Information Technology (IT) Investment Decisions Under Asymmetric Information: A Modified Rational Expectation Model

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INFORMATION TECHNOLOGY (IT) INVESTMENT DECISIONS UNDER ASYMMETRIC INFORMATION: A MODIFIED RATIONAL EXPECTATION MODEL

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In this paper, we propose that IT managers make investment decisions about new IT initiatives based on a modified rational expectation model. Unlike traditional rational expectation models, we emphasize the relevance of market uncertainty and its impact on the return of new IT investment. This results in information acquisition decisions by managers that can cause information asymmetry. This information asymmetry is endogenous and so the IT manager can become well informed if and only if it is beneficial to do so. We also capture different levels of IT investment across managers by introducing heterogeneity across managers in terms of different levels of initial capital. Based on a simulation analysis to validate our theoretical model, we find that it is the IT manager with larger initial capital outlay who is particularly interested in acquiring information about their IT investments in order to reduce any asymmetry with competitors. Furthermore, we find that holding other things constant, fewer IT investors are informed when information cost increases and in consequence the difference of investment level between the informed and uninformed investors is more pronounced.

Keywords: Asymmetric information; IT investment; rational expectations

1. Introduction

The IT revolution and its contribution to the economy have been widely studied in the literature.[1,2,3,16,19] Dedrick et al.[1] systematically discuss and confirm that greater investment in IT is associated with greater productivity growth. The evidence that supports this view is based on return of IT investment calculated from disaggregated firm level data.[4,5,6,7] Particularly, Anderson et al.[6] have found a positive relationship between firm value and relatively large IT spending *and* a negative relationship between firm value and relatively small IT spending. The question that is of interest here is that if greater IT investment is linked to greater firm value, then why don't all firms invest more in IT?

Specifically, we address the following research questions:
(i)   How do we measure the asymmetric information across IT managers?
(ii)   What happens to the size of IT investment if IT managers have asymmetric information regarding the future return of their IT investment?

Information asymmetry is created when one IT manager has more information than the others. We evaluate two types of managers: the *informed* and *uninformed* manager. The *informed manager* can perceive the return of his future investment by paying a cost for the information-gathering process. Whereas, the *uninformed manager* cannot observe the return but can observe the cost of the investment through the price and then deduce the future return. It is hypothesized that the existence of such information asymmetry may have significant effects on the level of IT investment. For example, the manager who has more information about the IT industry is perhaps more likely to have more profitable IT investments.

To address the research questions stated earlier, we propose a *theoretical model that suggests that different levels of IT investment across firms occur due to asymmetric information acquired by IT managers.* In other words, we investigate the *role of asymmetric information on IT investment decisions* by studying the link between the size of IT investment and the information used to make such decisions. We set up a rational expectation model wherein the measurement of asymmetric information depends upon the manager's initial capital expenditure. The rational expectation model introduces heterogeneous investors (in terms of initial capital) who decide whether to acquire costly information on the proposed IT investment. The number of informed investors is endogenously determined; in equilibrium, the market price reveals sufficient information such that the marginal investor is indifferent between acquiring and not acquiring information. We show that the informed investors have higher new IT investments, and we link the acquisition of information directly to initial capital expenditure by assuming that initial capital and absolute risk averseness are inversely related.

It should be noted that the authors of this paper are not the first to introduce the role of uncertainty in the context of IT investment decision making. As is typical of large capital outlays, IT investments are often evaluated using standard discounted cash flow techniques such as net present value. However, such techniques do not consider the uncertainties behind IT investment decisions. Kambil et al.,[9] Benaroch and Kauffman[10], Zhu,[11] and Tallon et al.[12] have previously addressed this shortcoming using real option analysis. These studies view technology investments as real options in the presence of asymmetric information across decision makers. In this setup, under uncertainty, firms may have the option to defer an investment until a later period. One specific assumption about this approach is that the firm has a monopoly power over an investment opportunity. In contrast, our proposed model views IT investments as asset investments (see Ref. 13, 14, and 15) and all IT decision makers as price-takers in the competitive market for the investment opportunity (which is important according to Ref 17). In addition, our model tries to investigate the inherent uncertainty in such decisions and makes the best choice before making investments.

Similarly, a study by Zhu and Weyant[8] shows how asymmetric information about firm's cost function affects firms' decisions to adopt the technology. Using a two player, two stage game theoretic model, they define asymmetric information as a situation wherein one of the firm's managers know its own cost function but do not know the cost of their competitor. This model demonstrates that market uncertainty may actually induce firms to act more aggressively under certain conditions. This study also shows that having better information is not always a good thing. In contrast to Zhu and Wyant[8] our model emphasizes the *market uncertainty* on return of new IT investment. This leads to an information acquisition decision by each manager. In this setup, the information

asymmetry is endogenous and so the decision maker will become informed if and only if it is beneficial to do so.

The rest of the paper is organized as follows. The next section characterizes the model and the corresponding results. Following this we use a simulation to validate our model. The final section provides some concluding remarks including implications for practice.

2. The Model

Our proposed model is an extension of the *noisy rational expectation model* with costly information acquisition introduced by Grossman and Stiglitz.[13] In order to capture the different levels of IT investment across managers we introduce heterogeneity across managers in terms of different levels of initial capital. One result of this assumption is that, in equilibrium conditions, some managers acquire an information advantage over others.

