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## **New Precision Agriculture technology Adoption for dealers under imperfect market**

Haili Jia  
Department of Agricultural Economics  
University of Kentucky

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Postal address: 440 C.E. Barnhart Bldg, Lexington, KY 40546  
E-mail address: [hjia2@uky.edu](mailto:hjia2@uky.edu)

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**Abstract:** Factors that affect agribusiness firms' investment decision on new Precision agriculture technique are identified and the real option model is used to derive both the lead and follow-on investment threshold. Results show that compared to the market demand uncertainty and new technique arrival uncertainty and noise in the new market, decreasing in initial irreversible capital cost of precision agriculture service has the most significant effect on bringing down the threshold level for both the leader and the follower.

**Keywords:** Precision agriculture, Real option, Demand uncertainty, New technique uncertainty, Noise

## **Section one: introduction and previous research**

Precision Agriculture (PA) refers to a suite of technologies that use sensing and geo-referencing innovations to apply inputs more precisely based on a field's biophysical variability. It promises more efficient input usage, higher profit and superior environmental benefits.

PA technologies can be divided into two categories:

- (1) Diagnostic techniques: are methods for gathering information and analyzing spatial variability among the soil and plant characteristics. They include remote sensing, topsoil thickness, yield monitor and grid soil sampling techniques.
- (2) Application techniques: use computer-controlled devices to vary inputs such as fertilizers, pesticides, seeding and liming by using the field maps.

Two major steps will be performed in adoption of precision agriculture. Usually, diagnostic techniques are first used to assessing the variability and then application techniques are applied to manage variability that is assessed from first step.

The major factors influencing farmer's adoption of PA technique are farm size, the costs of adoption, value and cost of product, scale economies, financial situation, location and human capital. Since high capital PA techniques are relatively expensive and technically complicated for small farms, it provides agribusiness firms with a business opportunity to

invest in high capital PA techniques and profit from renting the PA techniques to the small farms, and therefore these firms become key drivers in PA technique adoption in U.S agricultural production.

However, USDA data shows that agribusiness firms put their heaviest investment in low capital PA methods. 2006 USDA survey shows that only one third of the agribusiness dealers provide “high tech” services, including Multi-nutrient variable rate application, satellite/aerial imagery and/or variable seeding with GPS, which are more expensive in their initial investment. The rest mostly provide “low tech” or “Site-specific with no technology” service. Forty-seven percent of the agribusiness dealer in 2006 survey also shows that they profit from providing “high tech” service.

Here comes the conundrum. High tech/high expense precision agriculture equipment promise better profit. The adoption rate for the agribusiness firms is comparatively low. The reason has multiple dimensions. Given the uncertain demand for new high capital PA methods, agribusiness firms always enter into this market with the smallest capital outlay. When they need to make high capital PA technology investments, they face two major uncertainties: future demand uncertainty from farmers (consequently future cash flow uncertainty) and new technique arrival uncertainty (which makes the current investment obsolete). Besides these two uncertainties, the first mover in this market will face an unobservable demand associated with the brand new PA service, which means the demand

level can only be estimated with noise. In addition, the initial investment cost of the high capital PA technique is huge and irreversible due to the specific use of the PA equipment. It is all these uncertainties and noise, as well as the irreversible nature associated with the high capital PA technique investment, that makes waiting for more information valuable and therefore causes the agribusiness firms to delay their investment.

Since agribusiness firms are the key drivers of high capital PA techniques, the threshold and timing of their investment for high capital PA methods becomes an interesting question for policy maker. Thus valid economic analysis and model of their investment behavior is needed.

This study seeks to identify the underlying reasons that cause the slow adoption rate of high capital Precision Agriculture (PA) technique of agribusiness firms and to examine the potential policy strategies to improve the situation. The specific objectives include: (1) to identify two uncertainties associated with high capital PA technique investments for agribusiness firms: demand uncertainty from farmers and new technique arrival uncertainty; (2) to identify the noise associated with the unobservable demand level for a new high capital PA service by farmers; (3) to develop a real option model that incorporates the two uncertainties and noise, and examine how these factors affect agribusiness firms' investment threshold, and which will play different roles (leader, follower) in the market; (4) to suggest three agricultural policy alternatives that can improve the current situation.

