Fake news

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Overview

Fake news

- Deliberate misinformation or hoaxes.
- Traditional print and broadcast news media or online social media.
- Intend to mislead in order to gain financially or politically.
- Effectively influencing the society.

Literature Review

- Communication games (Crawford and Sobel 1982, Kamenica and Gentzkow 2011,...)
  - No/full commitment power vs. Dynamically learned trust
- Media market (Mullainathan and Shleifer 2002, Gentzkow and Shapiro 2006)
  - Deception due to biased belief vs. Deception due to stochasticity
- Deception games (Anderson and Smith 2013)
  - Brownian motion process vs. Point process

Model development

- Point Processes: A stochastic process that models the discrete occurrence of events as a series of random points in continuous time or geographic space.
- News traffic: $dY = Z_0 dN_0 + Z_a dN_a$
  - N_0, N_a: Point processes capturing the timing of true news and fake news. Denote their intensities as $\Lambda_0(t)$ and $\Lambda_a(t)$.
  - Z_0, Z_a: Random variables capturing the content of true news and fake news. Denote their event space as Ω and pdf's as P_0 and P_a.
  - Common knowledge for receiver and sender.

Information structure

- Information asymmetry: The fake news sender knows that he is sending fake news but the receiver does not.
- Formally speaking, there are two states:
  - State 1: The sender is sending fake news and $dY = Z_0 dN_0 + Z_a dN_a$.
  - State 2: The sender is not sending fake news and $dY = Z_0 dN_0'$, where N_0' is a point process whose intensity Λ_0' satisfies $\Lambda_0' = \Lambda_0 + \Lambda_a$.
- At each time t, the receiver has a belief $q(t) \in [0, 1]$ that the world is in State 1 and a belief $1 - q(t)$ that the world is in State 2.
- $q(t)$ is Bayesian updated through the observation of Y:

$$dq = \frac{q(1-q)\left(\frac{\Lambda_a P_a(dY) + \Lambda_0 P_0(dY)}{\Lambda_0 + \Lambda_a} - P_0(dY)\right)}{q \cdot \frac{\Lambda_a P_a(dY) + \Lambda_0 P_0(dY)}{\Lambda_0 + \Lambda_a} + (1-q) P_0(dY)}$$

- Assume that receiver's initial belief q_0 is common knowledge, then the receiver's belief $q(t)$ is common knowledge for all t.

Payoff structure

- At each time t, the receiver decides her dependence on the focal sender, $p(t) \in [0,1]$ to maximize her expected payoff:

$$E[\int_0^\infty p((1-q)(\Lambda_0 + \Lambda_a) + q(\Lambda_0 - L\Lambda_a))dt]$$

  - Normalize her payoff from outside options as 0.
  - Assume that she obtains 1 positive payoff consuming each piece of true news and suffers $L > 0$ loss from consuming each piece of fake news.
- At each time t, the sender decides the fake news intensity $\Lambda_a(t) \in [0,c]$ to maximize his expected payoff, which is how much he misleads the receiver:

$$E[\int_0^\infty e^{-rt} p\Lambda_a dt]$$

Equilibrium Analysis

- Markov equilibrium
  - Bayesian Nash equilibrium.
  - Both players' strategies are Markovian and the state variable is the receiver's belief $q(t)$.
- The receiver's strategy will not influence the evolution of the game, therefore, her dynamic optimization problem is equivalent to optimization at each static point.

$$p(q) \in \arg \sup_{p \in [0,1]} p((1-q)(\Lambda_0 + \Lambda_a) + q(\Lambda_0 - L\Lambda_a)) \quad \forall q \in [0,1] \quad (1)$$

Equilibrium Analysis

- The sender is facing a dynamic programming problem: trade-off between immediate gain from misleading the receiver and a dynamic loss of the trust of the receiver.
- In equilibrium, with Hamilton-Jacobi-Bellman equation, the sender's strategy $\Lambda_a(q)$ and value function $V(q)$ follow

$$\Lambda_a(q) \in \arg \sup_{\Lambda_a \in [0,c]} p\Lambda_a + V'(E[g(Z_0)|q,\Lambda_a]\Lambda_0 + E[g(Z_a)|q,\Lambda_a]\Lambda_a) \tag{2}$$

and

$$rV = p\Lambda_a + V'(E[g(Z_0)|q,\Lambda_a]\Lambda_0 + E[g(Z_a)|q,\Lambda_a]\Lambda_a) \quad \forall q \in [0,1] \tag{3}$$

- A Markov equilibrium is a 3-tuple (p, V, Λ_a), where each entry is a function of q, such that conditions (1),(2),(3) are satisfied.

Equilibrium Analysis

Theorem (Existence and uniqueness of equilibrium)

There exists a unique Markov equilibrium.