We assume the market for a new IT investment has a large number of investors, such that each investor has an infinitesimal effect on the IT market. The investors are uniformly distributed over the range [0, 1] according to the level of their initial capital. Besides this risky IT investment, the investor also has a risk-free asset to invest with a lower average return. Each investor makes two sequential decisions: strategic information acquisition about IT investment and demand decision of this risky IT investment (based on the important phases to formulate business strategies proposed by Ref 18). If the investor decides to acquire information, she pays a cost c. Otherwise she remains uninformed about the future return of the IT investment. In order to focus on the information acquisition decision, we *assume that there are no barriers to investment other than the cost of information*.

The decision to acquire information on a new IT investment is based on a comparison of the expected utility when informed to the expected utility when uninformed. To emphasize the role of asymmetric information, we assume IT manager as a representative of the firm who makes IT investment decisions to bring the highest profit or utility for the firm. This is true if the IT investment levels are small. It may be true that CIO's in most organizations need to have presidential or board level approval for capital expenditures above some dollar limit, however, the final decision may largely depend on how much information they brought to the board regarding the IT investment. By assuming the IT manager as a single investor who maximizes his utility, we eliminate the possibility of a principal-agent problem between the firm and its manager.

The information acquisition process leads to two types of investors in the market: the Informed (I) investors with information on IT market, and the Uninformed (U) investors. Below we identify a cutoff default initial capital $\overline{K}$, such that investors with initial capital above this cutoff become informed, and the investors with default investment below the cutoff remain uninformed. Given the distribution of initial capital $f(K_0)$, a higher cutoff $\overline{K}$ implies a lower proportion of informed investors (as the proportion of informed investors equals to $\int_{\overline{K}}^{1} f(K_0)dK_0 = 1 - \overline{K}$). Both informed and uninformed investors make demand decisions about the new IT investment. The quantity of investment of informed investors depends on the revealed information on the future return of the new IT investment. The demand of uninformed investors depends on

the asset prices only. Equilibrium prices clear the market by equating IT investment supply to its demand.

Since our rational expectation model is based on a two-stage game, we use the backward method. That is, starting with the second stage, we first solve the demand decisions given the information type. This is achieved by maximizing the IT investor's expected utility of future total return. The future total return is calculated from the return of current new IT investment and the return of risk-free investment. The First Order Condition (FOC) from this maximization producer yields the demand of new IT investment for both types of investors. Second, we solve the equilibrium price by equating total IT investment supply (which is given) to total IT investment demand (sum up the demand of new IT investment of informed and uninformed investors). We can then use the investment demand and supply information to make the first stage decision – that is the information acquisition decision. This decision is made by comparing the expected utility of being informed and being uninformed. The investor will choose to be informed if the expected utility of being informed is higher than that of being uninformed. The detail derivation and corresponding results for this analysis are elaborated in the next section.

2.1. The *New IT Investment Decision*

Assume that each investor has an initial capital K_0 that will be invested in two types of assets: a risk-free investment (also call risk-free asset) with normal return and a risky IT investment (also called risky asset) with higher return. Denote by I^l the demand of risky asset by individual of type l ($l = I, U$). Assume that investors have access to a risk-free asset available in limitless supply. Then the investor of type l will borrow/lend an amount of the risk-free asset equal to:

$$K_0 - (\rho c + I^l P),$$

where ρ is a function that equals zero if the investor is uninformed ($l = U$) and one if the investor is informed ($l = I$), P is the price of risky asset, and c is the information cost paid by an informed investor. Intuitively, it is the amount of money from initial capital (K_0) after paying off the information cost (ρc) and the new IT investment ($I^l P$).

Denote the gross real return of risky asset and the risk-free asset by R and r respectively. The variable R is defined as:

$$R = \theta + \varepsilon, \tag{2.1}$$

where the random variable θ has a normal distribution with mean $\overline{\theta}$ and variance ϕ. The error term ε is normally distributed with zero mean and variance σ^2. The random variables θ and ε have a multivariate normal distribution with $E(\theta\varepsilon) = 0$ and $Var(R \mid \theta) = \sigma^2$. θ is observable to the informed investors at cost c. Thus, given the

risk-free return r, the investor of type k with initial capital K_0 has future total investment return (in period one) K_1^l of the following form:

$$K_1^l = (K_0 - \rho c)r + I^l(R - rP).$$

That is, the future investment return consists of two parts: the total return from new IT investment $I^l R$, and the return from the risk-free investment r($K_0 - (\rho c + I^l P)$).
Next, we characterize the maximization of expected utility for two types of investors. Assuming an exponential utility function, the investor of type l ($l = I, U$) has utility $V(K_1^l)$ of the form:

$$V(K_1^l) = -\exp(-aK_1^l), \tag{2.2}$$

where a is the coefficient of absolute risk aversion for an individual. Given the above utility function, the demand for risky financial assets will rise with initial capital if the investors with higher capital are less risk averse. It is reasonable to assume that one will be less risk averse if he owns larger initial capital. We thus adopt the following simple form of the inverse relationship between initial capital and risk aversion: $a = a(K_0) = 1/K_0$.

