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Some Remarks on Leland's Model of Insider Trading

By Rafael Repullo

CEMFI and CEPR

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This paper shows that Leland's (1992) results on the positive effects of insider trading on investment are not robust to the introduction of noise in the insider's information. The paper then considers two variations of his model in which the insider is risk neutral (to ensure robustness), and the investment decision is prior to the placing of the stock in the market. It is shown that if insider trading takes place in the primary market, it has no effect on the level of investment, whereas if it takes place in the secondary market, it has a negative effect on investment.

Introduction

The impact of insider trading on economic efficiency is the subject of an ongoing debate. Insider trading moves the resolution of uncertainty forward, and this may bring benefits (better information for investment decisions) as well as costs (increased volatility of prices, and hence higher risk premia).

To analyse these effects, Leland (1992) constructs a model with an endogenous level of investment, and he shows that, when insider trading is permitted, stock prices will be higher on average, expected real investment will rise, and markets will be less liquid and more volatile.

Leland's model is, however, very special. First of all, he assumes that the risk-averse insider learns *exactly* the future return of the risky asset. In this paper, I analyse the robustness of Leland's results to the introduction of some noise in the insider's information. I show that, given the assumptions of his model, an arbitrarily small amount of noise is sufficient to make negligible all the effects of insider trading.

The source of this lack of robustness lies in the assumption that, because of risk aversion, the insider's trade is always negligible—except in the limit case where holding the asset entails no risk. To ensure robustness to the introduction of noise in the insider's information, I then consider a model with a risk-neutral insider. However, for this model insider trading does not have any effect on the average price of the risky asset, and hence no effect on the average level of investment.

Another feature of Leland's model is the fact that the (only) supplier of the risky asset is assumed to be a price-taker. This seems a fairly implausible assumption, so I propose an alternative model (with a risk-neutral insider) in which the investment decision is prior to the placing of the asset in the market, and which allows the supplier to have market power. The equilibrium of this model can be easily derived from Leland's analysis, and although we get the same results for the volatility of the price and the liquidity of the market, now insider trading has no effect on the level of investment. The result, however, depends crucially on the assumption that the supplier of the asset is risk-neutral; under risk aversion, the increase in price volatility would imply a negative effect on investment.

To further explore this issue, I consider a model in which insider trading takes place in a secondary market, and show that, for this model, the effect of insider trading on the volatility of the asset price in the secondary market has a cost, in terms of a higher risk premium in the primary market, that in turn reduces the level of investment (even when the supplier of the asset is risk-neutral).

This effect of insider trading on investment is similar to the one in Ausubel (1990). However, the prohibition of insider trading in his model takes the form of a disclose-or-abstain rule that leads to full revelation of inside information. By contrast, following Leland, I assume that if insider trading is prohibited the inside information will not be collected.

In an interesting paper, Bernhardt *et al.* (1995) analyse a dynamic setting with correlated productivity shocks in which the information revealed by insider trading in the secondary market helps future investment decisions. This feedback is absent from my static models.

The paper is organized as follows. I present in Section I Leland's original model, and give the intuition for his result on the effect of insider trading on investment. Section II then discusses the robustness of Leland's results, and Section III presents the model with a risk-neutral insider. I analyse in Section IV an alternative model (also with a risk-neutral insider) in which investment is prior to trading in the primary market, and I consider in Section V a variation of this model in which insider trading takes place in a secondary market for the asset. Section VI concludes.

I. Leland's Model

Consider an economy with two periods ($t=0, 1$) and two assets: a safe asset, whose net return is normalized to zero, and a risky asset, with gross return $v \sim N(\bar{v}, \sigma_v^2)$. Let p denote the price of the risky asset at $t=0$ in terms of the safe asset, which is taken to be the numeraire.[1]

The supply of the risky asset q at $t=0$ comes from the investment undertaken by a price-taking firm that maximizes its profits from selling the asset. These profits are given by

$$pq - C(q),$$

where $C(q)$ is a cost function of the form

$$C(q) = \begin{cases} \dfrac{Q^2}{2z} - \dfrac{Q}{z}q + \dfrac{1}{2z}q^2, & \text{if } q \geq Q \\ 0, & \text{if } q < Q, \end{cases}$$

and $Q>0$ and $z \geq 0$ are exogenous parameters. Thus, the cost of supplying the asset is zero up to Q, and then is a quadratic function of q.[2] Solving the corresponding first-order condition gives the supply function

$$s(p) = Q + zp. \tag{1}$$

In the *model without insider trading*, the demand for the risky asset comes from two sources:

1. a continuum of measure one of risk-averse investors characterized by constant absolute risk aversion (CARA) utility functions with risk aversion coefficient $a > 0$;
2. a set of liquidity traders who demand a random amount $u \sim N(0, \sigma_u^2)$ which is independent of v.

Given the normal distribution of returns, the demand function of the risk-averse investors is given by

$$(2) \qquad d'(p) = \frac{\bar{v} - p}{a\sigma_v^2},$$

where, following Leland, a prime will refer to the model without insider trading. Then, solving the equation

$$(3) \qquad s(p) = d'(p) + u,$$

we get the equilibrium price function in the absence of insider trading

$$(4) \qquad p' = \frac{\bar{v}g - Q}{z + g} + \frac{1}{z + g}u,$$

where $g \equiv (a\sigma_v^2)^{-1}$.

