# Non-Fundamental Information in Social Networks: Information Acquisition and Asset Prices

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# Overview

# Backgrounds and motivations

- Information sharing between investors can have significant impacts on their trading behavior and asset prices (e.g., Hong et al. (2005))
- Theories have revealed channels through which information sharing affects financial markets, e.g.,
  - Communication decreases investors' incentives to produce information and thus market efficiency (Han and Yang (2013))
  - Other theories: Walden (2019), Han et al. (2022)
- Existing models largely consider the spread of fundamental information (i.e., information about future asset payoff)
- Investors may also acquire non-fundamental information (e.g., order flow information, see Ganguli and Yang (2009))
  - The growth of financial technology increases investors' learning about order flow information (Farboodi and Veldkamp (2020))

# Backgrounds and motivations

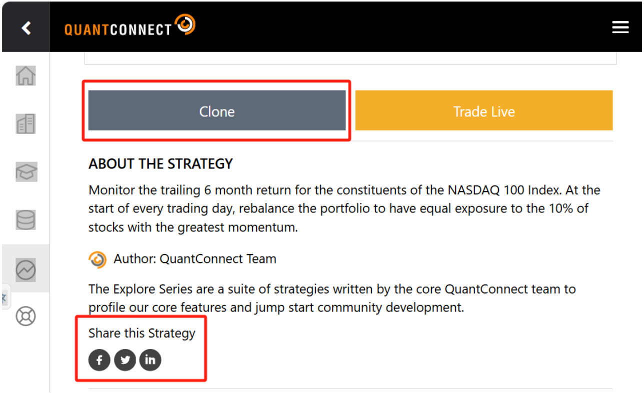


Figure: The spread of non-fundamental information: An example

# This paper

- How does the spread of non-fundamental information in social networks affect investor behavior and financial markets?
- Model
  - Investors are split into groups
  - Each investor can decide whether to become informed
  - Each informed investor can acquire both fundamental and non-fundamental information (information on noise trading), and share non-fundamental information with others within a same group
- Main result: Market informational efficiency is hump-shaped in the spread of non-fundamental information
  - Spread of non-fundamental information $\uparrow \Rightarrow$ number of investors trading against noise traders $\uparrow \Rightarrow$ mispricing $\downarrow$
  - Spread of non-fundamental information $\uparrow \Rightarrow$ investors' incentives to produce information $\downarrow \Rightarrow$ mispricing $\uparrow$

# Related literature

- Information acquisition and aggregation in financial markets
  - Grossman and Stiglitz (1980, AER); Benhabib, Liu, and Wang (2019, JF); Brunnermeier, Sockin, and Xiong (2022, RES); Cai (2019, JET); Farboodi and Veldkamp (2020, AER); Goldstein and Yang (2022, JF)
  - Contribution: Information acquisition on both extensive and intensive margins
- Social networks and financial markets
  - Theory: Han and Yang (2013, MS); Ozsoylev and Walden (2011, JET); Walden (2019, RES); Han, Hirshleifer, and Walden (2020, JFQA)
  - Evidence: Shiller and Pound (1989, JEBO); Hong, Kubik, and Stein (2005, JF); Ivkovic and Weisbenner (2007, RFS)
  - Contribution: Social networks + non-fundamental information

# Risky asset and investors

- Dividend process of a risky asset (e.g., stock)

$$d_{t+1} - d_t = (1 - G_d)(\mu_d - d_t) + v_{t+1}$$

- $v_{t+1} \sim N(0, \tau_v^{-1})$, $G_d \in [0, 1)$, $\mu_d \geq 0$
- Noise traders' demand for asset: $n_{t+1} \sim N(0, \tau_n^{-1})$

- In period $t$, $G_t > 0$ groups of rational investors are born
- Each group has $N_t > 0$ investors ($N_t$: "network connectedness")
- $\mu_t N_t$ of which are informed, $\mu_t \in [0, 1]$
- An informed investor can observe two private signals

$$z_{igt} = n_{t+1} + \varepsilon_{igt}^z, \quad \varepsilon_{igt}^z \sim N(0, (\tau_{igt}^z)^{-1})$$
$$x_{igt} = v_{t+1} + \varepsilon_{igt}^x, \quad \varepsilon_{igt}^x \sim N(0, (\tau_{igt}^x)^{-1})$$