Both informed investors and uninformed investors maximize the above expected utility in terms of the future capital income. Since the asset return components θ is observable to the informed investors, the expected utility of the informed investors ($l = I$) can be written as follows:

$$E(V(K_1^I \mid \theta)) = -\exp\left(-a\left(E(K_1^I \mid \theta) - \frac{a}{2}Var(K_1^I \mid \theta)\right)\right)$$

$$= -\exp\left(-a\left((K_0^I - c)r + I^I(\theta - rP)\right) + \frac{a^2}{2}I^{I2}\sigma^2\right)$$

The first order condition to the maximization of the above expected utility with respect to I^I yield:

$$I^I = \frac{\theta - rP}{a\sigma^2} \quad \text{where } a = \frac{1}{K_0} \tag{2.3}$$

The demand is positively related to the observed return, and negatively related to the price and the variance. Note that the larger the initial capital is, the larger the demand for risky assets because the individual is less risk averse.

The uninformed investors ($l = U$) infers partial information about this realized asset return component from the price function $P^*(\theta, s)$, where s, the random per capita supply of the risky asset, is independent of the random variables θ and ε. Thus the expected utility is as follows:

$$E(V(K_1^U \mid \theta, P^*)) = \exp\left(-a\left[E(K_1^U \mid (\theta, P^*)) - \frac{a}{2}Var(K_1^U \mid (\theta, P^*))\right]\right)$$

$$= \exp\left(-a\left(K_0^U r + I^U\left(E(R \mid P^*) - rP\right)\right) + \frac{a^2}{2}I^{U2}Var(R \mid P^*)\right)$$

where $E(R \mid P^*)$ denotes the expected return on asset for an uninformed investor based on the observed price. The first order condition to the maximization of the above expected utility with respect to I^U yields the following demand function for the uninformed:

$$I^U = \frac{E(R \mid P^* = P) - rP}{aVar(R \mid P^* = P)}, \qquad a = \frac{1}{K_0} \qquad (2.4)$$

Comparing Eq. (2.3) and Eq. (2.4), the demand of uniformed investor differs from that of the informed both in terms of the underlying variance in the return and in the expected return. The implications for relative demands of the informed versus the uniformed will be discussed in more detail in the equilibrium section.

2.2. Equilibrium Price Distribution

The equilibrium price of a new IT investment equates investment supply to investment demand. The supplied asset is purchased by both informed and uninformed investors. For the moment, we take as given that there is a common cutoff initial capital ($\overline{K}$) across investors with only investors with initial capital above $\overline{K}$ becoming informed. Thus the demand for the risky asset is the sum of the demand by informed investors and the demand by uninformed investors. Given the uniform distribution of investors, the demand is the integral of investors' demand over the initial capital distribution, and we have the following equilibrium condition for the risky asset:

$$\int_0^{\overline{K}} I^U f(K_0)dK_0 + \int_{\overline{K}}^1 I^I f(K_0)dK_0 = \int_0^1 sf(K_0)dK_0;$$

where s is per capita supply of the risky asset with mean $\overline{s}$ and variance χ. Therefore, the total demand in the left side of the above equation equal to the total supply in the right side.

According to the demand decisions based on Eqs. (2.3) and (2.4), the equilibrium condition can be simplified as:

$$s = \frac{E(R \mid P^* = P) - rP}{Var(R \mid (P^* = P)} \cdot \int_0^{\overline{K}} \frac{1}{a(K_0)}dK_0 + \frac{\theta - rP}{\sigma^2} \cdot \int_{\overline{K}}^1 \frac{1}{a(K_0)}dK_0, \qquad (2.5)$$

Similar to Grossman and Stiglitz, we define a prior price function w in order to characterize the equilibrium price.[13] In our context, the prior price function is defined as:

$$w(\theta, s) = \theta - \frac{\sigma^2(s - \overline{s})}{\frac{1}{2}(1 - \overline{K}^2)}, \qquad (2.6)$$

where $\bar{s}$ is the mean of random per capita supply of the asset. The price w equals the random variables θ plus a supply noise and an observation error as well, with its expectation $E(w \mid \theta) = \theta$ and variance $Var(w \mid \theta) = 4\sigma^4 \chi^2 / (1 - \bar{K}^2)^2$. This variance measures how effective the uninformed investors infer information from the perceived price. Obviously, the observation error σ and supply noise χ affect the information precision for the uninformed investors.

Assuming that θ, ε and s are mutually independent with a joint normal distribution, there exist an equilibrium price such that the equation in Eq. (2.5) are satisfied. The particular form of the prices is:

$$P = \frac{\dfrac{\frac{1}{2}(1-\bar{K}^2)\cdot w(\theta,s)}{\sigma^2} + \dfrac{\frac{1}{2}\bar{K}^2 \cdot E(R \mid w(\theta,s))}{Var(R \mid w(\theta,s))} - \bar{s}}{\dfrac{1}{2}r\left(\dfrac{1-\bar{K}^2}{\sigma^2} + \dfrac{\bar{K}^2}{Var(R \mid w(\theta,s))}\right)}, \tag{2.7}$$

Proof: See Appendix A. Note that Appendix A also demonstrates that variance in the return for asset , $Var(R \mid w(\theta,s))$ depends on the variance in information noise (ϕ), observation error (σ), and supply noise (χ).

From Eq. (2.7), it can be shown that an increase in the information noise, observation error or supply noise decreases the informativeness of the price system. Further, it is easy to see that the market price reveals more information regarding the return if the cutoff $\bar{K}$ is lower, implying a higher proportion of investors who are informed.