In the *model with insider trading*, it is assumed that one of the risk-averse investors learns at $t = 0$ the realization of v, so that for this agent (the insider) holding the asset does not involve any risk. Clearly, if the insider were a price-taker, his demand would be infinite whenever $v > p$, so Leland assumes that the insider is aware of the fact that buying or selling the asset has an effect on the price. If x denotes the demand of the insider, in equilibrium we must have

$$(5) \qquad s(p) = d(p) + x + u,$$

where $d(p)$ is the demand function of the risk-averse investors (the outsiders) when there is insider trading. Solving for p in this equation gives an equilibrium price function of the form $p(x + u)$.

Assuming, as Leland does, that the insider observes the demand u of the liquidity traders, his demand for the risky asset is obtained by maximizing

$$(6) \qquad [v - p(x + u)]x,$$

which gives a solution of the form $x(v, u)$.[3] Clearly, the equilibrium price of the risky asset $p(x(v, u) + u)$ will contain some information on the future return of this asset. Assuming that the distribution of $v|p$ is normal (which will be the case if p is linear in v and u), the outsiders' demand is now given by

$$(7) \qquad d(p) = \frac{E(v|p) - p}{a\,\mathrm{Var}\,(v|p)}.$$

Postulating a linear equilibrium price function of the form $p(x + u) = \alpha + \beta(x + u)$, with $\beta > 0$, it is straightforward to compute $d(p)$. Substituting the resulting expression and (1) into the equilibrium condition (5) and equating coefficients yields a nonlinear system of equations in α and β, which can be solved to get the equilibrium price function for the model with insider trading

$$p = \frac{\bar{v}g - Q}{2(z+g)} + \frac{1}{2}v + \frac{\beta}{2}u, \tag{8}$$

where[4]

$$\beta = \frac{2}{a\sigma_u^2\left[-1 + \left(1 + \frac{4(z+g)}{a\sigma_u^2}\right)^{1/2}\right]}.$$

Comparing the equilibrium price functions (8) and (4) for the models with and without insider trading, Leland obtains the following results.

1. The average price of the risky asset will be higher with insider trading: $E(p) > E(p')$.
2. If $z > 0$, the average level of investment will be higher with insider trading: $E(q) = Q + zE(p) > Q + zE(p') = E(q')$.
3. For reasonable parameter values (if and only if $z + g > 2a\sigma_u^2$), the liquidity of the (primary) market, measured by the inverse of the coefficient of the liquidity traders' demand u in the equilibrium price function, will be lower with insider trading: $2/\beta < z + g$.
4. For reasonable parameter values (if $z + g > 2a\sigma_u^2$), the price of the risky asset will be more volatile with insider trading: $\mathrm{Var}(p) > \mathrm{Var}(p')$.

Although Leland does not give much intuition for these results, it is straightforward to explain why the average price of the risky asset will be higher with insider trading. For this, we simply exploit the linearity in the price of the risky asset of the equilibrium equations (3) and (5). In particular, substituting (2) into the equilibrium condition (3) gives

$$q' = \frac{\bar{v} - p'}{a\sigma_v^2} + u,$$

so taking expectations we get

$$E(q') = \frac{\bar{v} - E(p')}{a\sigma_v^2}. \tag{9}$$

Similarly, substituting (7) into (5), and using the fact that the solution to the maximization of (6) with respect to x can be written as $(v - p)/\beta$, gives

$$q = \frac{E(v|p) - p}{a\,\mathrm{Var}(v|p)} + \frac{v - p}{\beta} + u.$$

Now taking expectations, and using the law of iterated expectations and the fact that $\mathrm{Var}(v|p)$ does not depend on p, we get

$$E(q) = \frac{\bar{v} - E(p)}{a\,\mathrm{Var}(v|p)} + \frac{\bar{v} - E(p)}{\beta}. \tag{10}$$

Comparing expressions (9) and (10), one can see that there are two reasons for the higher price of the risky asset in the presence of insider trading. First, since

$\mathrm{Var}\,(v|p) < \sigma_v^2$, holding the asset is now less risky for the outsiders, so their expected demand shifts to the right. Second, there is the additional demand of the insider that shifts total expected demand further to the right. Since the supply function is the same, the result follows (see Figure 1).

II. The Robustness of Leland's Results

To discuss the robustness of Leland's results, I consider what happens if, instead of learning the future return v of the risky asset, the insider observes a noisy signal of it. In particular, following Grossman and Stiglitz (1980), I assume that the insider observes at $t = 0$ the realization of a random variable θ such that

$$v = \theta + \varepsilon,$$

where $\theta \sim N(\bar{v}, \sigma_\theta^2)$, $\varepsilon \sim N(0, \sigma_\varepsilon^2)$ with $\sigma_\varepsilon^2 \in [0, \sigma_v^2]$, $\sigma_\theta^2 = \sigma_v^2 - \sigma_\varepsilon^2$, and θ and ε are independent. With these assumptions, we have $v \sim N(v, \sigma_v^2)$ and $v|\theta \sim N(\theta, \sigma_\varepsilon^2)$, so when $\sigma_\varepsilon^2 = 0$ the model is equivalent to Leland's.