An Illustrative Example

- Assume that the random variables capturing the contents of the true and fake news, Z_0 and Z_a, are binary, with frequency p_0 and p_a in one state and $1 - p_0$, $1 - p_a$ in the other state.
  - Likelihood of not passing some fact checking tool.
  - p_a characterizes the sender's technology of producing fake news.

Theorem (The game evolution)

When $0 < q < 1$, $E[dq/dt] > 0$. Therefore, there are only two absorbing states: $q = 0$ and $q = 1$. If the receiver's initial belief $q_0 > 0$, $q \to 1$ when $t \to \infty$.

An Illustrative Example

- Set $L = 3, c = 3, r = 0.1, \Lambda_0 = 1, p_0 = 0.1$, and compare strategies and payoffs between cases where $p_a = 0.3$ and $p_a = 0.4$.

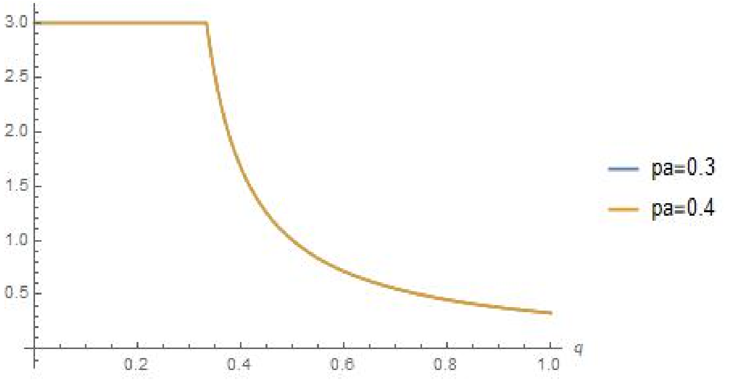

Figure: *Comparison of sender's strategies*

An Illustrative Example

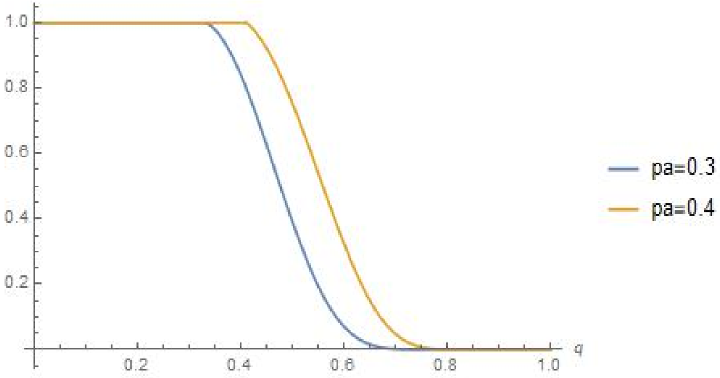

Figure: *Comparison of receiver's strategies*

An Illustrative Example

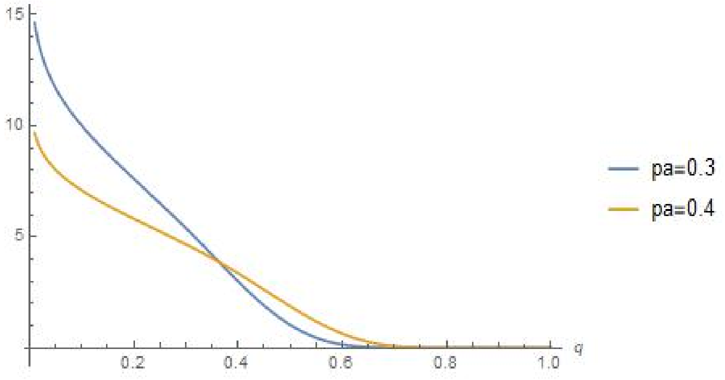

Figure: *Comparison of sender's payoffs*

An Illustrative Example

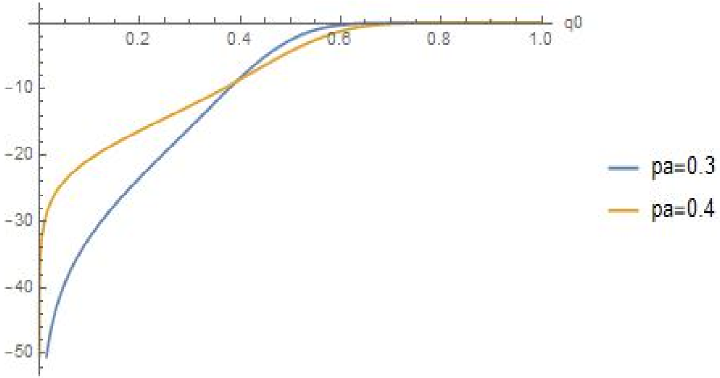

Figure: *Receiver's expected payoffs*

Off-equilibrium Analysis

- In equilibrium, it is assumed that the receiver knows the technology that the fake news sender would be using.
- Could be restrictive especially when the fake news sender is specialized while the receiver is relatively naive.
- With the binary characterization as in previous section, assume that the receiver anticipates the sender's technology to be characterized by p'_a.