# Social networks and information sharing

- An informed investor sends (noisier versions of) private signals to other investors within the same group

$$y^z_{igt} = z_{igt} + \eta^z_{igt}, \quad \eta^z_{igt} \sim N(0, (\tau^{\eta z})^{-1})$$
$$y^x_{igt} = x_{igt} + \eta^x_{igt}, \quad \eta^x_{igt} \sim N(0, (\tau^{\eta x})^{-1})$$

- $(\{v_t\}, \{n_t\}, \{\varepsilon^x_{igt}\}, \{\varepsilon^z_{igt}\}, \{\eta^x_{igt}\}, \{\eta^z_{igt}\})$ are independent
- Only consider symmetric information equilibrium: $\tau^z_{igt} = \tau^z_t$ and $\tau^x_{igt} = \tau^x_t$, $\forall i, g$
- Precision of a signal sent to others

$$\tau^{yz}_t = (Var[\varepsilon^z_{igt} + \eta^z_{igt}])^{-1} = [(\tau^z_t)^{-1} + (\tau^{\eta z})^{-1})]^{-1}$$
$$\tau^{yx}_t = (Var[\varepsilon^x_{igt} + \eta^x_{igt}])^{-1} = [(\tau^x_t)^{-1} + (\tau^{\eta x})^{-1})]^{-1}$$

# The structure of networks: An illustration

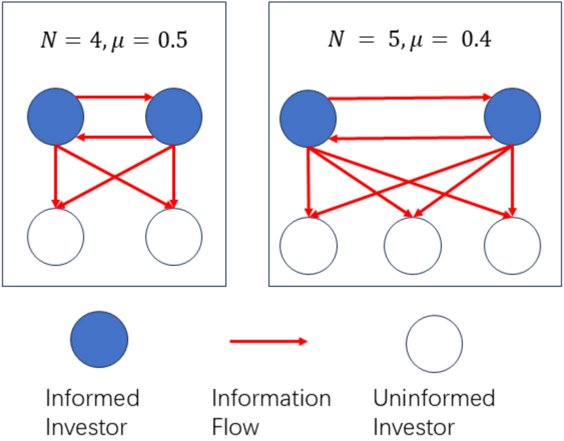


Figure: Two examples of the structure of a group of investors.

# Timeline for investors born at the beginning of period $t$

- In period $t$
  - Each investor decides whether to become informed by paying a fixed cost
  - Informed investors decide information precision (i.e., choose $\tau_{igt}^{z}$ and $\tau_{igt}^{x}$)
  - Each investor communicate with others in the same group
  - Financial market trading takes place, and the asset price $p_t$ is realize
  - The dividend $d_{t+1}$ is realized and paid to investors.
- In period $t+1$
  - Investors born in period $t$ sell all of their asset holdings to investors born in period $t+1$ and consume their wealth

# Investors' portfolio choices

- An investor's consumption

$$c_{ig,t+1} = (e_{igt} - m_{igt} p_t) r + m_{igt}(d_{t+1} + \psi p_{t+1}) - \mathbb{1}_{\{i \in I_{gt}\}} C_F$$

- $e_{igt}$: endowment; $m_{igt}$: risky asset holding; $C_F$: information cost; $\mathbb{1}_{\{\cdot\}}$: indicator function
- $\psi = 1$: Dynamic model; $\psi = 0$: Static model

- Portfolio choice:

$$\max_{m_{igt}} E\left[U(c_{ig,t+1}) | \mathcal{F}_{igt}\right] \quad (1)$$

- $U(c) = -\exp(-\gamma c)$; $\gamma > 0$: absolute risk aversion
- $\mathcal{F}_{igt} = \mathcal{F}_{igt}^{IN}$ ($\mathcal{F}_{igt}^{UN}$) if the investor is informed (uninformed)

# Financial market equilibrium

## Definition (Financial market equilibrium)

Given the sequence of the proportion of informed investors $\{\mu_t\}$, and the sequences of informed investors' private signal precision $\{\tau^x_{igt}\}$ and $\{\tau^z_{igt}\}$, a financial market equilibrium consists of a sequence of investors' risky asset holdings $\{m_{igt}\}$ and a sequence of the risky asset prices $\{p_t\}$, such that (i) each investor's risky asset holding $m_{igt}$ solves the utility maximization problem (1) subject to the budget constraint, and (ii) in each period $t$, the asset price $p_t$ clears the financial market, i.e.,

$$\lim_{G_t \to +\infty} \frac{1}{G_t} \sum_{g=1}^{G_t} \left[ \frac{1}{N_t} \left( \sum_{i \in I_{gt}} m_{igt} + \sum_{i \in U_{gt}} m_{igt} \right) \right] + n_{t+1} = s, \quad (2)$$

where $U_{gt}$ is the set of uninformed investors from group $g$ in period $t$.

