Insider trading, stochastic liquidity, and equilibrium prices

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- Question: how well do these measures perform at picking up the presence of informed trading?

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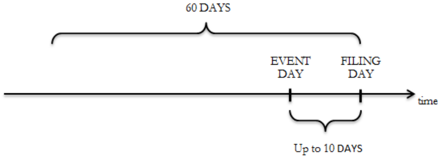

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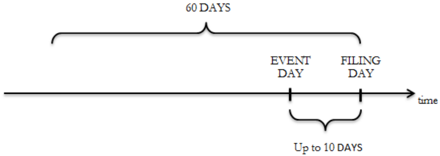

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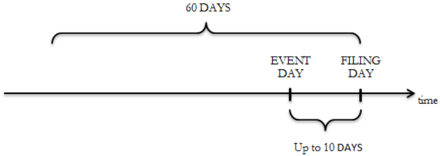

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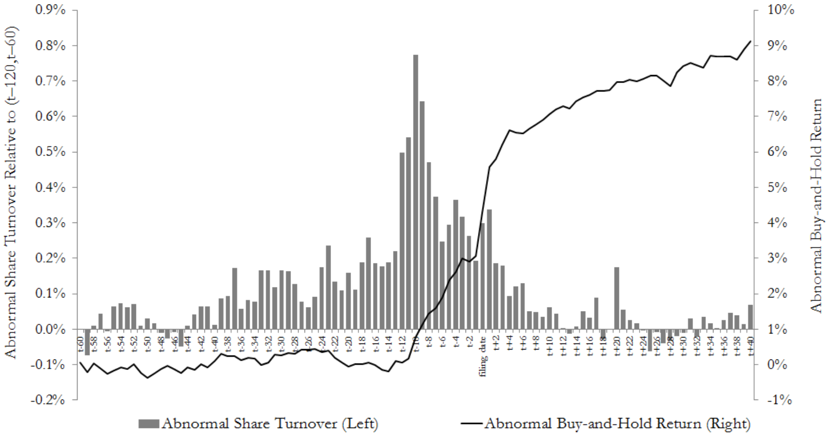
Find that measures of adverse selection are **lower** on days with informed trading

Buy-and-Hold Abnormal Return



Two month excess return is around 9%

Do informed trades move stock prices?

	days with informed trading (1)	days with no informed trading (2)	difference (3)	t-stat (4)
excess return	0.0064	-0.0004	0.0068***	9.94
turnover	0.0191	0.0077	0.0115***	21.67

Is adverse selection higher when informed trade?

	days with informed trading (1)	days with no informed trading (2)	difference (3)
Adverse Selection Measures			
$\lambda * 10^6$	14.3311	20.1644	-5.8334***
			[-8.38]
pimpact	0.0060	0.0064	-0.0004**
			[-2.18]
cumir	0.0013	0.0015	-0.0002**
			[-2.06]
trade − related	0.0654	0.0673	-0.0019
			[-0.99]
Other Liquidity Measures			
rspread	0.0081	0.0089	-0.0008***
			[-3.43]
espread	0.0145	0.0155	-0.001***
			[-3.25]

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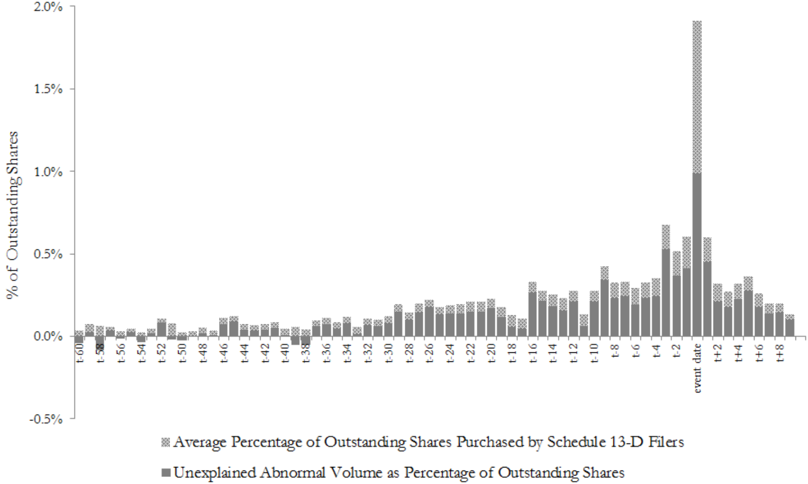
⇒ The endogeneity issue seems more problematic than the literature may have previously recognized.