In addition, I assume that, instead of a single insider, there is a positive measure λ of (potential) insiders who behave as a monopolistic cartel, while the remaining risk-averse agents, of measure $1 - \lambda$, behave competitively. I will analyse the behaviour of the equilibrium price functions (with and without insider trading) when $\sigma_\varepsilon^2 \to 0$ and $\lambda \to 0$.[5]

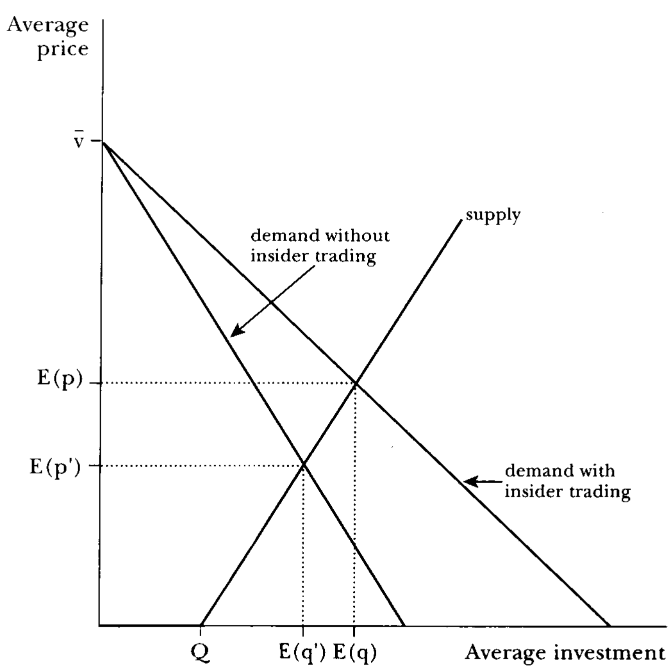

Figure 1. The effects of insider trading in Leland's model.

To solve for the equilibrium of the *model without insider trading*, note that the demand function of the competitive investors is now

$$(11) \qquad d'(p) = \frac{(1-\lambda)(\bar{v}-p)}{a\sigma_v^2}.$$

Substituting this expression and (1) into the equilibrium condition

$$(12) \qquad s(p) = d'(p) + x + u$$

and solving for p gives the function $p(x+u) = \alpha + \beta(x+u)$, with $\beta = [z + (1-\lambda)g]^{-1}$. The total demand x of the monopolistic cartel of insiders is then obtained by maximizing the expected utility of a representative member of the cartel, which is given by

$$E\left[-\exp\left(-a(v - p(x+u))\frac{x}{\lambda}\right)\middle| u\right]$$
$$= -\exp\left[-a\left((\bar{v} - p(x+u))\frac{x}{\lambda} - \frac{a}{2}\left(\frac{x}{\lambda}\right)^2\sigma_v^2\right)\right].$$

From here it is immediate to get

$$(13) \qquad x'(p) = \frac{\lambda(\bar{v}-p)}{a\sigma_v^2 + \lambda\beta}.$$

Substituting (1), (11) and (13) into the equilibrium condition (12) and solving for p yields the equilibrium price function

$$(14) \qquad p'(\lambda) = \frac{\bar{v}\gamma - Q}{z+\gamma} + \frac{1}{z+\gamma}u,$$

where $\gamma \equiv g - (g\lambda)^2/(z+g)$. Since $\lim_{\lambda\to 0}\gamma = g$, it follows that

$$\lim_{\lambda\to 0} p'(\lambda) = p',$$

where p' is Leland's equilibrium price function for the model without insider trading.

For the *model with insider trading*, the total demand of the cartel of insiders is given by

$$(15) \qquad x(p) = \frac{\lambda(\theta - p)}{a\sigma_\varepsilon^2 + \lambda\beta}.$$

On the other hand, assuming that the distribution of $v|p$ is normal, the demand of the competitive outsiders is now

$$(16) \qquad d(p) = \frac{(1-\lambda)(E(v|p) - p)}{a\,\mathrm{Var}\,(v|p)}.$$

Postulating a linear equilibrium price function of the form $p(x+u) = \alpha + \beta(x+u)$, with $\beta > 0$, and proceeding as in Leland's original model, we arrive at a nonlinear system of equations in α and β, which can be solved to get the following equilibrium price function

$$p(\lambda, \sigma_\varepsilon^2) = \alpha(1-H) + H\theta + \beta(1-H)u, \quad (17)$$

where

$$H \equiv \frac{\beta\lambda}{a\sigma_\varepsilon^2 + 2\beta\lambda}, \quad (18)$$

and α and β are given in the Appendix.