This paper is organized as follows. The current section briefly reviews the existing studies of precision agriculture techniques adoption problem. In section 2, we describe the model that is based on the previous research and discuss the methodology that will be used. In section 3 solution of model will be derived. In section 4, realistic parameter will be applied and discussed. In the last section, we summarize the main results.

## **Section 2: Model description**

Three assumptions are given for the model:

1. There is an initial investment cost for the high capital PA investment and no further variable cost. This means that the gross revenue is the profit.
2. There is a duopoly market, with one leader and one follower, competing for the new PA service market
3. Before entering a new PA service market, the demand for the new PA service is unobservable for the leader. But once the initial development occurs, the true product demand is revealed and observable to the follower.
4. All firms are risk-neutral

The two uncertainties that associate with agribusiness firms' high capital PA investment decision are demand uncertainty from small farmers and new technique arrival uncertainty. Unpredictable market situation and farmers' different taste as well as preference cause the

demand for certain PA techniques has dynamic change over time. The arriving of new technique will not only make the old PA investment obsolete, but increase the supply of available PA services and therefore drag down the market equilibrium price of PA service. Thus the PA technique investment should consider both uncertainties.

Last paragraph explain agribusiness firms, no matter the leader or the follower, both face demand uncertainty. The assumption 3, however, specifies that the demand for the new PA service is only unobservable for the leader. The follower can always observe the demand level after the initial development established by leader. Since the leader faces an unobservable market, the demand for the new PA service can only be estimated with error. Therefore leader has different demand function from the follower.

The inverse demand function for the follower can be expressed as

$$P = X D(Q(N, T))$$

This is a multiplicative form of inverse demand function. The equilibrium price of PA service  $P$  is determined by product of two factors,  $X$  and  $D$ .  $X$  is the true demand shock from the market, which is assumed to follow a Log-normal process.  $D(\cdot)$  denotes technique induced uncertainty and follows a lognormal stochastic process.  $N$  denotes the number of firm in the market.  $T$  denotes the current available techniques.

Let  $D1 = D(Q(1,T))$  Where there is one firm case

$D2 = D(Q(2,t))$ , where there is two firms case

$$\begin{aligned} \text{and } dX(t) &= \mu_X X(t)dt + \sigma_X X(t)dZ_X \\ dD1(t) &= \mu_{D1} D1(t)dt + \sigma_{D1} D1(t)dZ_{D1} \\ dD2(t) &= \mu_{D2} D2(t)dt + \sigma_{D2} D2(t)dZ_{D2} \end{aligned}$$

Let  $P1 = XD1$

$P2 = XD2$

According Ito's lemma, the dynamic of  $P1$  and  $P2$  is as followed.

$$dP1(t) = (\mu_X + \mu_{D1} + \rho_1 \sigma_X \sigma_{D1})P1(t)dt + (\sigma_X dZ_X + \sigma_{D1} dZ_{D1})P1(t)$$

$$dP2(t) = (\mu_X + \mu_{D2} + \rho_2 \sigma_X \sigma_{D2})P2(t)dt + (\sigma_X dZ_X + \sigma_{D2} dZ_{D2})P2(t)$$

Where  $\rho_1$  is the correlation between  $X$  and  $D1$ , and  $\rho_2$  is the correlation between  $X$  and  $D2$ . Assume the  $X$  and  $D1$ ,  $X$  and  $D2$  are independent, thus  $\rho_1$  and  $\rho_2$  are both zero.

### **Section 3: model solution**

Let  $P_1^l$  denote the leader's investment threshold level and  $P_2^f$  denotes the follower's threshold investment level.

For the game-theoretical situation with two firms, equilibrium is determined by backward induction. And for the comparison purpose, the noiseless market case will be analyzed first.