2.3. Equilibrium and Information Acquisition Decision

We now define the equilibrium cutoff initial capital $\bar{K}$, such that for the marginal investor with capital $\bar{K}$, the expected utility of becoming informed is equal to that of remaining uninformed. Given the above demand decisions and price functions, we derive the expected utility from being informed ($E(V(K_1^I))$) versus being uninformed ($E(V(K_1^U))$) in the Appendix B. For the marginal investor, $E(V(K_1^I)) = E(V(K_1^U))$, which can be solved for the cutoff of initial capital for the marginal investor, $\bar{K}$. In particular, we have the following equilibrium condition that determines the capital of the marginal investor:

$$\exp(a(\bar{K})rc) \cdot \sqrt{\frac{Var(R \mid \theta)}{Var(R \mid w)}} = 1, \quad \bar{K} \in (0,1] \tag{2.8}$$

Given r, c and the variance parameters, we can solve Eq. (2.8) for the equilibrium $\bar{K}$.

To better understand the above equilibrium, we now characterize the individual decision of information acquisition, which compares the expected utility of being informed and uninformed. The expected gain of acquiring information is the difference between the expected utility of being informed and the utility of being uninformed.

Appendix B and Appendix C provide a detailed derivation of the expected gain. An investor becomes informed if the expected gain is positive. We show that the expected gain to becoming informed is an increasing function of the initial capital and a decreasing function of the cost of information at Appendix C.

The above results suggests that the investors who have the lowest information cost per unit of initial capital (hereafter referred to as the *information cost ratio*, c/K_0) will purchase the information first, and so on until the gain of acquiring information goes to zero and the equilibrium $\overline{K}$ is determined. We thus have the following proposition:

Proposition 1: Given our assumption of a uniform distribution of investors' capital, information cost ratios are monotonically decreasing over the range $[0,1]$. There exists a cutoff information ratio, $c/\overline{K}$, such that an investor purchases information if and only if $c/K_0 \leq c/\overline{K}$.

Proposition 1 provides a characterization of which investors will acquire information concerning the new IT investment; those investors with initial capital $K_0 > \overline{K}$ become informed and the other investors remain uninformed. The intuitive reasoning for this result is that the lower risk aversion that accompanies higher initial capital results in individuals acquiring a larger new IT investment; this makes it more advantageous to pay the fixed cost c to become informed regarding such risky investment.

Now consider the marginal investor, who is indifferent between being informed and uninformed in equilibrium. If we increase the information cost, then the gain of information for the original marginal investor will be negative, and the marginal investor will have a clear preference to remain uninformed. We thus have the following proposition with respect to the equilibrium cutoff level of initial capital $\overline{K}$.

Proposition 2: Given the parameters defining the home and foreign markets, the equilibrium cutoff capital, $\overline{K}$, is an increasing function of the information cost. That is, $\partial \overline{K} / \partial c \geq 0$.

See Appendix D for the proof of Proposition 2. Proposition 2 has important implications for the discussion of the different level of investment decision.

To explore this issue, we first discuss how costly information leads to different level of investment by comparing expected demands derived from Eqs. (2.3) and (2.4). The expected demand by an uninformed investor is less than his expected demand of informed investors. That is:

$$E(I^U) \leq E(I^I), \tag{2.9}$$

where strict inequality holds if and only if the information cost is positive ($c > 0$). The detail proof of this result appears at Appendix E.

Intuitively, there are two factors that lead to the above results. First, the uninformed investors can only infer partial market information through the asset prices, which results in larger potential risks that limit their investments. Second, the uninformed investors have smaller initial capital, which makes them more risk averse. Thus they have less risky asset investment than informed investors.

If we summarize the expected demand of investment for both types of investors, the above results lead to the following proposition.

Proposition 3: The expected demand of one's new IT investment is lower for the uninformed investors than for the informed investors.

Proposition 3 implies different new IT investment levels among investors under asymmetric information. A positive information cost for the market entails information asymmetry. Thus, we have the result in Eq. (2.9). By presenting a dynamic information acquisition process for investors and explicitly introducing information costs, we can further characterize the change in the difference of investment level by a change in information cost. The difference can be measured from the ratio of the demand between the informed and the uninformed:

$$\frac{E(I^I)}{E(I^U)} = \frac{\sigma^2 + \phi^2 - \frac{\phi^4}{\phi^2 + \frac{4\sigma^4\chi^2}{(1-\bar{K})^2}}}{\sigma^2}$$

Now suppose that the information cost c increases. Recall that in Proposition 2 we have shown that the cutoff initial capital for the marginal investors $\bar{K}$ is an increasing function of information cost. In addition, the value of $\dfrac{E(I^I)}{E(I^U)}$ is increased from above equation. Therefore, we have the next proposition.

Proposition 4: The investment level between the informed and uninformed will be more pronounced if the information cost increases.

Another new feature of our model is that we identify different degrees of investment across investors. Proposition 1 suggests that the investors with a lower information cost ratio will be informed. Proposition 3 further shows that these informed investors have more investment. Thus we anticipate that investors with a relatively low information cost ratio will be more likely to have larger investments.

Proposition 5: Given the information cost for acquiring information, investors with larger initial capital tend to invest more in the new IT investment.

The information cost ratio allows us to interpret the effect of asymmetric information on investment levels in two ways. First, we expect to see that the different levels of investment will be more pronounced if the cost for information gathering increases. Second, we have an implication to further empirical studies that the extent of investment tends to be larger for those investors who have larger initial capital.