It is interesting to note that the function $p(\lambda, \sigma_\varepsilon^2)$ is discontinuous at the origin. This is illustrated in Figure 2, which plots the average price of the risky asset, $E(p(\lambda, \sigma_\varepsilon^2))$, for an example with $v = 10$, $z = a = \sigma_v^2 = \sigma_u^2 = 1$ and $Q = 0$. Moreover it is proved in the Appendix that

$$\lim_{\lambda \to 0} p(\lambda, \sigma_\varepsilon^2) = \begin{cases} p, & \text{if } \sigma_\varepsilon^2 = 0 \\ p', & \text{if } \sigma_\varepsilon^2 > 0, \end{cases}$$

where p and p' are, respectively, the equilibrium price functions of Leland's model with and without insider trading. Thus, when there is no noise in the insider's information, we converge to Leland's equilibrium with insider trading. However the presence of any amount of noise is sufficient to make the equilibrium converge to Leland's equilibrium without insider trading. Since the equilibrium price function without insider trading is continuous, we conclude that, if the measure λ of insiders is small, any noise is sufficient to eliminate Leland's results: insider trading would have a negligible effect on stock prices and hence on investment.

The discontinuity in the equilibrium price function can be explained by noting that the limit as $\lambda \to 0$ of the total demand of the insiders (15) is given

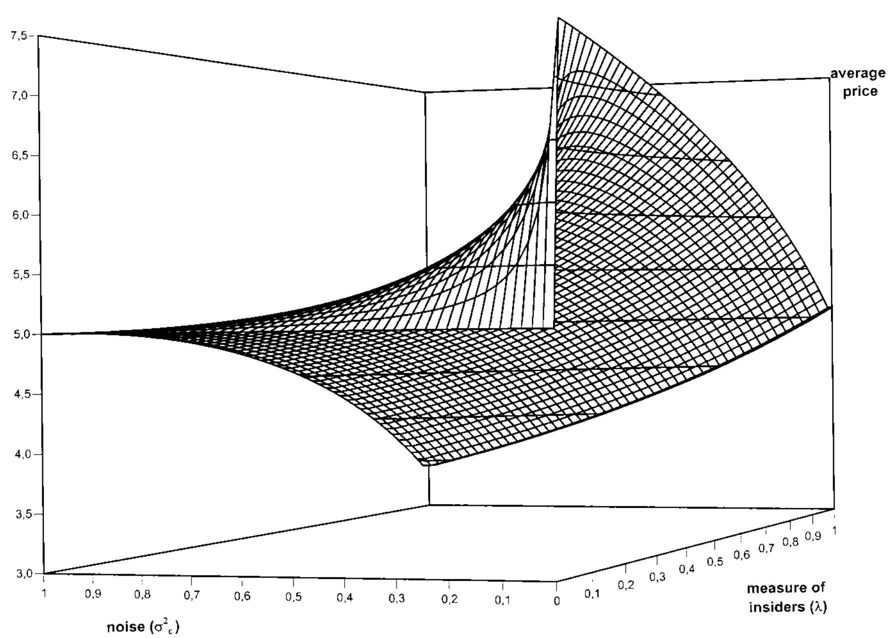

FIGURE 2. Average price as a function of the noise and the measure of insiders.

by

$$\lim_{\lambda \to 0} x(p) = \begin{cases} \dfrac{v-p}{\beta}, & \text{if } \sigma_\varepsilon^2 = 0 \\ 0, & \text{if } \sigma_\varepsilon^2 > 0. \end{cases}$$

Hence in the limit the demand of the risk-averse insiders discontinuously drops to zero when σ_ε^2 becomes positive. Intuitively, a zero mass insider can have a positive effect on the market only if she trades an infinite amount of the asset, which she will never do if she is risk-averse and holding the asset entails some risk.

At any rate, one can compute the average price of the risky asset for $\lambda > 0$ with and without insider trading. Taking expectations in (14) and (17) gives

$$E(p'(\lambda)) = \frac{\bar{v}\gamma - Q}{z+\gamma} = \bar{v} - \frac{\bar{v}z + Q}{z+\gamma}$$

and

$$E(p(\lambda, \sigma_\varepsilon^2)) = \alpha(1-H) + H\bar{v} = \bar{v} - (1-H)\frac{\bar{v}z + Q}{z+\Gamma},$$

where Γ is given in the Appendix. Although it is difficult to compare these expressions in general, it is easy to prove that

$$\lim_{\sigma_\varepsilon^2 \to 0} E(p(\lambda, \sigma_\varepsilon^2)) > \lim_{\sigma_\varepsilon^2 \to 0} E(p'(\lambda)),$$

so that for small σ_ε^2 average prices and hence investment will be higher with insider trading. Moreover, simulations of the model for a wide range of parameter values show that Leland's qualitative results hold true: the average price of the risky asset and the average level of investment are higher with insider trading, even when there is noise in the insider's information, but the effects tend to zero when $\lambda \to 0$. This is illustrated in Figure 3 for the same parameter values as in Figure 2 and $\sigma_\varepsilon^2 = 1/2$.

III. The Model with a Risk-Neutral Insider

In the previous section I have shown how Leland's results depend on the assumption of perfect information. Specifically, the risk-averse (potential) insider will have no impact on the market if she does not observe the return of the asset, or if she learns it with any noise; but she will make a difference if she observes the return without noise (because she will behave as a risk-neutral agent). In this section I consider an alternative setup in which the (potential) insider is directly assumed to be risk-neutral.