#### Investment by follower in the noise/non-noise market

It will be no difference for the follower in noise market case or noiseless one. Since the demand level will still be fully revealed by the leader to the follower in the noise market. The follower can always observe the full-information demand term  $X(t)$ . Thus the demand



function face by the follower still be:

$$P = XD(Q(N,T)) = XD_2$$

Assume the cost of PA investment is  $K$  for both companies and the investment is irreversible. Conditional on that lead investment has occurred, the follower hold the option on the investment of the second project. Give then demand function faced by the follower, the investment threshold level for follower is

$$P_2^{f*} = \frac{\beta}{\beta - 1} \delta K$$

Where

$$\beta = \frac{\frac{1}{2}\sigma_{p_2}^2 - \mu_{p_2} + \sqrt{\left(\frac{1}{2}\sigma_{p_2}^2 - \mu_{p_2}\right)^2 + 2r\sigma_{p_2}^2}}{\sigma_{p_2}^2}, \text{ K is initial investment cost}$$

$\delta$  is depreciating rate

Since the  $X$  and  $D_2$  are independent, thus

$$\mu_p = \mu_x + \mu_{D_2}$$

$$\sigma_{P_2}^2 = \sigma_x^2 + \sigma_{D_1}^2$$

The follower's value function is as following:

$$V^{f*} = \begin{cases} \frac{P}{\delta} - K & , P \geq P_2^{f*} \\ \left(\frac{P}{P_2^{f*}}\right)^\beta \left[\frac{P_2^{f*}}{\delta} - K\right] & , P < P_2^{f*} \end{cases} \quad (1)$$

When  $P \geq P_2^{f*}$ , the follow on investment will occurred, and investment value is equal to expected value less the sunk investment cost. When  $P < P_2^{f*}$ , the follower holds a

proprietary investment option on the second development project.

Investment by leader when demand is fully observable (noiseless market)

$P(t)$  has dynamic changes over time. If  $P(0) < P_2^{f*}$  and  $P(t) \geq P_2^{f*}$  at some time  $t > 0$ , the leader will already have made the investment. If  $P(t) < P_2^{f*}$ , the follower will wait and the leader will get the monopoly profit from the investment until  $P(t)$  hit the threshold boundary. If  $P(t) > P_2^{f*}$  for some  $t > 0$ , the follow-on investment will occur, and the leader will share the market profit with the follower and thus they has the same current value. The leader's asset value can therefore be written as:

$$V^l = \begin{cases} \frac{P}{\delta} - K & , P \geq P_2^{f*} \\ \frac{P}{\delta} \left[ 1 - \left( \frac{P}{P_2^{f*}} \right)^{\beta-1} \right] + \frac{P_2^{f*}}{\delta} \left( \frac{P}{P_2^{f*}} \right)^{\beta} - K & , P < P_2^{f*} \end{cases} \quad (2)$$

From Maskin and Tirole (1997) and Vives (1999) papers, we can infer that a symmetric perfect Markov equilibrium obtains when

$$V^l(P_1^{l*}) = V^f(P_1^{l*})$$

That is, conditional on competitors are identical, agents are indifferent between leading and following at the time lead investment occurs in equilibrium.

Equating value function for both leader and follower will get the dealer's critical investment value. After simplification, the relation is

$$\frac{P_1^{f*}}{\delta} \left[ 1 - \left( \frac{P_1^{f*}}{P_2^{f*}} \right)^{\beta-1} \right] = K \left[ 1 - \left( \frac{P_1^{f*}}{P_2^{f*}} \right)^{\beta} \right] \quad (3)$$

Where  $P_1^{f*}$  can be determined implicitly.

Investment by leader when demand is not fully observable (noise market)

The follower's investment threshold level in noise market will stay the same as the noiseless case. The leader, however, can only observe the noise-involved market value  $Z(t)$ .

But the leader will use the best estimate of true value,  $M(t)$ , to make the investment decision.