Abnormal Share Turnover - Revisited



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  - Informed trade more aggressively when noise trading volatility is higher and when measured price impact is lower.
  - More information makes its way into prices when noise trading volatility is higher.
  - Aggregate adverse selection execution costs for uninformed noise traders can be higher when noise trading is higher (and lambda is lower).

Insider

- We follow Back (1992) and develop a continuous time version of Kyle (1985)
- Risk-neutral insider's maximization problem:

$$\max_{\theta_t} \mathrm{E}\left[\int_0^T (\upsilon - P_t)\theta_t dt \,|\mathcal{F}_t^Y, \upsilon\right] \tag{1}$$

- As in Kyle, we assume there is an insider trading in the stock with perfect knowledge of the terminal value υ
- It is optimal for the insider to follow absolutely continuous trading strategy (Back, 1992).
- Related work: Back and Pedersen (1998), Admati Pfleiderer (1988) and others...

Market Maker

- The market maker is also risk-neutral, but does not observe the terminal value. Instead, he has a prior that the value υ is normally distributed $N(\mu_0, \Sigma_0)$
- The market maker only observes the total order flow:

$$dY_t = \underbrace{\theta_t dt}_{\substack{informed \\ order\ flow}} + \underbrace{\sigma_t dZ_t}_{\substack{uninformed \\ order\ flow}} \tag{2}$$

- where σ_t is the stochastic volatility of the uninformed order flow:

$$d\sigma_t = m(t, \sigma^t)dt + \nu(t, \sigma^t)dM_t$$

  and M_t is orthogonal (possibly discontinuous) martingale.

- Since the market maker is risk-neutral, equilibrium imposes that

$$P_t = \mathrm{E}\left[\upsilon \,|\, \mathcal{F}_t^Y\right] \tag{3}$$

- We assume that the market maker and the informed investor observe σ_t.

Preview of Results

- This may seem like a trivial extension of the Kyle (1985) model, as one might conjecture that one can simply 'paste' together Kyle economies with different noise-trading volatilities . . . . . . But, not so!

- The insider will optimally choose to **trade less in the lower liquidity states** than he would were these to last forever, because he anticipates the future opportunity to trade more when liquidity is better and he can reap a larger profit

- Of course, in a rational expectations' equilibrium, the market maker foresees this, and adjusts prices accordingly. Therefore, **if noise trader volatility is predictable,** price dynamics are more complex than in the standard Kyle model:
    - Price displays stochastic volatility
    - Price impact measures are time varying and not necessarily related to informativeness of order flow.

Solving for Equilibrium

- First, we conjecture a trading rule followed by the insider:

$$\theta_t = \beta(t, \sigma^t, \Sigma_t)(\upsilon - P_t)$$

- Second, we derive the dynamics of the stock price consistent with the market maker's filtering rule, conditional on a conjectured trading rule followed by the insider

$$dP_t = \lambda(t, \sigma^t, \Sigma_t)dY_t$$

- Then we solve the insider's optimal portfolio choice problem, given the assumed dynamics of the equilibrium price
- Finally, we show that the conjectured rule by the market maker is indeed consistent with the insider's optimal choice

General Features of Equilibrium

- Price impact is stochastic:

$$\lambda_t = \sqrt{\frac{\Sigma_t}{G_t}} \tag{4}$$

- where Σ_t is remaining amount of private information

$$\Sigma_t = \mathrm{E}\left[(\upsilon - P_t)^2 \,|\, \mathcal{F}_t^Y\right] \tag{5}$$

- and G_t is remaining amount of uninformed order flow variance, solves the Backward stochastic differential equation (BSDE):

$$\sqrt{G_t} = \mathrm{E}\left[\int_t^T \frac{\sigma_s^2}{2\sqrt{G_s}} ds | \sigma^t\right] \tag{6}$$

- Optimal strategy of insider is:

$$\theta_t = \frac{1}{\lambda_t} \frac{\sigma_t^2}{G_t} (\upsilon - P_t) \tag{7}$$

$\Rightarrow$ Insider trades more aggressively when
- the ratio of private information (σ_t) to 'equilibrium-expected' noise trading volatility (G_t) is higher, and
- when price impact λ_t is lower.