Clearly, the equilibrium of the *model with a risk-neutral insider* (and no noise) is identical to that of Leland's model. Moreover, this equilibrium is robust to the introduction of noise in the insider's information. To see this,

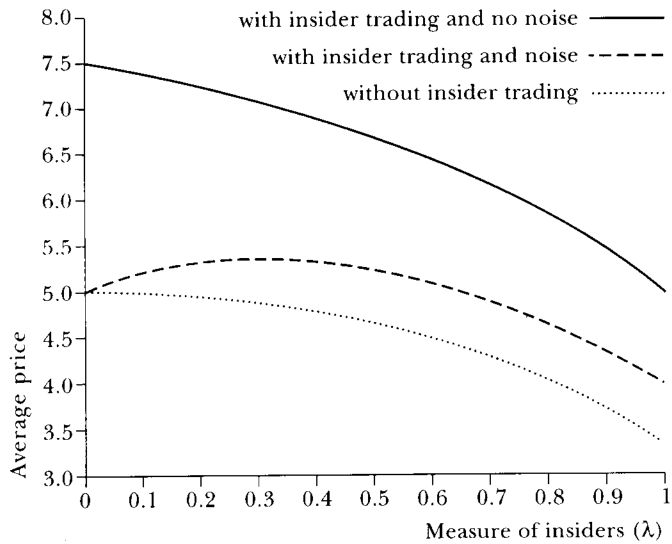

FIGURE 3. Average price as a function of the measure of insiders.

note that, by setting $a = 0$ in (13), we have

$$x(p) = \begin{cases} \dfrac{v-p}{\beta}, & \text{if } \sigma_\varepsilon^2 = 0 \\ \dfrac{\theta - p}{\beta}, & \text{if } \sigma_\varepsilon^2 > 0, \end{cases}$$

so the demand function of the insider is continuous in σ_ε^2.[6]

To compute the equilibrium of the *model with a risk-neutral uninformed investor*, note that the demand function of the risk-averse investors is once again

$$(19) \qquad d''(p) = \frac{\bar{v} - p}{a\sigma_v^2},$$

where a double prime will refer to the model with a risk-neutral uninformed investor. Substituting this expression and (1) into the equilibrium condition

$$(20) \qquad s(p) = d''(p) + x + u$$

and solving for p gives the function $p(x+u) = \alpha + \beta(x+u)$, with $\beta = (z+g)^{-1}$. Substituting this expression into the objective function of the risk-neutral trader, $E\{[v - p(x+u)]x \mid u\}$, and maximizing with respect to x gives

$$(21) \qquad x''(p) = (\bar{v} - p)(z+g).$$

Substituting (1), (19) and (21) into the equilibrium condition (20) and solving for p then gives the new equilibrium price function for the model without insider trading

$$(22)\qquad p'' = \frac{\bar{v}g - Q}{2(z+g)} + \frac{1}{2}\bar{v} + \frac{1}{2(z+g)}u.$$

Comparing the equilibrium price functions (8) and (22) for the models with and without insider trading, we now obtain the following results:

1. The average price of the risky asset will be the same for both models: $E(p) = E(p'')$.
2. The average level of investment will be the same for both models: $E(q) = Q + zE(p) = Q + zE(p'') = E(q'')$.
3. For all parameter values, the liquidity of the (primary) market, measured by the inverse of the coefficient of the liquidity traders' demand u in the equilibrium price function, will be lower with insider trading: $2/\beta < 2(z+g)$.[7]
4. For all parameter values, the price of the risky asset will be more volatile with insider trading: $\text{Var}(p) > \text{Var}(p'')$.

Thus, although we get the same results for the volatility of the price and the liquidity of the market, insider trading now has no effect on the average price of the risky asset, and no effect on the average level of investment. As before, the intuition behind these results can be explained as follows. Substituting (19) and (21) into the equilibrium condition (20) gives

$$q'' = \frac{\bar{v} - p''}{a\sigma_v^2} + (\bar{v} - p'')(z+g) + u,$$

so taking expectations we get

$$(23)\qquad E(q'') = \frac{\bar{v} - E(p'')}{a\sigma_v^2} + (\bar{v} - E(p''))(z+g).$$

Comparing expressions (10) and (23), it follows that, with insider trading, the outsiders' expected demand function shifts to the right (since $\text{Var}(v|p) < \sigma_v^2$), whereas the insider's expected demand function shifts to the left (since, as noted above, $1/\beta < z+g$). However, it can be checked that

$$\frac{1}{a\,\text{Var}(v|p)} + \frac{1}{\beta} = \frac{1}{a\sigma_v^2} + (z+g),$$

so that total expected demand remains unchanged.

To conclude this section, two remarks should be made. First, one should not expect this somewhat surprising result to be robust to alternative parameterizations of the model. Second, it is important to realize that, even if insider trading does not have any effect on the average level of investment, it does improve the efficiency of the investment: it will be high (low) when v is high (low).

IV. The Model with Investment prior to Trading

In this section, I first criticize a particular feature of Leland's model that I have not discussed so far: namely, the fact that the supplier of the risky asset is assumed to be a price-taker. Then I will propose an alternative model in which the investment decision is prior to the placing of the asset in the market, and which allows the supplier to have market power.