The demand function the leader used for decision is:

$$\bar{P} = MD(Q(N,T))$$

At lead threshold, competitors will be different between leading and following in an expected value rather than a deterministic value in equilibrium. That is, the competitors will equalize the conditional expected values of their payoffs that result from pioneering investment.

If both the leader's and follower's value function (1) and (2) is written as expected value, the perfect Markov equilibrium obtains when

$$\int_0^{P_2^{f*}} \frac{P}{\delta} \left[ 1 - \left( \frac{P}{P_2^{f*}} \right)^{\beta-1} \right] g(P(t)/I(t)) dP(t) = \int_0^{P_2^{f*}} K \left[ 1 - \left( \frac{P}{P_2^{f*}} \right)^{\beta} \right] g(P(t)/I(t)) dP(t) \quad (4)$$

Where  $g(P(t)/I(t))$  denotes the probability distribution of the unobserved true value  $P(t)$ , conditional on the information available at that time,  $I(t)$ .

And  $P_2^{f^*}$  is critical since if the revealed P is at or above it, the follower invests immediately, and if revealed P is below the it, the follower refrains from investment and holds a call option with exercise price K.

Let  $M(t) = E[X(t)/I(t)]$  represent the expected value conditional on the available information.

$\gamma(t) = Var[X(t)/I(t)]$  represents the variance of the estimated value around the true value.

And denote  $\bar{P} = MD$

The COR paper (Childs,P.S.,S.H, Ott and T.J.Riddiough.2002) proved that:

$$\int_0^{X^{f^*}} X^b(t)g(X(t)/I(t))dX(t) = (M(t)e^{1/2(b-1)\gamma(t)})^b \Phi[-d(X^{f^*}, b, \gamma(t))]$$

$\Phi(\cdot)$  denotes the cumulative standard normal distribution with d defined as

$$d(X^{f^*}, b, \gamma(t)) = \frac{\ln\left(\frac{M(t)}{X^{f^*}}\right) + (b - \frac{1}{2})\gamma(t)}{\sqrt{\gamma(t)}}$$

Follow the similar logic, we can proof that:

$$\int_0^{P_2^{f^*}} P^b(t)g(P(t)/I(t))dP(t) = (\bar{P}(t)e^{1/2(b-1)\gamma_{\bar{P}}(t)})^b \Phi[-d(P_2^{f^*}, b, \gamma(t))]$$

$\Phi(\cdot)$  denotes the cumulative standard normal distribution with d defined as

$$d(P_2^{f^*}, b, \gamma(t)) = \frac{\ln\left(\frac{\bar{P}(t)}{P_2^{f^*}}\right) + (b - \frac{1}{2})\gamma(t)}{\sqrt{\gamma(t)}}$$

The symmetric perfect Markov equilibrium  $\bar{P}^l$  s determined by:

$$\frac{\bar{P}}{\delta_x} \left\{ \Phi(-d(P_2^{f*}, 1, \gamma(t))) - \left( \frac{\bar{P} e^{\frac{1}{2}\beta\gamma(t)}}{P_2^{f*}} \right)^{\beta-1} \Phi(-d(P_2^{f*}, \beta, \gamma(t))) \right\} =$$

$$K \left\{ \Phi(-d(P_2^{f*}, 0, \gamma(t))) - \left( \frac{\bar{P} e^{\frac{1}{2}(\beta-1)\gamma(t)}}{P_2^{f*}} \right)^{\beta} \Phi(-d(P_2^{f*}, \beta, \gamma(t))) \right\}$$
(5)

(The proof will be provided upon request)

Determining  $\bar{P}(t) = \bar{P}^*(t)$  in the equation (5) is an application of iterative numerical method.

$\bar{P}^*(t)$  is a function of time, which result from that  $\gamma(t)$  is in general time dependent.