General Features of Equilibrium

- Stock price displays time-varying volatility:

$$dP_t = \frac{(v - P_t)}{G_t}\sigma_t^2 dt + \sqrt{\frac{\Sigma_t}{G_t}}\sigma_t \, dZ_t \qquad (8)$$

- Note, that information asymmetry is necessary for price process to be non-constant.
- G_t is the crucial quantity to characterize equilibrium. Its BSDE solution satisfies:

$$G_t \leq \mathrm{E}[\int_t^T \sigma_s^2 ds]$$

- If $\underline{\sigma} \leq \sigma_t \leq \overline{\sigma}$ then we can show that there exists a maximal bounded solution to the recursive equation for G with:

$$\underline{\sigma}^2 (T - t) \leq G_t \leq \overline{\sigma}^2 (T - t) \qquad (9)$$

- For several special cases we can construct an explicit solution to this BSDE:
  - σ_t deterministic.
  - σ_t general martingale.
  - $\log \sigma_t$ Ornstein-Uhlenbeck process.
  - σ_t continuous time Markov Chain.

General Features of Equilibrium

- $\lim_{t \to T} P_t = v$ 'Stochastic bridge' property of price in insider's filtration.
- Market depth $(1/\lambda_t)$ is martingale.
- Price impact (λ_t) is a submartingale (liquidity is expected to deteriorate over time).
- $d\Sigma_t = -dP_t^2$ (stock price variance is high when information gets into prices faster, which occurs when noise trader volatility is high).
- Total profits of the insider are equal to $\sqrt{\Sigma_0 G_0}$.
- Realized execution costs of uninformed can be computed pathwise as

$$\int_0^T (P_{t+dt} - P_t)\sigma_t dz_t = \int_0^T \lambda_t \sigma_t^2 dt$$

- Unconditionally, expected aggregate execution costs of uninformed equal insider's profits.

General martingale dynamics

- We assume that uninformed order flow volatility is unpredictable (a martingale):

$$\frac{d\sigma_t}{\sigma_t} = \nu(t, \sigma^t) dM_t, \tag{10}$$

- We can solve for $G(t) = \sigma_t^2 (T - t)$,
- Then market depth is a martingale:

$$\frac{1}{\lambda_t} = \frac{\sigma_t}{\sigma_\upsilon},$$

where $\sigma_\upsilon^2 = \frac{\Sigma_0}{T}$ is the annualized initial private information variance level.

- The trading strategy of the insiders is $\theta_t = \frac{\sigma_t}{\sigma_\upsilon (T-t)} (\upsilon - P_t)$
- Equilibrium price dynamics are identical to the original Kyle (1985) model:

$$dP_t = \frac{(\upsilon - P_t)}{T - t} dt + \sigma_\upsilon dZ_t. \tag{11}$$

Implications of martingale dynamics

This example shows we can extend Kyle's equilibrium by simply 'plugging-in' stochastic noise trading volatility:

- Market depth varies linearly to noise trading volatility,
- Insider's strategy is more aggressive when noise trading volatility increases,
- Both effects offset perfectly so as to leave prices unchanged (relative to Kyle):
  - Prices display constant volatility.
  - Private information gets into prices linearly and independently of the rate of noise trading volatility (as in Kyle).

$\Rightarrow$ In this model empirical measures of price impact will be time varying (and increasing over time on average), but do not reflect any variation in asymmetric information of trades.

General Diffusion Dynamics

- Suppose that volatility follows a strictly positive process of the form:

$$\frac{d\sigma_t}{\sigma_t} = m(t, \sigma^t)dt + \nu(t, \sigma^t)dW_t \tag{12}$$

- If the expected growth rate of noise trading volatility follows a deterministic process m_t:
  - $G(t)$ admits the solution: $G(t) = \sigma_t^2 \int_t^T e^{\int_t^u 2m_s ds} du$
  - Private information enters prices at a deterministic rate
  - Equilibrium price volatility is deterministic

- For the insider to change his strategy depending on the uncertainty about future noise trading volatility, the growth rate of noise trading volatility m_t has to be stochastic.