Underestimation

We say that the receiver *underestimates* the sender's technology if $p_0 < p_a < p'_a$ or $p'_a < p_a < p_0$. The larger $(p_0 - p'_a)/(p_0 - p_a)$ is, we say that the sender is *more underestimated*.

Off-equilibrium Analysis

- Although the sender's technology is characterized by p_a, the receiver is using the equilibrium strategy where the technology is characterized by p'_a.
- The belief is updated based on the wrong anticipation.
- The sender knows that the receiver is misunderstanding and utilizes this by optimally responding to the receiver's suboptimal strategy.

Off-equilibrium Analysis

Theorem (The off-equilibrium game revolution)

Assume that $Lc > \Lambda_0$*. If the sender is underestimated, then there exists a unique* $q_e \in (0,1)$*, such that:*

i) when $0 < q < q_e$*,* $E[dq/dt] > 0$

ii) when $q = q_e$*,* $E[dq/dt] = 0$

iii) when $q_e < q < 1$*,* $E[dq/dt] < 0$

Therefore, other than $q = 0$ *and* $q = 1$*,* q_e *is another absorbing state. If* $0 < q(t_0) < 1$*, as* $t \to \infty$*,* q *will fluctuates around* q_e *and the sender's intensity fluctuates around* $\Lambda_a(q_e)$*. Specifically,* $\Lambda_a(q_e)$ *satisfies:*

i) $\Lambda_a(q_e) = \frac{p_0 - p'_a}{Lp_0 + p'_a - p_a - Lp_a}\Lambda_0$*, if* $\frac{p_0 - p'_a}{p_0 - p_a} < \frac{c}{c + \Lambda_0}(1 + L)$*.*

ii) $\Lambda_a(q_e) = c$*, if* $\frac{p_0 - p'_a}{p_0 - p_a} \geq \frac{c}{c + \Lambda_0}(1 + L)$

Off-equilibrium Analysis

Theorem (Effect of underestimation)

If the receiver has initial belief $0 < q(t_0) < 1$ *and underestimates the sender's technology, she will receive more fake news in the long run if the sender is more underestimated. Formally,* $\Lambda_a(q_e)$ *is an increasing function with respect to* $(p_0 - p'_a)/(p_0 - p_a)$.

Off-equilibrium Analysis

- Set $L = 3, c = 3, r = 0.1, \Lambda_0 = 1, p_0 = 0.1$, and compare strategies and payoffs between equilibrium cases where $p_a = 0.3$ and $p_a = 0.4$ and off-equilibrium case where $p_a = 0.3, p'_a = 0.4$

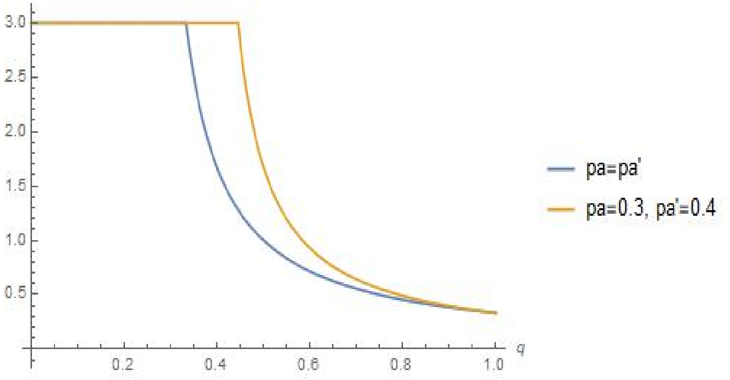

Figure: *Comparison of sender's equilibrium strategies and off-equilibrium strategy*

Off-equilibrium Analysis

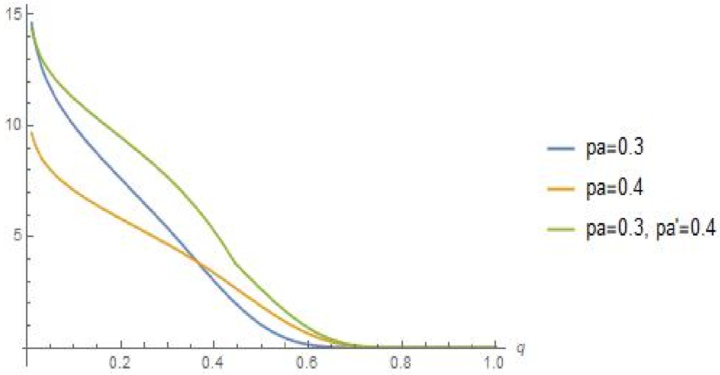

Figure: *Comparison of sender's equilibrium payoffs and off-equilibrium payoff*

Future directions

- Synergies between pieces of news
- The receiver's optimal fake news checking method.
- The sender's optimal fake news generation technology.
  - Trade-off between how deceptive the news is and how much the news can mislead readers.
- ...

Thank you!