3. An Example Simulation

The theoretical model proposed in the last section analyzed how asymmetric information leads to different degrees of IT investment. In this section, we investigate the effect of asymmetric information on the different degrees of investment via the use of simulations.

The simulation is conducted using Maple software. To do this simulation, we first initiate the parameters in our model using Macro data (for the mean of the gross return of risky asset and risk-free asset) or calibrated parameters from other literature (the variances of the return, observation error and asset supply are referred from Coval).[20] Second, we generate 1000 observations for the random supply of new IT investment and the return of this IT investment according to its normal distribution using the given mean and variance. Third, for a fixed cost, we calculate the cutoff initial capital and thus the proportion of informed investors. We further calculate the price and the demand of new

IT investment for each observation. We also calculate the gain of information acquisition for each investor. Finally, we take an average of the new IT investment over 1000 observations for each investor. In order to show how information costs affect the level of new IT investment, we repeat the third step by increasing the information cost, and then collect the new demand of IT investment. We illustrate these results in Figure 1 and Figure 2.

Table 1 lists the simulation parameters for the model. The average gross return for risky asset is set to 1.12 referring to the annualized monthly return for equity asset, including IT assets. The return of risk-free asset is set to 1%. The variances of the return, observation error and asset supply are referred from Coval.[20] The mean of the asset supply is set to be 1 unit. The initial capital is assumed to be uniform distribution in the model across the investors; however we choose an array of the number between 0 and 1 so that we can describe the individual decisions.

Table 1. The parameter values

Parameters	Values
The return for risk-free asset	$r = 1.01$
The average return for risky assets	$E(\theta) = 1.12$
The variance for the return	$\phi = 0.5$
The variance of the observation error of the return	$\sigma = 0.4531$
The average supply of risky assets	$\bar{x} = 1$
The variance of the asset supply	$\chi = 0.5735$
The distribution of the initial investment	$[0,.1,.2,.3,.4,.5,.6,.7,.8,.9,1]$
The coefficient of risk aversion	$a = a(K_0) = 1/K_0$
The information cost	$c_1 = c_{t-1} + 0.04$

For calculating information cost, we use a recurrence function $c_t = c_{t-1} + 0.03$ to generate a series of cost for the purpose of repeated simulations, where t is used to represent different simulations. The initial cost c_0 is chosen to be close to 0 so that we try to see the situation with the low information cost. The choice of this function follows the criteria: (1) for each information cost, there exists an equilibrium $\bar{K}$ with the range of $[0,1]$, where $\bar{K}$ is the cutoff initial capital for the marginal investor, who is indifferent between being informed and being uninformed; and (2) the different information costs chosen can properly reflect the effect of asymmetric information on the different degrees of investment.

The simulations describe the information acquisition process and investment decision. We first generate 1000 observations of the asset returns and the total asset supplies, which are normally distributed with means and variances given in Table 1. To identify the information acquisition process, we first calculate the cutoff initial capital for the marginal investor in equilibrium according to Eq. (2.8). Then each investor with different initial capital decides to be informed or not informed based on the sign of the gain function at Appendix E. If the gain is positive, then he becomes informed. Otherwise he stays uninformed. Both types of investors make their investment decision based on the demand function in Eqs. (2.3) and (2.4) where prices are calculated from Eq. (2.7). For the same draw of asset returns and supplies, we repeat the information acquisition and investment decisions at different information costs.

Figure 1 illustrates the relationship between the proportion of informed investors and the information costs. When cost is as low as 0.004, the cutoff capital is approximately 0.67. In an economy with the uniform distribution of the investors, this implies approximately 33 percent of investors become informed. A check indicates that the gain to information acquisition is negative for the investors with initial capital less than 0.67, and positive for the investors with initial capital higher than 0.67. When the information cost increases from 0.004 to 0.274, the cutoff initial capital for the marginal investors increases from 0.67 to 0.99. That is, an increase in the information cost increases the percentage of uninformed investors.
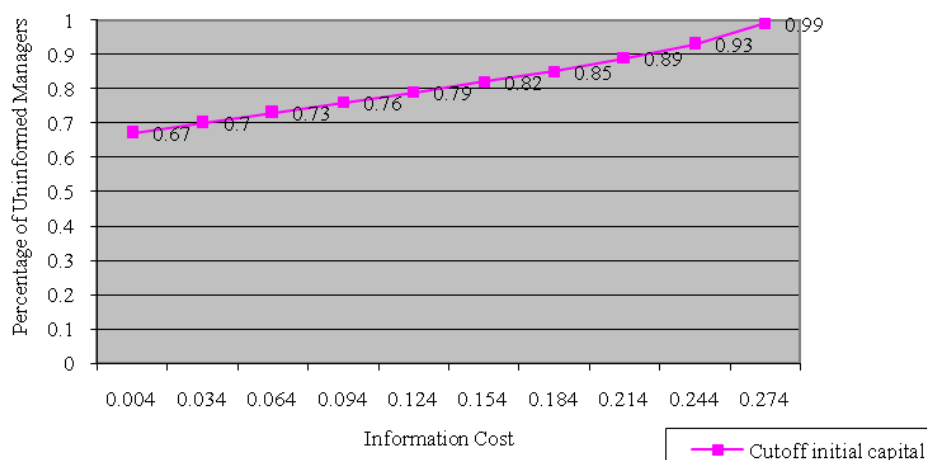