Constant Expected growth rate

- We assume that uninformed order flow volatility follows a geometric Brownian Motion:

$$\frac{d\sigma_t}{\sigma_t} = mdt + \nu dW_t, \tag{13}$$

- We can solve for $G(t) = \sigma_t^2 B_t$ where $B_t = \frac{e^{2m(T-t)}-1}{2m}$,
- Then market depth is $\frac{1}{\lambda_t} = e^{-mt}\sigma_t\sqrt{\frac{B_0}{\Sigma_0}}$
- Equilibrium price dynamics follow a one-factor Markov non-homogenous bridge process:

$$dP_t = \frac{(\upsilon - P_t)}{B_t}dt + e^{mt}\sqrt{\frac{\Sigma_0}{B_0}}dZ_t. \tag{14}$$

Implications of constant growth rate

- As soon as there is predictability in noise trader volatility, equilibrium prices change (relative to Kyle):
  - Price volatility increases (decreases) deterministically with time if noise trading volatility is expected to increase (decrease).
  - Private information gets into prices slower (faster) if noise trading volatility is expected to increase (decrease).
- Interesting separation result obtains:
  - Strategy of insider and price impact measure only depends on current level of noise trader volatility.
  - Equilibrium is independent of uncertainty about future noise trading volatility level (ν).
  - As a result, equilibrium price volatility is deterministic
  - Private information gets into prices at a deterministic rate, despite measures of price impact (and the strategy of the insider) being stochastic!

Implications of constant growth rate

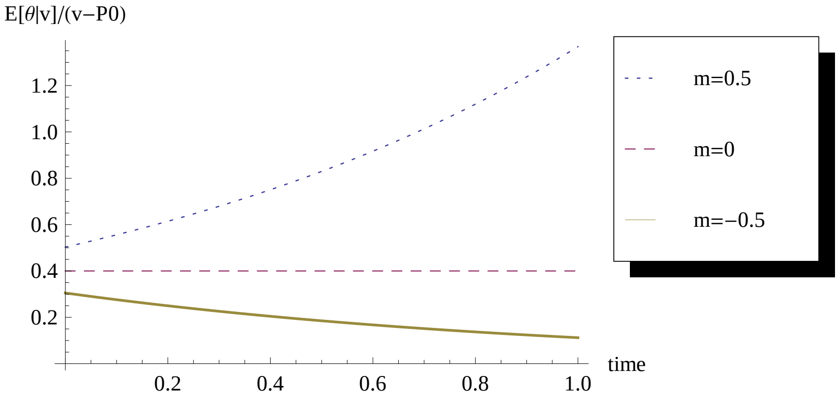

FIGURE: The Trading Strategy of the Insider

A two-state Continuous Markov Chain example

- Assume uninformed order flow volatility can take on two values $\sigma(0) < \sigma(1)$ where regime indicator $S_t \in [0, 1]$ follows:

$$dS_t = (1 - s_t)dN_0(t) - s_t dN_1(t), \tag{15}$$

where $N_i(t)$ is a standard Poisson counting process with jump intensity η_i respectively

- The solution is $G(t, s_t) = \mathbf{1}_{\{s_t=0\}} G^0(T - t) + \mathbf{1}_{\{s_t=1\}} G^1(T - t)$, where the deterministic functions G^0, G^1 satisfy the system of ODE (with boundary conditions $G^0(0) = G^1(0) = 0$):

$$\begin{aligned} G^0_\tau(\tau) &= \sigma(0)^2 + 2\eta_0(\sqrt{G^1(\tau)G^0(\tau)} - G^0(\tau)) && (16) \\ G^1_\tau(\tau) &= \sigma(1)^2 + 2\eta_1(\sqrt{G^1(\tau)G^0(\tau)} - G^1(\tau)) && (17) \end{aligned}$$

- We compute execution costs of uninformed numerically in this case.
- Show that uninformed execution costs can be higher when noise trading volatility is higher (and Kyle lambda is actually lower).

