Enforcing Truthful-Rating Equilibria in Electronic Marketplaces

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Overview

- Problem definition and related work
- The basic model (fixed punishments) and its analysis
- The extended model (reputation-based punishments) and its analysis
- Conclusions – Future Work
Reputation in Peer-to-Peer Systems

- Reputation reveals hidden information
- Only effective with reputation-based policies [1]
  - “Provider Selection” and “Contention Resolution” ones
- But, reputation is vulnerable to false or malicious ratings
- Thus, collect ratings from both transacted parties and punish both in case of disagreement [2]
  - At least one of them is lying
  - Punishment is not monetary

The Context

- Reputation is studied in electronic marketplaces where participants act
  - both as providers and as clients
  - competitively, so as to maximize their market share
  - E.g. exchanging vinyl records among collectors, software modules among programmers, etc.

- Provider selection based on reputation

- Malicious rating may offer competitive advantage
Our Objectives

- Provide incentives for truthful rating in such a context

To this end:
- Analyze the dynamics of fixed monetary punishments
- Find necessary conditions for stable truthful rating equilibrium
- Customize punishments w.r.t. reputation to reduce social unfairness
Related Work – Monetary Penalty Approaches

- Miller, Resnick, Zeckhauser: Truthful rating is a Nash equilibrium for clients if certain penalties are induced to them for potential lying.

- Jurca, Faltings: Side-payments upon evidence of lying; clients do not act as providers.

- Dellarocas: Penalty to provider to compensate payoff gains from offering lower quality than promised. Nash equilibrium for truthful clients.
What is innovative

- Dual role of participants
- Reputation-based competition and impact on incentives for truthful reporting
- Stability analysis of truthful-rating Nash equilibrium enforced by each mechanism
- Tailored reputation-based punishments
The Basic Model
The Basic Model

- E-marketplace with $N$ participants
  - $N$ either fixed or mean number of participants with geometrically distributed lifetimes

- Each participant has a probability $a_i$ to provide service instances successfully, i.e. of satisfactory quality
  - Private information; reputation is an estimate for it

- A successfully provided service instance:
  - Offers fixed utility $u$ to the client
  - Demands costly effort $v$
  - Costs $b$ to the client, with pre-payment $p \cdot b$ to balance the risks

- Time is discretized in rounds
At each round...

- Each participant may act as a provider with probability $q$ and as a client with probability $1-q$

- Reputation-based policy: Clients associate to providers probabilistically fair to the reputation of the latter
  - Demand attracted by provider $i$ is proportional to his rank $R_i = \frac{r_i}{\bar{r}}$

- Both transacted parties have to rate service provision
  - Upon agreement, the client pays $(1-p)\cdot b$ and the vote is registered for the provider
  - Disagreement incurs fixed punishment $c$ to both
Single Transaction Game

- Two sub-games depending on the service provision outcome: success or failure

- Reporting strategies in $S = \{Witness, Lie, Duck\}$

- Impact of agreed rating to future payoffs of participants
  - A positive rating results to $w_p > 0$ and $-w_c < 0$ payoff impacts for the provider and the client respectively
  - A negative rating results to $-w_p' < 0$ and $-w_c' > 0$ payoff impacts for the provider and the client respectively

- $w_p, w_p', w_c, w_c'$ are taken fixed
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Truthful Equilibrium Conditions and Stability
Truthful Nash Equilibrium

- Derive conditions for disagreement punishment so as truthful reporting is a Nash equilibrium in both sub-games.

- Disagreement may **rationally** happen only in two cases:
  - Upon success: providers Witness and clients Lie or Duck.
  - Upon failure: clients Witness and providers Lie or Duck.

- Witness is **best response** to itself when \( c > (1-p) \cdot b + w_c \) and \( c > w_p' \).