Fig. 1. Information cost and information acquisition decision

Figure 2 illustrates the cumulated IT investment for the mangers that are uniform distributed between 0 and 1. We took four representative cases with the equilibrium cutoff initial capital at 0.67, 0.73, 0.82 and 0.93 (corresponding to the information cost ratio 0.004, 0.064, 0.154 and 0.244 respectively; notice the rest of the cases will follow the same pattern as one of these four cases). We report the cumulative level of the investment from the investors with initial capital 0.1 to 1. As we expected, the level of investment is low for the uninformed investor with the low initial capital, and the level of investment rises when the investors becomes informed. For example, when cost is equal 0.064, the cutoff initial capital is 0.73. This implies that, in our sample, the investor with initial capital 0.8 will become informed. This appears in the figure that there is a jump in the level of investment at manager with initial capital 0.8. The jump points happen at initial capital at 0.9 and 1 for the case of cost = 0.154 and cost = 0.244 respectively.
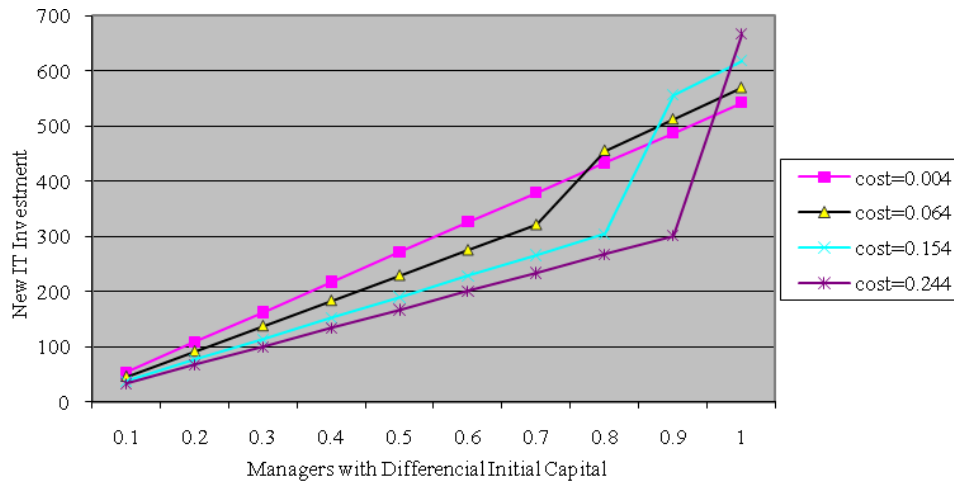
Fig. 2. Differencial new IT investment across managers

Figure 2 also indicates the difference in new investment between informed managers and uninformed managers is more pronounced when information costs increase. This can be seen from the curves before kink points and after. Before the kink points, the uninformed investors invest less when information cost increases. This is because high information costs lead to less proportion of informed investors, and thus decrease the "informativeness" of the price system. After the kink points, we see the new IT investment jumped to a higher level for the higher information cost cases, which is caused by the informed managers. Therefore, we can see that the difference in the level of new IT investments between informed managers and uninformed managers becomes bigger.

In summary, the simulations detailed above illustrate the effect of asymmetric information on different levels of IT investment. Holding other things constant, *fewer IT investors are informed when information cost increases, and in consequence the difference of investment level between the informed and uninformed investors is more pronounced.*

4. Conclusion

This paper explores the role of asymmetric information in explaining the different levels of IT investment made by IT managers at the firm level. Our model considers the information acquisition process with heterogeneous investors as the context in which such investment decisions are made. Using a simulation, we demonstrate a direct link between initial capital available, the cost of acquiring information and the different levels of new IT investments made by IT managers.

Recent empirical research at the firm level suggests that the marginal returns on investments in IT far exceed the marginal cost.[21,13] Anderson et al. provide further evidence that firm value is positively associated with relatively large IT investment.[6] All

of this evidence reiterates the importance of IT investment and its impact on firm value or productivity. However, in contrast, our study of the different levels of IT investment in firms indicates that not all firms have taken advantage of IT investments. The reason, as our model and simulation shows, is related to the lack of awareness and understanding by managers of the true nature of returns on IT investment due to the cost of acquiring information. Specifically, we found that firms with larger initial capital outlay have a competitive advantage in their ability to acquire information about the context of their IT investment portfolio because the information cost per unit of investment is relatively low.

Our research has important implications for IT managers who make critical investment decisions in their firms, particularly relating to new IT initiatives. The results also provide some indication as to how IT projects should be evaluated and the managerial ability needed to effectively invest and optimize an organization's IT portfolio. For example, IT managers who can obtain more information about the IT industry and different IT applications and understand costs and risks associated with emerging IT, are perhaps, likely to have more profitable IT investments.

Indeed, the theoretical model puts some limitations on real application. For instance, we assume an exponential utility and negative relationship between risk aversion and initial investment capitals to simplify the calculation. Therefore it leaves many issues open for further empirical study to justify the information role relating to IT investments. For example, an issue for further research is the need to evaluate the correlation between the size of IT investments (or a proxy such as the number of IT projects) and the measurement of asymmetric information. Our theoretical model posits that if managers have more initial capital outlay on related IT investment choices, we should find an increase in the investment devoted to new IT investment. This follows from the fact that the managers with a larger initial capital find it advantageous to acquire information on the new IT investment, and thus eliminate the asymmetric information rationale for the IT investment. The larger initial capital can be a result of previous investment or previous projects. One possible way to empirically analyze the role of asymmetric information on the size of IT investment is to check the correlations between the current investment and previous investment.