Leland assumes that the firm is a price-taker because he needs to give market power to the (perfectly informed) insider in order to bound his trading. However, this seems a fairly implausible assumption: surely the only supplier of the asset should be aware of the fact that the more it puts in the market, the lower the price will be.

The question then is how to get rid of this assumption without having to deal with the complexities of a bilateral monopoly model (with asymmetric information). Fortunately, there is a variation of Leland's model, with a different timing of events, that allows the firm to have market power at no (modelling) cost. To describe this alternative model, I first recall that the timing of events in Leland's model is as follows:

$t = 0$	$t = 1$
• Investment • Placing of asset • Insider trading	• Returns

Thus, here all the action takes place at $t = 0$. By contrast, the alternative model assumes that there is a time lag between the investment decision and the placing of the asset in the market, so the timing of events is as follows:

$t = -1$	$t = 0$	$t = 1$
• Investment	• Placing of asset • Insider trading	• Returns

In the alternative model there is a time $t = -1$ when real investment occurs, and it is only after the investment is in place that the firm can be sold in the primary market at $t = 0$. Clearly, in this setup there is no technical problem in assuming that the firm knows the relationship between the supply of the asset in the market and its (expected) price.

The equilibrium of this model (with a risk-neutral insider) can be easily derived from Leland's analysis. Let $\bar{q}$ denote the (fixed) supply of the risky asset at $t = 0$. To compute the equilibrium price function $p(\bar{q})$ corresponding to this q for the model with insider trading, simply take $Q = q$ and $z = 0$ (the case of no production flexibility in Leland's terminology); see equation (1). Substituting these parameter values into (8) then yields

$$p(\bar{q}) = \frac{\bar{v}g - \bar{q}}{2g} + \frac{1}{2}v + \frac{\beta_0}{2}u, \tag{24}$$

where

$$\beta_0 = \frac{2}{a\sigma_u^2[-1 + (1 + 4g/a\sigma_u^2)^{1/2}]}.$$

Similarly, substituting $Q = \bar{q}$ and $z = 0$ into (22) yields the equilibrium price function $p''(q)$ for the model with a risk-neutral uninformed investor

$$(25) \qquad p''(\bar{q}) = \frac{\bar{v}g - \bar{q}}{2g} + \frac{1}{2}\bar{v} + \frac{1}{2g}u.$$

Taking expectations in (24) and (25) then gives

$$E(p(\bar{q})) = E(p''(\bar{q})) = \frac{\bar{v}g - \bar{q}}{2g} + \frac{1}{2}\bar{v} = \bar{v} - \frac{1}{2g}\bar{q},$$

so insider trading has no effect on the average price of the risky asset (for any given q). However, it does increase its variance[8]

$$\mathrm{Var}\,(p(\bar{q})) = \tfrac{1}{4}(\sigma_v^2 + \beta_0^2\sigma_0^2) > \tfrac{1}{4}g^{-2}\sigma_u^2 = \mathrm{Var}\,(p''(\bar{q})).$$

To determine the level of investment at $t = -1$, the firm maximizes with respect to q its expected profits from selling the asset at $t = 0$

$$E(p(\bar{q}))\bar{q} - C(\bar{q}) = \left(\bar{v} - \frac{1}{2g}\bar{q}\right)\bar{q} - C(\bar{q}),$$

which gives[9]

$$\bar{q} = \frac{g(\bar{v}z + Q)}{z + g}.$$

From this result one can immediately derive that a reduction in the cost of investment ($\Delta z > 0$), in the degree of risk aversion of the investors ($\Delta a < 0$), or in the variability of the asset's return ($\Delta\sigma_v^2 < 0$), increases the level of investment.

To conclude this section, it should be noted that the result that insider trading does not have any effect on the level of investment crucially depends on the assumption that the supplier of the asset is risk-neutral; under risk aversion, the fact that insider trading increases the volatility of the price would imply a negative effect on investment. Thus, in this case, Leland's result would be reversed.

V. Insider Trading in a Secondary Market

In this section I consider a variation of the previous model in which insider trading takes place in a secondary market for the asset. I will show that, in this model, the effect of insider trading on the volatility of the price in the secondary market has a cost in terms of a higher risk premium in the primary market that, in turn, reduces the level of investment (even when the supplier of the asset is risk-neutral).

Specifically, let us assume that insider trading takes place at an interim period ($t = 1$) between the placing of the asset in the primary market (at $t = 0$) and the realization of the return (at $t = 2$), so that the timing of events is now as follows:

$t=-1$	$t=0$	$t=1$	$t=2$
• Investment	• Placing of asset	• Insider trading	• Returns

To model trading in the secondary market in the simplest possible manner, I assume, following Dennert (1989), that there is a first generation of constant absolute risk-averse investors at $t=0$ who have to sell the asset at $t=1$, and a second generation of identical investors at $t=1$ who buy the asset from the first-generation investors. In addition, there is at $t=1$ a set of liquidity traders, who demand a random amount of the asset u, and a risk-neutral investor, who may or may not be informed about the future return of the asset, and demands an amount x.