The special cases of  $k \rightarrow \infty$  and  $k = 0$  will illustrate the properties of the lead investment boundary. As  $k \rightarrow \infty$ , the observed value,  $Z(t)$ , reverts to the true value  $X(t)$ . this implies the residual variance  $\gamma(t) \rightarrow 0$  for all  $t$ , the expected threshold relation in equation (4) reduce to the certainty relation in equation (3). As  $k = 0$ , noise accumulates at the rate of  $\rho^2 \sigma_y^2$ . In this case,  $\gamma(t)$  will increase over time  $t$  and the lead investment threshold become higher. This follows because accumulating noise increase the probability of making an exercise error, which creates the incentive to further delay lead investment and pump up the lead threshold.

#### **Section 4.Application and discussion**

To analyze the characteristic of the lead investment threshold,  $\bar{P}^*(t)$ , in great detail.

Realistic parameter values for each variable are used to exam how and in what degree the lead and follow-on investment threshold will be affected.

Assume there are three incentive polices existing to encourage the adoption of high capital precision agriculture techniques and each of them will affect certain parameters in the model. Different policies' effect on the lead and follow-on investment threshold will be

check and compared respectively.

The first policy is to provide the agribusiness firms lump-sum subsidy for investing the PA equipment and therefore decrease the initial capital cost K.

The second policy is to help the agribusiness firms to do market research and reduce the noise level in the new market. This policy will help to reduce the initial noise level  $\sigma_{y_0}$  (segmazero) and increase the noise dissipate rate (k) in the market.

The third policy is to invest on the research and development of new PA technique. This policy will increase the supply of PA service in the market and therefore decrease the price of PA service, which makes the drift value,  $\mu_{D2}$ , of dynamic D2 have bigger absolute value,

The parameters applied in the model are

$$\mu_X = -0.01, \mu_{D2} = -0.01, \sigma_X = 0.1, \sigma_{D2} = 0.1, \sigma_{y_0} = 0.1, r = 0.06, k = 0.5$$

$$K=10$$

Each of the policy is analyzed in the following

Policy one : Lump-sum subsidy

Lump-sum subsidy for agribusiness firms make their initial investment costs K go down.

Figure 1: lead investment threshold as a function of noise volatility-segam-y( $\sigma_y$ ) with initial capital investment K = 10

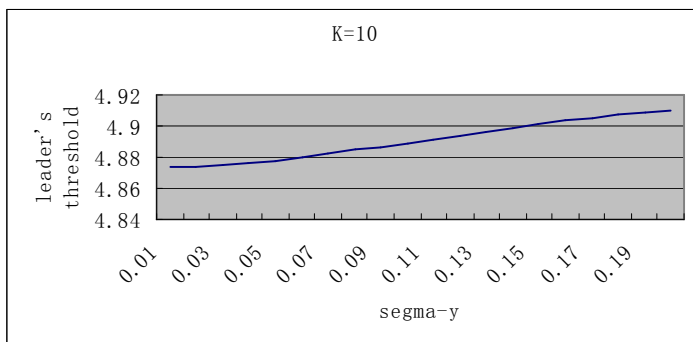


Figure 2: lead investment threshold as a function of noise volatility-segam-y( $\sigma_y$ ) with initial capital investment  $K = 6$

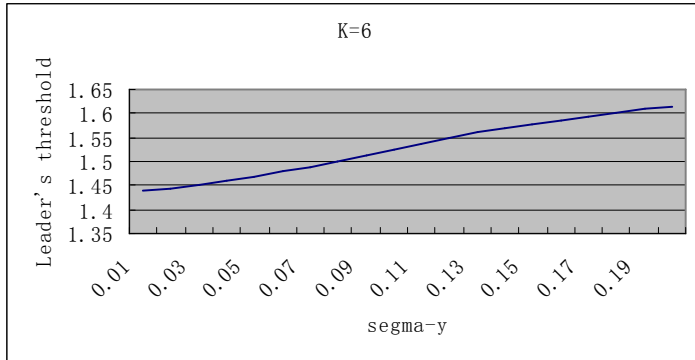


Figure 3: follow-on investment threshold as a function of noise volatility-segam-y( $\sigma_y$ ) with initial capital investment  $K = 10$