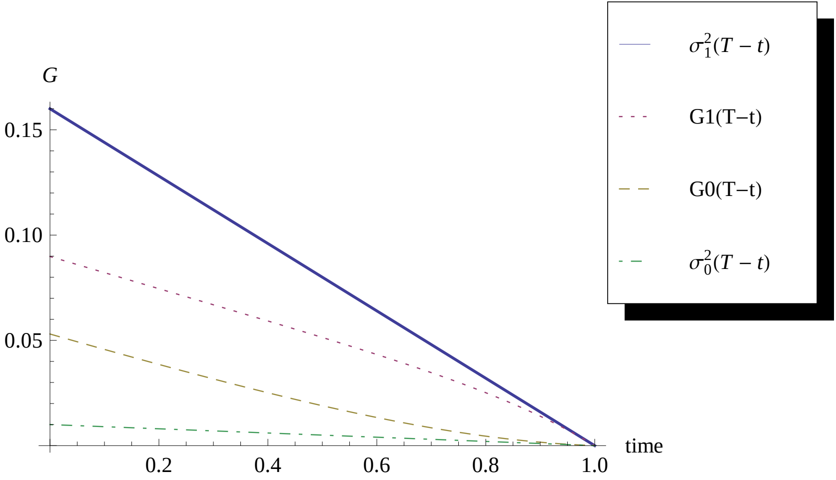

FIGURE: G function in high and low state

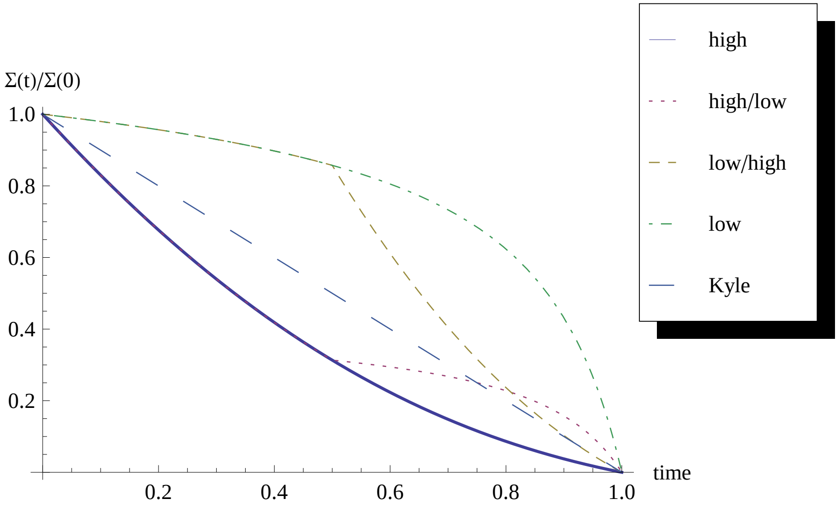

FIGURE: Four Private information paths

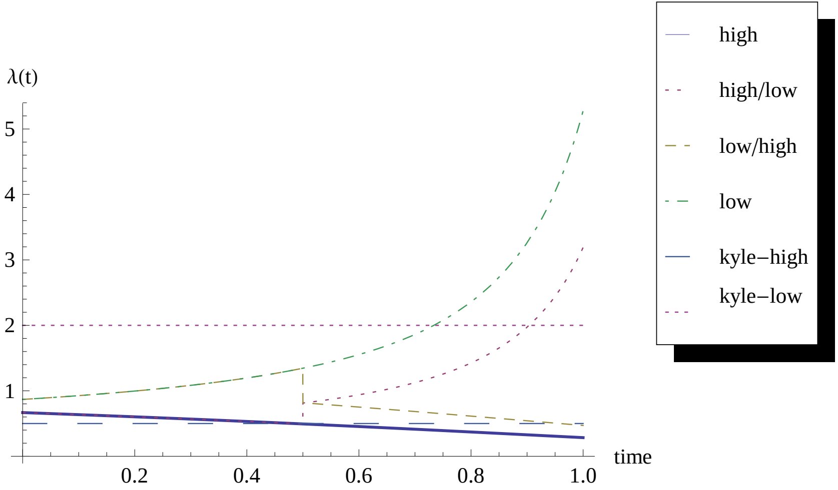

FIGURE: Four paths of price impact λ_t

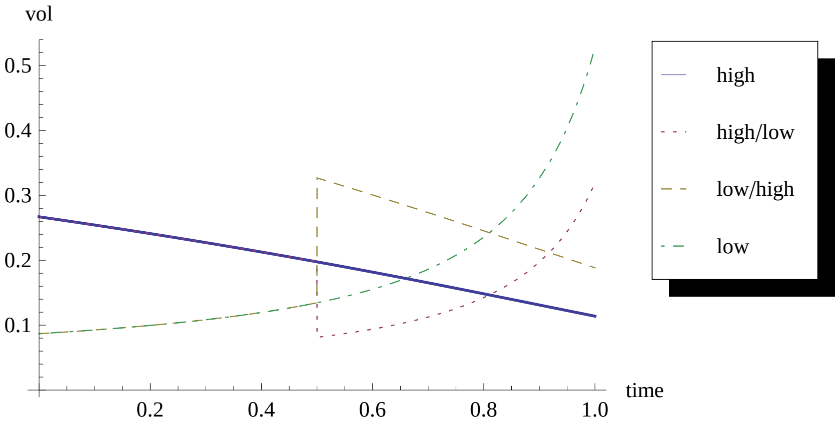

FIGURE: Four paths of Stock price volatility

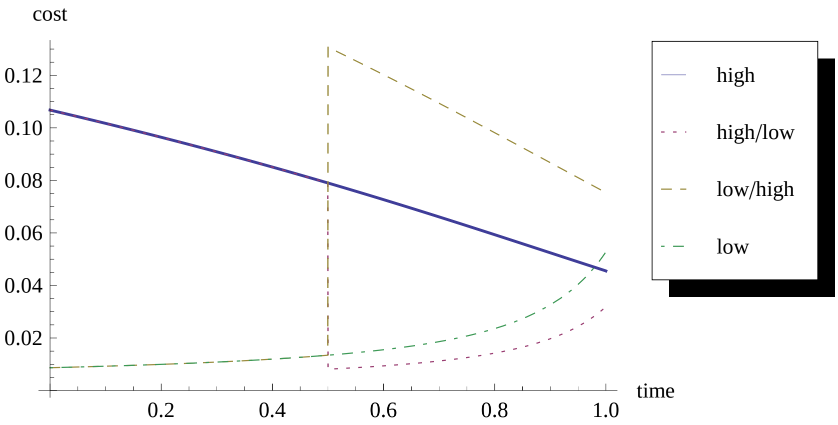

FIGURE: Four paths of uninformed traders execution costs

	Noise trading volatility paths			
	high	low	high/low	low/high
Total 'number' of uninformed ($\int_0^T \sigma_t^2 dt$)	0.16	0.01	0.085	0.085
Average price impact ($\int_0^T \lambda_t dt$)	0.487	1.740	1.023	0.853
Execution costs ($\int_0^T \lambda_t \sigma_t^2 dt$)	0.078	0.017	0.054	0.057
Normalized execution costs ($\frac{\int_0^T \lambda_t \sigma_t^2 dt}{\int_0^T \sigma_t^2 dt}$)	0.487	1.740	0.636	0.671

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- Average price-impact is not informative about execution costs to uninformed traders.
- Normalizing by 'abnormal' trading volume is crucial.
- Even so, average execution costs to uninformed are path-dependent.

Conclusion

- Recent empirical paper finds that standard measures of adverse selection and stock liquidity fail to reveal the presence of informed traders
- Propose extension of Kyle (1985) to allow for stochastic noise trading volatility. Seems more consistent with evidence:
  - Insider conditions his trading on 'liquidity' state.
  - Price impact measures are time-varying, and not necessarily higher when more private information flows into prices.
  - Execution costs can be higher when measured price impact is lower.
  - Generates stochastic price volatility.
- Future work:
  - Better measure of liquidity/adverse selection?
  - Model of activist insider trading with endogenous terminal value. Why the 5% rule?
  - Absence of common knowledge about informed presence.