# Financial market equilibrium

## Proposition (Characterization of financial market equilibrium)

*The equilibrium risky asset price in period $t$ is expressed as*

$$p_t = \beta_{0t} + \beta_{1t} v_{t+1} + \beta_{2t} n_{t+1} + \beta_{3t}(d_t - \mu_d),$$

*where $\beta_{0t}$, $\beta_{1t}$, $\beta_{2t}$, and $\beta_{3t}$ satisfy the following system of difference equations,*

$$\begin{aligned}
\beta_{0,t} &= \frac{-s}{r(\omega_t^{IN} + \omega_t^{UN})} + \frac{1}{r}(\psi\beta_{0,t+1} + \mu_d), \\
\beta_{1,t} &= \frac{\omega_t^{IN}}{r(\omega_t^{IN} + \omega_t^{UN})}(1 + \psi\beta_{3,t+1})V_t^{IN}(\tau^x + (\mu_t N_t - 1)\tau_t^{yx} + \tau_t^{\tilde{p}}) \\
&\quad + \frac{\omega_t^{UN}}{r(\omega_t^{IN} + \omega_t^{UN})}(1 + \psi\beta_{3,t+1})V_t^{UN}(\mu_t N_t \tau_t^{yx} + \tau_t^{\hat{p}}), \\
\beta_{2,t} &= \frac{\omega_t^{IN}}{r(\omega_t^{IN} + \omega_t^{UN})}(1 + \psi\beta_{3,t+1})V_t^{IN}\tau_t^{\tilde{p}}\frac{\beta_{2,t}}{\beta_{1,t}}\frac{\tau_n}{\tau_n + (\mu_t N_t - 1)\tau_t^{yz} + \tau^z} \\
&\quad + \frac{\omega_t^{UN}}{r(\omega_t^{IN} + \omega_t^{UN})}(1 + \psi\beta_{3,t+1})V_t^{UN}\tau_t^{\hat{p}}\frac{\beta_{2,t}}{\beta_{1,t}}\frac{\tau_n}{\tau_n + \mu_t N_t \tau_t^{yz}}, \\
\beta_{3,t} &= \frac{G_d}{r - \psi G_d}, V_t^{IN} = Var[\psi p_{t+1} + d_{t+1}|\mathcal{F}_{igt}^{IN}], V_t^{UN} = Var[\psi p_{t+1} + d_{t+1}|\mathcal{F}_{igt}^{UN}]
\end{aligned} \tag{3}$$

# Signal precision choices

- Before receiving signals, each informed investor solves

$$\max_{\tau^x_{igt},\tau^z_{igt}} E[U(c_{ig,t+1})|\{d_s\}_{s\leq t}] \tag{4}$$

- Subject to $(\tau^x_{igt})^2 + \chi(\tau^z_{igt})^2 \leq H_t$
- $H_t$: Financial data technology (Farboodi and Veldkamp (2020))
- Symmetric information equilibrium condition: $\tau^z_{igt} = \tau^z_t$ and $\tau^x_{igt} = \tau^x_t$, $\forall i, g$
- Optimal precision choice:

$$\tau^x_t = \frac{\sqrt{H_t}}{\sqrt{1 + (\frac{\beta_{1t}}{\beta_{2t}})^4 \frac{1}{\chi}}}, \quad \tau^z_t = \frac{1}{\chi}\left(\frac{\beta_{1t}}{\beta_{2t}}\right)^2 \frac{\sqrt{H_t}}{\sqrt{1 + (\frac{\beta_{1t}}{\beta_{2t}})^4 \frac{1}{\chi}}}. \tag{5}$$

# Choosing whether to be informed

- At the beginning of a period, each investor decides whether to become an informed investor by paying a cost $C_F$
- Benefit of being informed:

$$\Delta U_t(\mu_t) = E[E[U(c_{ig,t+1})|\mathcal{F}^{IN}_{igt}]|\{d_s\}_{s\le t}]|_{\mu_t} - E[E[U(c_{ig,t+1})|\mathcal{F}^{UN}_{igt}]|\{d_s\}_{s\le t}]|_{\mu_t}$$

- In equilibrium, being informed and being uninformed should be indifferent: $\Delta U_t(\mu_t) = 0$. (Grossman and Stiglitz (1980))