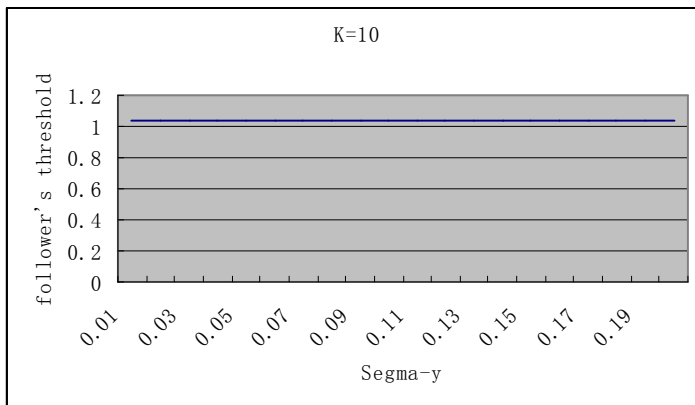
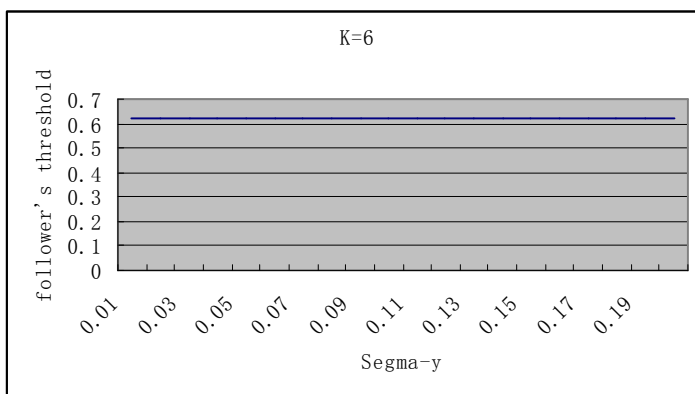


Figure 4: follow-on investment threshold as a function of noise volatility-segam-y( $\sigma_y$ ) with initial capital investment  $K = 6$



Discussion: Following figures show the lead threshold level increase as the noise volatility  $\sigma_y$  increase. This follows because increasing noise volatility increases the probability of making exercise investment option error and therefore creates the incentive for the leader to delay and pump up the threshold level.

Comparing figure 1 and figure 2, we find that the decrease of initial capital from  $K=10$  to  $K=6$  will dramatically drag down the lead threshold level by the same degree. And lead threshold does increase as the noise volatility  $\sigma_y$  increase.

Comparing figure 3 and figure 4, we find that the decrease of initial capital from  $K=10$  to  $K=6$  will decrease the follow-on threshold level from 1.03 to 0.62. And follow-on threshold is not affected as the noise volatility  $\sigma_y$  increase.

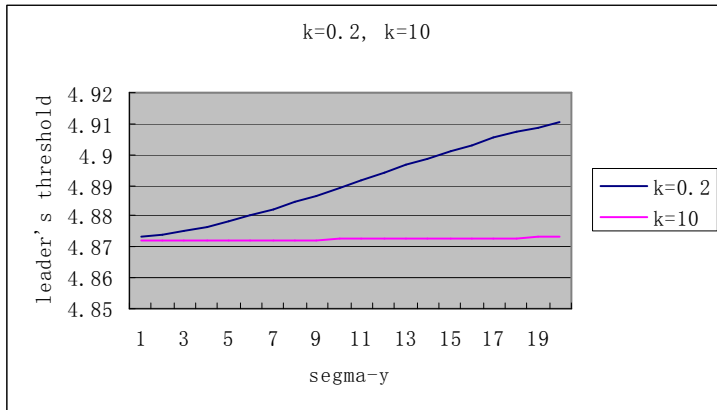
Comparing figure 1 and figure 3, figure 2 and figure 4, we find the lead threshold is much higher than the follow-on threshold. It is mainly because the lead faces not only uncertainties but also noise in the brand new market. The information generated by the leader's investment is a public good and will be fully revealed to the follower. Therefore it creates a powerful incentives for delay and much higher lead threshold.