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Appendix A. Derivation of Price Functions

We prove that the price of the asset is a solution to Eq. (2.5). We start with:

$$P = \frac{\dfrac{\frac{1}{2}(1-\bar{K}^2)\cdot w(\theta,s)}{\sigma^2} + \dfrac{\frac{1}{2}\bar{K}^2 \cdot E(R|w(\theta,s))}{Var(R|w(\theta,s))} - \bar{s}}{\dfrac{1}{2}r\left(\dfrac{1-\bar{K}^2}{\sigma^2} + \dfrac{\bar{K}^2}{Var(R|w(\theta,s))}\right)}$$

Because θ, ε and s are mutually independent, with Eq. (2.6) we have the following equations:

$$E(R \mid w) = E(w) + \frac{\text{cov}(R, w)}{Var(w)}(w - E(w)) = E(\theta) + \frac{\phi^2}{Var(w)}(w - E(\theta))$$

$$Var(R \mid w) = Var(R) - \frac{[\text{cov}(R, w)]^2}{Var(w)} = \phi^2 + \sigma^2 - \frac{\phi^4}{Var(w)}$$

$$Varw = \phi^2 + \frac{4\sigma^4 \cdot \chi^2}{(1 - \bar{K}^2)^2}$$

With above equations, we can see that P is a linear function of the price function w, thus we have:

$$E(R \mid P^*(\theta, s) = P) = E(R \mid w(\theta, s))$$

$$Var(R \mid P^*(\theta, s) = P) = Var(R \mid w(\theta, s))$$

Note that the risk aversion coefficient is:

$$a(K_0) = \frac{1}{K_0}$$

Substituting the price function into the right side of the equilibrium condition (first equation of Eq. (2.5)), we have

$$\frac{\theta - rP}{\sigma^2} \cdot \int_{\bar{K}}^{1} \frac{1}{a(K_0)} dK_0 + \frac{E(R \mid P^* = P) - rP}{Var(R \mid (P^* = P))} \cdot \int_{0}^{\bar{K}} \frac{1}{a(K_0)} dK_0$$

$$= \frac{\theta - rP}{\sigma^2} \cdot \frac{1}{2} K_0^2 \Big|_{\bar{K}}^{1} + \frac{E(R \mid w(\theta, s)) - rP}{Var(R \mid w(\theta, s))} \cdot \frac{1}{2} K_0^2 \Big|_{0}^{\bar{K}}$$

$$= s$$

Thus we have shown that demand for the asset at the specified equilibrium price does equal the supply of that asset.

Appendix B. Calculation of the Expected Utility for the Informed and Uninformed

We calculate below an explicit form for the expected utility of an informed investor. To begin, we have expected utility:

$$E(V(K_1^I) \mid K_0^I, \theta, s) = -\exp\left(-a\left(E(K_1^I \mid K_0^I, \theta, s) - \frac{a}{2} Var(K_1^I \mid K_0^I, \theta, s)\right)\right).$$

Using demand functions and the fact that the price is the function of (θ, s), we have

$$E(K_1^I \mid K_0^I, \theta, s) = (K_0^I - c)r + I^I(E(R \mid \theta) - rP)$$

$$Var(K_1^I \mid K_0^I, \theta, s) = (I^I)^2 Var(R \mid \theta)$$

Substituting these equations, we obtain,

$$E(V(K_1^I) \mid K_0^I, \theta, s) = -\exp\left(-a(K_0^I - c)r - \frac{(E(R \mid \theta - rP))^2}{2\sigma^2}\right)$$

Recall that the price is a linear function of w_λ which is also determined by a particular (θ, s). Applying this to above equation yields:

$$E\left(V(K_1^I) \mid K_0^I, \theta, s\right) = -\exp\left(-a(K_0^I - c)r\right) \cdot E\left[\exp\left(-\frac{(E(R \mid \theta) - rP)^2}{2\sigma^2}\right) \mid K_0^I, P\right]$$

Now define:
$$g = Var(E(R \mid \theta)/w) = Var(\theta \mid w)$$
$$z = \frac{E(R \mid \theta) - rP}{\sqrt{g}}$$

We thus obtain:

$$E(V(K_1^I) \mid K_0^I, P) = \exp(arc)V(rK_0) \cdot E\left[\exp\left(-\frac{gz^2}{2\sigma^2}\right) \mid w\right] = \exp(arc)V(rK_0) \cdot \frac{\exp\left(\frac{-(E(z \mid w))^2 \frac{g}{2\sigma^2}}{1 + 2\frac{g}{2\sigma^2}}\right)}{\sqrt{1 + 2.\frac{g}{2\sigma^2}}}$$

Note that:

$$E(E(R \mid w)) = E(R \mid w) = E(\theta) + \frac{\phi^2}{Varw}(w - E(\theta))$$

$$E(z \mid w) = \frac{E(R \mid w) - rP}{\sqrt{g}}$$

So we have:

$$E\left[\exp\left(-\frac{gz^2}{2\sigma^2}\right) \mid w\right] = \sqrt{\frac{Var(R \mid \theta)}{Var(R \mid w)}} \cdot \exp\left(-\frac{(E(R \mid w - rP))^2}{2Var(R \mid w)}\right)$$