## Proposition (The proportion of informed investors)

*In period t, (a) if $\Delta U_t(0) > 0$ and $\Delta U_t(1) < 0$, the proportion of informed investors $\mu_t$ must satisfy the following equation,*

$$\sqrt{\frac{Var[\psi p_{t+1} + d_{t+1}|\mathcal{F}^{UN}_{igt}]|_{\mu_t}}{Var[\psi p_{t+1} + d_{t+1}|\mathcal{F}^{IN}_{igt}]|_{\mu_t}}} = e^{\gamma C_F}. \tag{6}$$

*(b) If $\Delta U_t(0) \le 0$, then the equilibrium proportion of informed investors is $\mu_t = 0$. (c) If $\Delta U_t(1) \ge 0$, then the equilibrium proportion of informed investors is $\mu_t = 1$.*

# The full equilibrium

- Equilibrium price coefficients, signal precision, and proportion of informed investors can be derived by solving Eqs. (6), (5), and (3) simultaneously
- Equilibrium price: $p_t = \beta_{0t} + \beta_{1t} v_{t+1} + \beta_{2t} n_{t+1} + \beta_{3t}(d_t - \mu_d)$
- Price informativeness: $\frac{\beta_{1t}}{\beta_{2t}}$

$$Var[d_{t+1} | d_t, p_t] = [\tau_v + (\frac{\beta_{1t}}{\beta_{2t}})^2 \tau_n]^{-1}$$

- Start from the static case: $\psi = 0$, $G_d = 0$, $\mu_d = 0$
- In this case, the asset price is

$$p = \beta_0 + \beta_1 v + \beta_2 n$$

- The price informativeness is $\frac{\beta_1}{\beta_2}$

# Main result: Impact of sharing order flow information

- Assume that investors only share order flow information, without sharing fundamental information (i.e., $\tau^{\eta z} > 0$ and $\tau^{\eta x} = 0$)
- Result: The price informativeness is hump-shaped in network connectedness

## Proposition (The impacts of sharing order flow information)

*Assume that $\psi = G_d = \mu_d = 0$. Also assume that $\tau^{\eta x} = 0$ so that no fundamental information is shared. (a) If $\Delta U(1) \geq 0$, then $\mu$ is fixed at 1. Moreover, we have $\frac{\partial(\beta_1/\beta_2)}{\partial N}|_{\tau^{\eta x}=0} > 0$, $\frac{\partial \tau^x}{\partial N}|_{\tau^{\eta x}=0} < 0$, and $\frac{\partial \tau^z}{\partial N}|_{\tau^{\eta x}=0} > 0$. (b) If $\Delta U(0) > 0$ and $\Delta U(1) < 0$, then $\mu$ satisfies the following equation,*

$$\mu = \frac{[\tau^x + (\frac{\beta_1}{\beta_2})^2(\tau^z - \tau^{yz})] - (e^{2\gamma C_F} - 1)(\tau_v + (\frac{\beta_1}{\beta_2})^2 \tau_n)}{N(e^{2\gamma C_F} - 1)(\frac{\beta_1}{\beta_2})^2 \tau^{yz}}. \quad (7)$$

*Moreover, we have $\frac{\partial(\beta_1/\beta_2)}{\partial N}|_{\tau^{\eta x}=0} < 0$, $\frac{\partial \tau^x}{\partial N}|_{\tau^{\eta x}=0} > 0$, and $\frac{\partial \tau^z}{\partial N}|_{\tau^{\eta x}=0} < 0$.*

# Main result: Impact of sharing order flow information

- Assume that investors only share order flow information, without sharing fundamental information (i.e., $\tau^{\eta z} > 0$ and $\tau^{\eta x} = 0$)
- Result: The price informativeness is hump-shaped in network connectedness

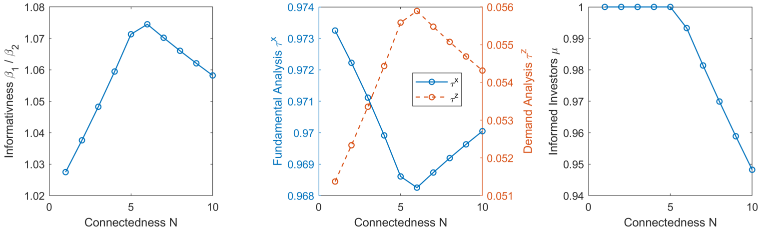


Figure: Impacts of network connectedness (static case, $\psi = 0$). This figure plots the price informativeness ($\frac{\beta_1}{\beta_2}$), fundamental analysis ($\tau^x$), demand analysis ($\tau^z$), and proportion of informed investors ($\mu$) as functions of network connectedness ($N$).