Policy two: conduct market research to reduce the market noise

Reducing market noise can be achieve either by increasing the noise dissipation rate  $k$  or decreasing the initial noise level  $\sigma_y$ .

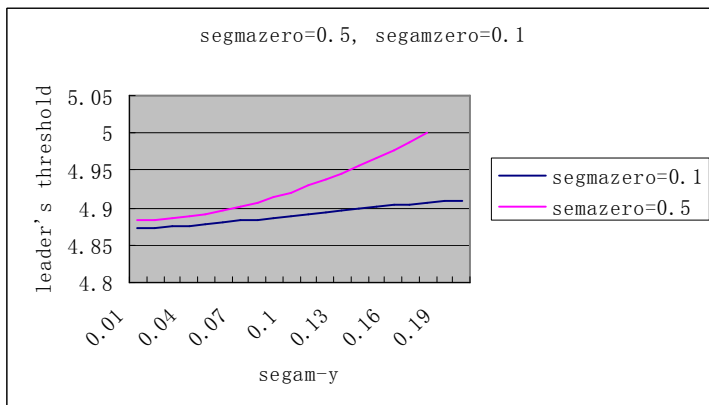
Figure 5: lead investment threshold as a function of noise volatility- $\sigma_y$  with mean reversion rate  $k = 0.2$  and  $k = 10$





Discussion: Figure 5 shows that increase in the dissipate rate of noise only slightly decrease the lead threshold. This follows because the noise only exists in the demand uncertainty, not in new technique uncertainty. Percentage wise, the change of the noise dissipate rate will much less effect on the lead threshold.

Figure 6: lead investment threshold as a function of noise volatility-segam-y( $\sigma_y$ ) with initial noise level segmazero ( $\sigma_{y_0}$ ) = 0.1 and segmazero ( $\sigma_{y_0}$ ) = 0.5



Discussion: Figure 6 shows that decrease in the initial noise in the market only slightly decrease the lead threshold. This follows because the noise only exists in the demand uncertainty, not in new technique uncertainty. Percentage wise, the change of the noise

dissipate rate will much less effect on the lead threshold.

And because the follower always has the full information of market demand, the reduction in noise level has no effect on follower's threshold level.

Policy three: investing on R&D of PA technique

The faster the PA technique improve, the faster the PA service price goes down in the market, which implies higher absolute value of  $\mu_{D2}$ .

Figure 7: lead investment threshold as a function of noise volatility-segam-y( $\sigma_y$ ) with technique improvement speed  $\mu_{D2} = -0.01$

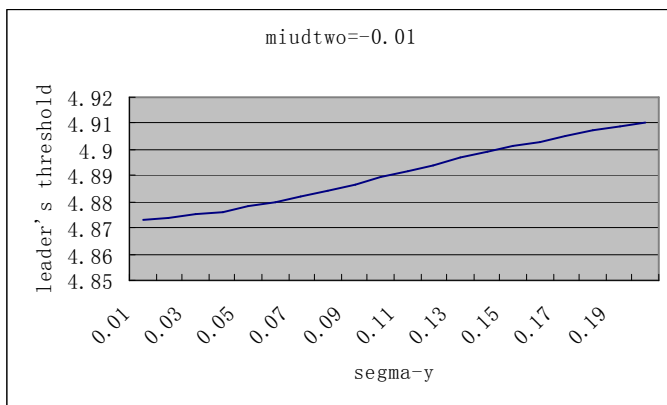


Figure 8: lead investment threshold as a function of noise volatility-segam-y( $\sigma_y$ ) with higher technique improvement speed  $\mu_{D2} = -0.05$

