
Constant	1.170 (0.06)	–0.726 (0.69)	–0.027 (0.18)	1.727 (5.08)
Δ Value added/ capital$_{(-1)}$	0.031 (2.80)		0.028 (2.11)	0.263 (1.76)
Profit rate$_{(-1)}$	0.024 (2.65)	0.003 (0.18)	0.032 (2.34)	0.031 (2.4)
Ln (size)	0.060 (1.71)		0.067 (1.62)	0.022 (0.48)
Firm age	–0.003 (0.47)		–0.002 (0.47)	–0.002 (0.40)
MRPK	0.048 (2.39)			
Expected mean demand growth	0.009 (1.048)	–0.001 (0.15)		0.002 (1.48)
Variance of expected demand (β7)	–0.002 (2.65)	0.008 (2.43)		–0.002 (2.49)
Variance* Reversibility (β8)	0.001 (1.2)	–0.008 (1.32)		0.001 (2.06)
Output/capital		0.18 (8.18)		
Capital/employment		–0.001 (0.19)		
Lambda		0.002 (0.31)		0.073 (0.45)
$MRPK - \hat{h}$			0.121 (3.17)	
Number of observations	226	116	153	94
Ln (likelihood)	–140.37		–95.33	
% correctly predicted	67		61	
Adjusted R^2		0.54		0.25
F-test (degrees of freedom)		16.2 (14, 101)		4.48 (15, 78)
χ^2 test of restriction: β7 + β8 = 0	1.56(1), $p = 0.21$	0.31(1), $p = 0.99$		6.49 (1), p = 0.01

Source: Authors' estimates using Ghana Manufacturing Enterprise Survey data.

Notes: The table uses *REV* = 1 if firms either bought used capital, leased capital, or sold capital. The figures in parentheses are the absolute values of the *t*-statistics, except for the *F*-test, where they are the degrees of freedom. The standard errors in column (3) have been corrected following Murphy and Topel (1985).

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 the effect of uncertainty 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 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.

VII. 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 these 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. Moreover, 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.

APPENDIX I

The Model

The production function is Cobb-Douglas:

$$Q_t = \left[K_t^a \left(AL_t\right)^{1-\alpha}\right]. \tag{A1}$$

The firm faces a constant elasticity demand function:

$$B_t = D_t Q_t^{\mu-1}, \tag{A2}$$

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:

$$\Pi\left(K_t,\ w_t,\ D_t\right) = \max_{L_t}\ B_t Q_t - w_t L_t, \tag{A3}$$

subject to equations (A1) and (A2). Operating profits can be written in reduced form as

$$\Pi\left(K_t,\ w_t,\ \mathrm{D_t}\right) = \frac{1}{1+\beta} K_t^{1+\beta} Z_t, \tag{A4}$$

where

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

The business condition parameter Z_t can be written as

$$Z_t = f\left(\alpha,\ \mu,\ \beta;\ \mathrm{D_t},\ \mathrm{w_t},\ \mathrm{A_t}\right). \tag{A5}$$

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, with a constant mean growth rate η and variance σ^2.

The firm's dynamic investment problem is

$$V^*\left(K_t,\ Z_t\right) = \underset{\{x(\tau)\}}{Max}\ E_t \int_t^\infty e^{-r(\tau-t)}\left[\frac{1}{1+\beta} K_\tau^{1+\beta} Z_\tau d\tau - P_\tau dX_\tau\right] \tag{A6}$$

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

and to $dX_\tau \geq 0.$

It can be shown that the solution is that the firm invests when

$$\left[\left(K^\beta Z\right)/\left(r+\delta-\eta\right)\right]dK = \gamma/\left(\gamma-1\right)PdK, \tag{A7}$$

where $\gamma/(\gamma-1)=f(\eta,\ \sigma^2)$.

APPENDIX II

Subjective Probability Distribution Question from Ghana Survey

Entrepreneurs were asked the following question in the survey. Note that the survey was administered orally so that the survey field staff were able to provide clarification on the question:

> This question tries to ascertain by how much you expect the demand for your products 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.

		1 by what % do you expect demand for your product to grow next year? (in % terms)	2 by what % do you expect average demand for your product 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

Section V describes the method used for calculating the expected mean demand growth and the variance of expected demand. We assume that the central value of the open intervals “more than 30 percent” is 40 percent. Assuming alternative central values does not significantly change the results in Section VI.

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