- Does this equilibrium arise? Is it stable?
Evolutionary Stability

- Evolutionary Stable Strategy (ESS):
  1. Nash equilibrium
  2. Better reply to any mutant strategy than the latter to itself

- Strict Nash equilibrium of the asymmetric game $\Leftrightarrow$ ESS of its symmetric version

- Evolutionary dynamics for strategy $s$ with payoff $\pi_s$ played by a population fraction $x_s$:

$$\dot{x}_s = \frac{dx_s}{dt} = x_s (\pi_s - \bar{\pi})$$
Stable Truthful Reporting

- \( (x_1, x_2, x_3) \) (resp. \( (y_1, y_2, y_3) \)) the population fractions of providers (resp. clients) that play \( (\text{Witness}, \text{Lie}, \text{Duck}) \) respectively

- Basin of attraction: Region for population mix that ultimately leads to the stable equilibrium

- **Proposition 1**: The basin of attraction of ESS truthful reporting is the region \( X^* \times Y^* \) given by the conditions on \( x_2, x_3 \) and \( y_2, y_3 \) ...
The Basin of Attraction

\[ \frac{1-x_3(2c+w_c')/(c+w_c')}{(c-w_c-b(1-p)-(c-w_c)x_3)/(2c+w_c'-w_c)} \]

\[ \frac{1-y_3(2c-w_p'/(c-w_p')}{(1-y_3)(c-w_p')/(2c-w_p'+w_p)} \]
The Extended Model
The Extended Model

Two important differences from basic model:

- Monetary disagreement punishment is **not fixed** but depends on the transacted participant’s rank and its role.
- Payoff impacts of a vote are **not taken fixed**, but they are calculated algebraically.
- Expected payoff at round $t$ for a participant $i$:

$$V(R_i^{(t)}, a_i) = q \frac{1-q}{q} R_i^{(t)}[a_i(b-v) + (1-a_i)pb] + \\
+ (1-q)[\bar{a}(u-b) + (1-\bar{a})(-pb)]$$
Innovative Reputation Metric

- Beta reputation metric: 
  $$r' = \frac{\beta z + 1(\text{success})}{\beta n + 1}$$

- Results to time-dependent impact of a single vote to rank values of transacted parties

- Solution: An innovative reputation metric 
  $$r' = \beta r + 1(\text{success})(1 - \beta)$$

- Now, rank impacts are not time-dependent, e.g.
  $$\Delta R_p^+ = \frac{1-q}{q} R \left( \frac{\beta R \bar{r} + 1 - \beta}{\bar{r} + \frac{1 - \beta}{N}(1 - \bar{r})} - R \right)$$
Rank-based Punishments

- Derive conditions for disagreement punishments enforcing the truthful rating equilibrium
  - Proposition 2

- Outline of Proof. Single stage deviation from truthful reporting at stage $t$ should not be beneficial.

  Conditions on $c_i$ and $c_j$ are ...
Conditions on $c_i, c_j$

$\square$ $c_i$ is given by:

$$c_i(R_i^{(t)}) > \sum_{\tau=t+1}^{\infty} \delta^{\tau-t} [V(\tilde{R}_i^{(\tau)}) - V(R_i^{(\tau)})]$$

- As $N$ is large, $c_i$ is approximated by a simple formula

$\square$ $c_j$ is given by:

$$c_j(R_j^{(t)}) > (1 - p)b + \sum_{\tau=t+1}^{\infty} \delta^{\tau-t} [V(\tilde{R}_j^{(\tau)}) - V(R_j^{(\tau)})]$$

- This can be bounded from above and below
Numerical Example

\[ N=1000, \ q=0.4, \ p=0.2, \ b=2, \ u=2.5, \ v=0.5, \ \beta=0.6 \]
Social Loss Estimation
Social Loss

Disagreement punishment is unfairly induced to one of the transacted peers → social loss

When punishment is fixed, $c > q w_p' + (1-q)[(1-p)b + w_c]$
- The maximum payoff impacts $w_p'$, $w_c$ have to be assumed

Thus, an unfairness is created for all the non-highest ranked participants → greater social loss

Reputation-based punishments prevent this unfairness!
Numerical Example

- Average ratio of social loss per participant per disagreement for various mean reputation values

- Normal distribution of ranks with \((\mu, \sigma) = (1, 0.5)\)
Concluding Remarks
Summary of our Contribution

- Proposed a simple mechanism that provides incentives for truthful rating in an interesting context of an e-marketplace
  - Reputation-based competition
  - Dual role of participants
- Derived conditions on the effectiveness of such a mechanism with fixed punishments
  - Stability analysis of truthful-rating Nash equilibrium
- Tailored reputation-based punishments
  - Calculated the payoff impacts of a rating to provider and client
- Calculated the attained social loss reduction
Recent and Future Work

- Employ different fixed punishments for provider and client
- Relax the condition on fixed success probability of participants
- Derive upper bound in the achievable social loss reduction by reputation-based disagreement punishments
- Explore stability conditions for truthful equilibrium with reputation-based disagreement punishments