Given this structure, it is clear that the model at $t=1$ is identical to the model of the previous section, so the equilibrium price functions at $t=1$ with and without insider trading, $p_1(q)$ and $p_1''(q)$, are given by (24) and (25), respectively.

To compute the equilibrium prices at $t=0$ in the two alternative scenarios, we solve the equilibrium conditions

$$\bar{q}=\frac{E(p_1(\bar{q}))-p_0(\bar{q})}{a\operatorname{Var}(p_1(\bar{q}))} \quad \text{and} \quad \bar{q}=\frac{E(p_1''(\bar{q}))-p_0''(\bar{q})}{a\operatorname{Var}(p_1''(\bar{q}))},$$

to get

$$p_0(\bar{q})=\bar{v}-\frac{a}{4}(3\sigma_v^2+\beta_0^2\sigma_u^2)\bar{q} \quad \text{and} \quad p_0''(\bar{q})=\bar{v}-\frac{a}{4}(2\sigma_v^2+g^{-2}\sigma_u^2)\bar{q}.$$

Since $3\sigma_v^2+\beta_0^2\sigma_u^2>2\sigma_v^2+g^{-2}\sigma_u^2$, it follows that insider trading shifts to the left the demand for the risky asset in the primary market. Maximizing the firm's expected profits from selling the asset at $t=0$, we then obtain

$$\bar{q}=\frac{\bar{v}z+Q}{1+(az/2)(3\sigma_v^2+\beta_0^2\sigma_u^2)}<\frac{\bar{v}z+Q}{1+(az/2)(2\sigma_v^2+g^{-2}\sigma_u^2)}=\bar{q}''.$$

Hence we conclude that, because of its effects on the volatility of the asset price in the secondary market, insider trading now reduces the level of investment.

VI. Conclusion

This paper first noted that Leland's results on the effects of insider trading on investment are not robust to the introduction of noise in the insider's information. In particular, although the qualitative results remain unchanged, the quantitative effects become negligible. I then considered two variations of Leland's original model, in which (1) the insider is risk-neutral (to ensure robustness), and (2) the investment decision is prior to the placing of the security in the market (to give market power to the supplier of the asset). I have shown that if insider trading takes place in the primary market it has no effect on the level of investment, whereas if it takes place in the secondary market it has a negative effect on investment.

The relationship between investment and the timing of security issues is, of course, an empirical question. Investment sometimes precedes security issues, and sometimes depends on the success of the issue. The timing might also depend on the existence of alternative sources of financing: when investment is prior to the placing of the security, one should explain how the investment is paid for. These are certainly interesting topics for future research.

Another important issue concerns the modelling of liquidity traders. Unless their behaviour is properly justified, it is difficult to take seriously welfare comparisons like the ones in Section 6 of Leland's paper. In this respect, some progress has been recently made by introducing shocks to the investors' intertemporal consumption preferences to model liquidity trading (see Bernhardt *et al.* 1995, and Bhattacharya and Nicodano 1996).

Despite these shortcomings, I believe that a tentative lesson can be drawn from the results. Insider trading at the time of the investment, by bringing the resolution of uncertainty forward, may be beneficial—although the precise nature of the welfare gains cannot be safely stated. However, future insider trading has costs in terms of a higher risk premium, which may have an overall negative effect on investment and welfare.

APPENDIX

To derive the equilibrium of the insider trading model with $\lambda > 0$ and $\sigma_\varepsilon^2 > 0$, we postulate a linear equilibrium price function $p(x+u) = \alpha + \beta(x+u)$ with undetermined coefficients α and β. The equilibrium price must satisfy the equation $p = \alpha + \beta(x(p) + u)$, where $x(p)$ is given by (15). Solving for p in this equation gives (17). Now using (17) and the properties of normal distributions, we can compute

$$E(v|p) = \bar{v}(1-K) - \frac{\alpha K(1-H)}{H} + \frac{K}{H}p \qquad \text{and} \qquad \text{Var}\,(v|p) = \sigma_\varepsilon^2 + (1-K)\sigma_\theta^2,$$

where

$$K \equiv H\frac{\text{Cov}\,(v,p)}{\text{Var}\,(p)} = \frac{H^2\sigma_\theta^2}{H^2\sigma_\theta^2 + \beta^2(1-H)^2\sigma_u^2}.$$

Substituting these expressions into (16) yields

$$d(p) = \frac{1-\lambda}{a[\sigma_\varepsilon^2 + (1-K)\sigma_\theta^2]}\left[\bar{v}(1-K) - \frac{\alpha K(1-H)}{H} - \left(1 - \frac{K}{H}\right)p\right] \equiv m - np.$$

Equilibrium requires

$$s(p) = Q + zp = m - np + x + u = d(p) + x + u,$$

which implies

$$p = \frac{m-Q}{z+n} + \frac{1}{z+n}(x+u).$$

Hence we have to solve for α and β the following system of equations:

(A1) $$\alpha = \frac{m-Q}{z+n},$$

(A2) $$\beta = \frac{1}{z+n}.$$

Since n depends only on β, the system is recursive. After some tedious manipulations, (A2) can be simplified to the following cubic equation in β:

$$\text{(A3)}\quad [a\sigma_v^2(\beta z-1)+\beta(1-\lambda)]\sigma_u^2(a\sigma_\varepsilon^2+\beta\lambda)^2-\lambda(1-\lambda)\sigma_\theta^2(a\sigma_\varepsilon^2+\beta\lambda) + a\lambda^2\sigma_\varepsilon^2\sigma_\theta^2(\beta z-1)=0.$$

When $\lambda\to 0$, this equation converges to the linear equation

$$[a\sigma_v^2(\beta z-1)+\beta]\sigma_u^2(a\sigma_\varepsilon^2)^2=0,$$

which has the solution[10]

$$\text{(A4)}\quad \beta(0,\sigma_\varepsilon^2)=\frac{1}{z+g}.$$

On the other hand, when $\sigma_\varepsilon^2\to 0$, (A3) converges to the equation

$$[a\sigma_v^2(\beta z-1)+\beta(1-\lambda)]\sigma_u^2(\beta\lambda)^2-\lambda^2(1-\lambda)\sigma_v^2\beta=0,$$

which has a single positive solution

$$\text{(A5)}\quad \beta(\lambda,0)=\frac{2(1-\lambda)}{a\sigma_u^2\left[-1+\left(1+\dfrac{4[z+(1-\lambda)g](1-\lambda)}{a\sigma_u^2}\right)^{1/2}\right]}.$$

This solution converges to Leland's β when $\lambda\to 0$.

Once β is derived from (A3), we can solve for α in (A1) to get

$$\alpha(\lambda,\sigma_\varepsilon^2)=\frac{\bar{v}\Gamma-Q}{z+\Gamma},$$

where

$$\Gamma\equiv\frac{(1-\lambda)(1-K)}{a[\sigma_\varepsilon^2+(1-K)\sigma_\theta^2]}.$$

For $\sigma_\varepsilon^2>0$ we have $\lim_{\lambda\to 0}H=0$, which implies $\lim_{\lambda\to 0}K=0$ and $\lim_{\lambda\to 0}\Gamma=(a\sigma_v^2)^{-1}=g$, so that

$$\text{(A6)}\quad \alpha(0,\sigma_\varepsilon^2)=\frac{\bar{v}g-Q}{z+g}.$$

On the other hand, since

$$\lim_{\sigma_\varepsilon^2\to 0}\Gamma=(1-\lambda)(a\sigma_v^2)^{-1}=(1-\lambda)g,$$

we have

$$\text{(A7)}\quad \alpha(\lambda,0)=\frac{\bar{v}(1-\lambda)g-Q}{z+(1-\lambda)g}.$$

Now substituting (A4) and (A6) into (17), and using the fact that $\lim_{\lambda\to 0}H=0$, we conclude that for $\sigma_\varepsilon^2>0$

$$p(0,\sigma_\varepsilon^2)=\lim_{\lambda\to 0}p(\lambda,\sigma_\varepsilon^2)=\frac{\bar{v}g-Q}{z+g}+\frac{1}{z+g}u=p',$$

as in Leland's model without insider trading—see (4).

Finally, substituting (A5) and (A7) into (17), and using the fact that $\lim_{\sigma_\varepsilon^2\to 0}H=1/2$, we have

$$p(\lambda,0)=\lim_{\sigma_\varepsilon^2\to 0}p(\lambda,\sigma_\varepsilon^2)=\frac{\bar{v}(1-\lambda)g-Q}{2[z+(1-\lambda)g]}+\frac{1}{2}v+\frac{\beta(\lambda,0)}{2}u,$$

so, taking limits again, we conclude that

$$\lim_{\lambda \to 0} p(\lambda, 0) = \frac{\bar{v}g - Q}{2(z+g)} + \frac{1}{2}v + \frac{\beta}{2}u = p,$$

as in Leland's model with insider trading—see (8).

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NOTES

1. It should be noted that the notation employed is slightly different from that of Leland, but closely follows the more standard one of Kyle (1985).
2. Note that the cost function is continuous and differentiable at $q = Q$.
3. It should be noted that, if the function $p(x+u)$ is linear with slope $\beta > 0$ (as it will be shown below), then the solution to this problem satisfies the first-order condition $x = (v - p)/\beta$. This means that the insider does not really have to observe the demand u of the liquidity traders, but only to trade on the basis of his information v and the market price p.
4. There is a typo in Leland's expression for $\beta\ (\equiv M^{-1})$ in the text, but not in the Appendix.
5. In private correspondence, Leland noted that 'my assumption is that insider mass is negligible—not zero. If it were literally zero, there would be no insider trading since there would be no insiders!' Thus, one may interpret his setup as the limit when the measure λ of the cartel of insiders tends to zero.
6. Recall that $v = \theta + \varepsilon$, so $\theta \to v$ when $\sigma_\varepsilon^2 \to 0$.
7. Since it can be shown that $1/\beta < (z+g)$ if and only if $(z+g)/a\sigma_u^2 > 0$.
8. Since $1/\beta < (z+g)$ (as noted in n. 7) implies $\beta_0 > 1/g$.
9. Assuming that $\bar{v}g > Q$, so that $q > Q$.
10. Recall that $g \equiv (a\sigma_v^2)^{-1}$.

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