# Main result: Dynamic case

- Only non-fundamental information is shared
  - $\tau^{\eta x} = 0$, $\tau^{\eta z} > 0$
- Network connectedness evolves according to $N_t = t$

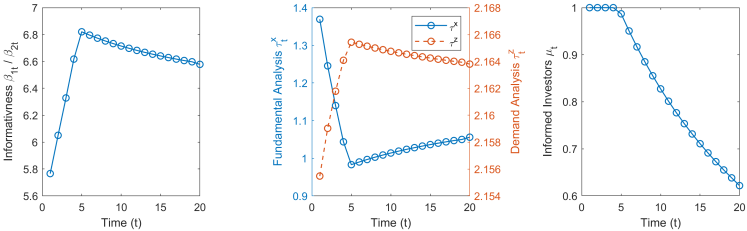


Figure: Impacts of network connectedness (dynamic case, $\psi = 1$). This figure plots the time series of price informativeness $\{\frac{\beta_{1t}}{\beta_{2t}}\}$, fundamental analysis $\{\tau_t^x\}$, demand analysis $\{\tau_t^z\}$, and the proportion of informed investors $\{\mu_t\}$.

# Explanation

- When network connectedness $N$ is low:
  - Network connectedness $N \uparrow \Rightarrow$ Number of investors observing order flow information $\uparrow \Rightarrow$ Number of investors trading against noise traders $\uparrow \Rightarrow$ Mispricing $\downarrow$ and informativeness $\uparrow$

$$m_{ig}^{UN} = \frac{\tau_{ig}^{\hat{p}}}{\tau_v + \tau_{ig}^{\hat{p}}} \left\{ \frac{p - \beta_0}{\beta_1} - \frac{\beta_2}{\beta_1} \frac{\mu N \tau^{yz}}{\tau_n + \mu N \tau^{yz}} \left[ n + \frac{1}{\mu N} \sum_{j \in I_g} (\varepsilon_{jg}^z + \eta_{jg}^z) \right] \right\} - \frac{rp}{\tau_v + \tau_{ig}^{\hat{p}}}$$

- When network connectedness $N$ is high:
  - Network connectedness $N \uparrow \Rightarrow$ Order flow information provided by others $\uparrow \Rightarrow$ Number of investors acquiring private order flow information $\downarrow \Rightarrow$ Investors' information about noise trading $\downarrow \Rightarrow$ Aggressiveness of trading against noise traders $\downarrow$ $\Rightarrow$ Mispricing $\uparrow$ and informativeness $\downarrow$

# Application: Quantitative trading platforms

- Trading based on non-fundamental signals resembles quantitative trading (both profit from mispricing)
- Sharing non-fundamental signals resembles sharing quantitative strategies
- Quantitative trading platforms (e.g., QUANTCONNECT and JointQuant) facilitate the sharing of quantitative strategies
  - Strategy developers upload strategy codes
  - Strategy users copy strategy codes
- Group of investors $\rightarrow$ platform; network connectedness $\rightarrow$ platform size; informed investor $\rightarrow$ strategy developer
- Early stage: an increase in platform size allows more investors to engage in quantitative trading, mitigating mispricing
- Later stage: an increase in platform size reduces the investors' incentives to develop their own strategies, exacerbating mispricing

# Appendix: Sharing both kinds of information

## Proposition (The impacts of network connectedness)

*Assume that $\psi = \mu_d = G_d = 0$. Define $\Delta U(\mu) = E[E[U(c_{ig})|\mathcal{F}_{ig}^{IN}]]|_\mu - E[E[U(c_{ig})|\mathcal{F}_{ig}^{UN}]]|_\mu$. (a) If $\Delta U(1) \geq 0$, then the proportion of informed investors is fixed at $\mu = 1$. Moreover, a higher network connectedness increases the price informativeness, decreases the fundamental analysis, and increases the demand analysis, i.e., $\frac{\partial(\beta_1/\beta_2)}{\partial N} > 0$, $\frac{\partial \tau^x}{\partial N} < 0$, and $\frac{\partial \tau^z}{\partial N} > 0$. (b) If $\Delta U(0) > 0$ and $\Delta U(1) < 0$, then the proportion of informed investors $\mu$ satisfies the following equation,*

$$\mu = \frac{[\tau^x - \tau^{yx} + (\frac{\beta_1}{\beta_2})^2(\tau^z - \tau^{yz})] - (e^{2\gamma C_F} - 1)(\tau_v + (\frac{\beta_1}{\beta_2})^2\tau_n)}{N(e^{2\gamma C_F} - 1)[\tau^{yx} + (\frac{\beta_1}{\beta_2})^2\tau^{yz}]}. \qquad (8)$$