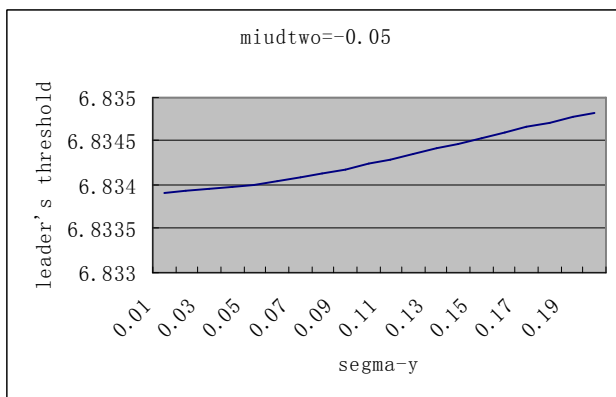


Figure 9: follow-on investment threshold as a function of noise volatility-segam-y( $\sigma_y$ ) with technique improvement speed  $\mu_{D2} = -0.01$

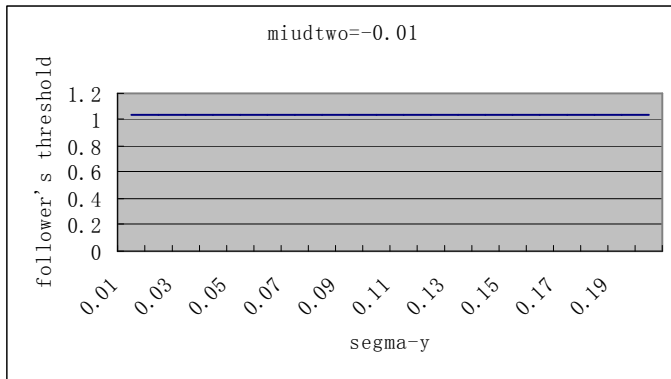
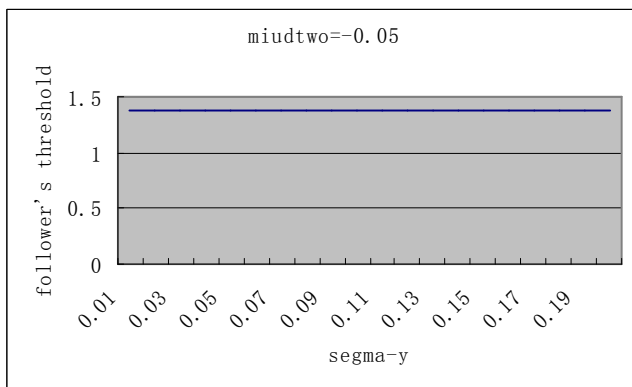


Figure 10: Follow-on investment threshold as a function of noise volatility-segam-y( $\sigma_y$ ) with higher technique improvement speed  $\mu_{D2} = -0.05$



Discussion: for  $\mu_{D2}$  goes from -0.01 to -0.05, the lead threshold goes up. The faster the new PA technique improves, the more agribusiness firms hesitate to invest on the PA equipment. It follows because agribusiness firms will be concerned that their current investment will be obsolete under the fast PA technique improvement. Therefore they need higher threshold level to justify their PA investment. The same story is for the follow-on threshold. The faster the technique changes, the higher the follow-on threshold level.

## **Section 5: Conclusion**

A game theoretical model is set up for agribusiness firms' investing on higher capital PA equipment. Two uncertainties, demand uncertainty from farmers and new technique arrival uncertainty, are identified. The irreversible feature of the investment feature and the noise in the new PA service market are taken in account. Three potential incentive policies are proposed and analyzed.

Application results show that lump-sum subsidy to the agribusiness firms has the most direct and significant effect on dragging down the investment threshold hold for both the leader and the follower. Support on market research to decrease the market noise level only has a trivial effect on leader's investment threshold but not follower's. Support on the R&D on the new PA technique, on the contrary, pumps up both the lead and the follow-on investment threshold. The concern about the obsolescence of their investment makes agribusiness firms require higher price to justify their investment.

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