Thus, combining the above expressions, we have that,

$$E(V(K_1^I) \mid K_0^I, P) = \exp(arc) \cdot V(rK_0) \cdot \sqrt{\frac{Var(R \mid \theta)}{Var(R \mid w)}} \cdot \exp\left(-\frac{(E(R \mid w - rP))^2}{2Var(R \mid w)}\right)$$

Similarly, the expected utility for the uninformed investors is given by:

$$E(V(K_1^U) \mid K_0^U, P) = V(rK_0) \cdot \exp\left(-\frac{(E(R \mid w - rP))^2}{2Var(R \mid w)}\right)$$

Appendix C. Calculation of the Gain to Information Acquisition

The expected gain of information acquisition is obtained by comparing the utility of becoming informed to that of remaining uninformed.   Based on Appendix B, the gain is given by:

$$G = E(V(K_1^I) \mid K_0^I, P) - E(V(K_1^U) \mid K_0^U, P)$$

$$= \exp(arc) \cdot V(rK_0) \cdot \cdot \exp\left(-\frac{(E(R \mid w - rP))^2}{2Var(R \mid w)}\right)\left(\sqrt{\frac{Var(R \mid \theta)}{Var(R \mid w)}} - 1\right)$$

It follows that $\dfrac{\partial G}{\partial K_0} \geq 0$ and $\dfrac{\partial G}{\partial c} \leq 0$.

Appendix D. Proof of Proposition 2

The proof of Proposition 2 follows from the equilibrium conditions. According to the equilibrium Eq. (2.8), we have

$$\exp(a(\bar{K})rc)\sqrt{\frac{Var(R \mid \theta)}{Var(R \mid w)}} = \exp(a(\bar{K})rc) \cdot \sqrt{\frac{\sigma^2}{\sigma^2 + \phi^2 - \frac{\phi^4}{\phi^2 + \frac{4\sigma^4\chi^2}{(1-\bar{K}^2)^2}}}} = 1 \text{ (AD.1)}$$

Taking square and then logarithms of both sides of the above equation and differentiating with respect to $\bar{K}$ and c, we obtain after rearranging:

$$\frac{\partial \bar{K}}{\partial c} = \frac{1}{\dfrac{c}{\bar{K}} + \dfrac{8\phi^4\sigma^4\chi^2}{A\left(\phi^2 + \frac{4\sigma^4\chi^2}{(1-\bar{K}^2)^2}\right)^2 r\left(1 - \bar{K}^2\right)^3}} \geq 0$$

where $A = \sigma^2 + \phi^2 - \dfrac{\phi^4}{\phi^2 + \frac{4\sigma^4\chi^2}{(1-\bar{K}^2)^2}}$, note that $A = \sigma^2 \exp(2a(\bar{K})rc) \geq 0$ from Eq.

(AD.1). Thus we have shown that the equilibrium cutoff $\bar{K}$ is monotonically increasing in the information cost c.

Appendix E. Comparison of Expected Asset Demand

From Eq. (2.3), we have:

$$E(I^I) = \iint I^I f(\theta)f(s)d\theta ds = \frac{1}{a\sigma^2}(\bar{\theta} - \iint rPf(\theta)f(s)d\theta ds)$$

From Appendix C, we already have:

$$E(I^U) = \frac{1}{a(\sigma^2 + \phi^2 - \frac{\phi^4}{\phi^2 + \frac{4\sigma^4\chi^2}{(1-\bar{K})^2}})}(\bar{\theta} - \iint rPf(\theta)f(s)d\theta ds)$$

Thus, comparing $E(I^I)$ with $E(I^U)$ leads to:

$$\frac{E(I^I)}{E(I^U)} = \frac{\sigma^2 + \phi^2 - \dfrac{\phi^4}{\phi^2 + \frac{4\sigma^4 \chi^2}{(1-\bar{K})^2}}}{\sigma^2} \geq 1 \qquad (AE.1)$$

The last inequality is a natural result from equilibrium Eq (2.9):

$$\exp(a(\bar{K})rc)\sqrt{\frac{Var(R \mid \theta)}{Var(R \mid w)}} = \exp(a(\bar{K})rc).\sqrt{\frac{\sigma^2}{\sigma^2 + \phi^2 - \dfrac{\phi^4}{\phi^2 + \frac{4\sigma^4 \chi^2}{(1-\bar{K}^2)^2}}}} = 1 \ .$$

The last equality implies:

$$\phi^2 - \frac{\phi^4}{\phi^2 + \frac{4\sigma^4 \chi^2}{(1-\bar{K})^2}} = \sigma^2(e^{2a(\bar{K})rc} - 1) \geq 0 \, ,$$

where the strict inequality holds due to costly information ($c > 0$). Therefore, we have shown that

$$\frac{1}{\sigma^2} \geq \frac{1}{(\sigma^2 + \phi^2 - \dfrac{\phi^4}{\phi^2 + \frac{4\sigma^4 \chi^2}{(1-\bar{K})^2}})}$$

Thus we prove that $E(I^U) \leq E(I^I)$, where strict inequality holds due to costly information ($c > 0$).