*Moreover, a higher network connectedness decreases the price informativeness, increases the fundamental analysis, and decreases the demand analysis, i.e., $\frac{\partial(\beta_1/\beta_2)}{\partial N} < 0$, $\frac{\partial \tau^x}{\partial N} > 0$, and $\frac{\partial \tau^z}{\partial N} < 0$.*

# Appendix: Sharing both kinds of information

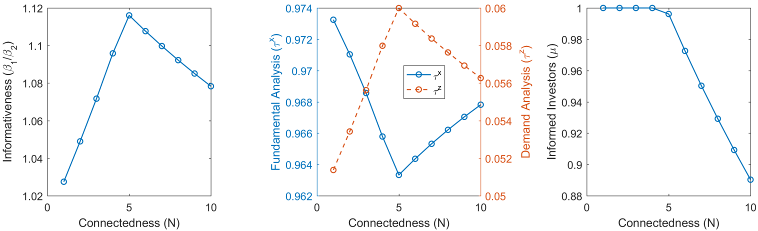


Figure: Impact of network connectedness when the proportion of informed investors is endogenous (static case). This figure plots price informativeness $\frac{\beta_1}{\beta_2}$, fundamental analysis $\tau^x$, demand analysis $\tau^z$, and proportion of informed investors $\mu$ as functions of network connectedness $N$. Parameter values: $\tau_v = 1$, $\tau_n = 1$, $\tau^{\eta x} = 0.01$, $\tau^{\eta z} = 0.01$, $\gamma = 1$, $\chi = 20$, $H = 1$, $C_F = 0.17$, and $\psi = G_d = \mu_d = 0$.

# Appendix: Networks and information received (informed)

- Information about noise traders' demand $n_{t+1}$ received by an *informed* investor $j$ from others in group $g$ can be summarized as

$$Y_{jgt}^{IN,z} = \frac{1}{\mu_t N_t - 1} \sum_{i \in I_{gt} \setminus \{j\}} y_{igt}^{z} = n_{t+1} + \frac{1}{\mu_t N_t - 1} \sum_{i \in I_{gt} \setminus \{j\}} (\varepsilon_{igt}^{z} + \eta_{igt}^{z})$$

- $I_{gt}$: the set of informed investors from group $g$ in period $t$
- The precision of $Y_{jgt}^{UN,z}$ is

$$\left( Var\left[ \frac{1}{\mu_t N_t - 1} \sum_{i \in I_{gt} \setminus \{j\}} (\varepsilon_{igt}^{z} + \eta_{igt}^{z}) \right] \right)^{-1} = (\mu_t N_t - 1)\tau_t^{yz}$$

- $Y_{jgt}^{IN,x}$ is similarly defined

# Appendix: Networks and information received (uninformed)

- Information about noise traders' demand $n_{t+1}$ received by an *uninformed* investor $j$ from others in group $g$ can be summarized as

$$Y_{jgt}^{UN,z} = \frac{1}{\mu_t N_t} \sum_{i \in I_{gt}} y_{igt}^z = n_{t+1} + \frac{1}{\mu_t N_t} \sum_{i \in I_{gt}} (\varepsilon_{igt}^z + \eta_{igt}^z),$$

- The precision of $Y_{jgt}^{UN,z}$ is

$$\left( Var \left[ \frac{1}{\mu_t N_t} \sum_{i \in I_{gt}} (\varepsilon_{igt}^z + \eta_{igt}^z) \right] \right)^{-1} = \mu_t N_t \tau_t^{yz}.$$

- $Y_{jgt}^{UN,x}$ is similarly defined
- Information sets for informed and uninformed investors

$$\mathcal{F}_{igt}^{IN} = \{ x_{igt}, z_{igt}, Y_{igt}^{IN,x}, Y_{igt}^{IN,z}, \{d_s\}_{s \le t}, \{p_s\}_{s \le t} \}$$
$$\mathcal{F}_{igt}^{UN} = \{ Y_{igt}^{UN,x}, Y_{igt}^{UN,z}, \{d_s\}_{s \le t}, \{p_s\}_{s \le t} \}$$

# Appendix: Another example


Figure: The spread of non-fundamental information: An example