Building Socially Intelligent AI systems

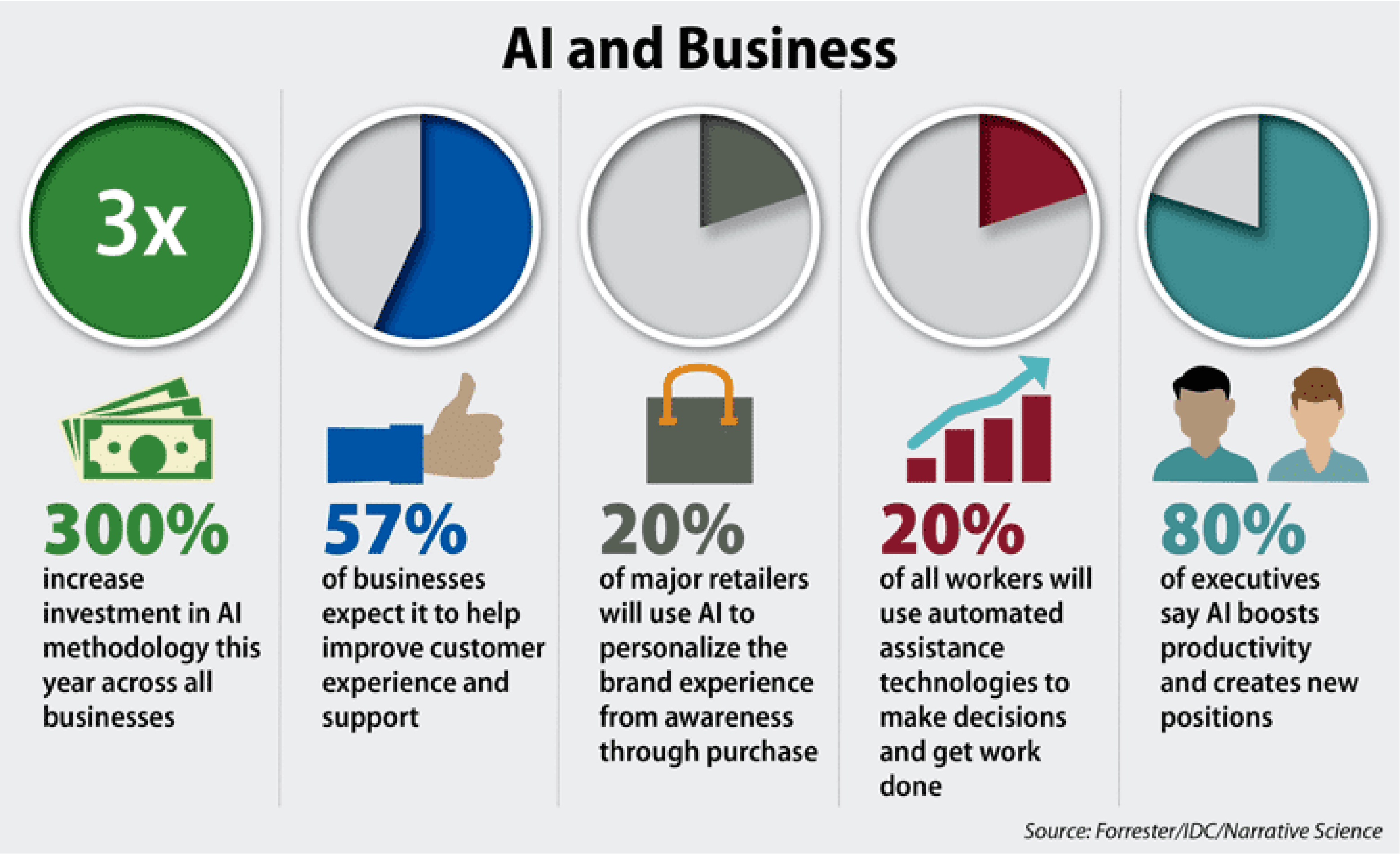
Haijing Zhang

Wu, Jason Xianghua, et al. "Building socially intelligent AI systems: Evidence from the trust game using artificial agents with deep learning." *Management Science* 69.12 (2023): 7236-7252.

Table of Content

Introduction

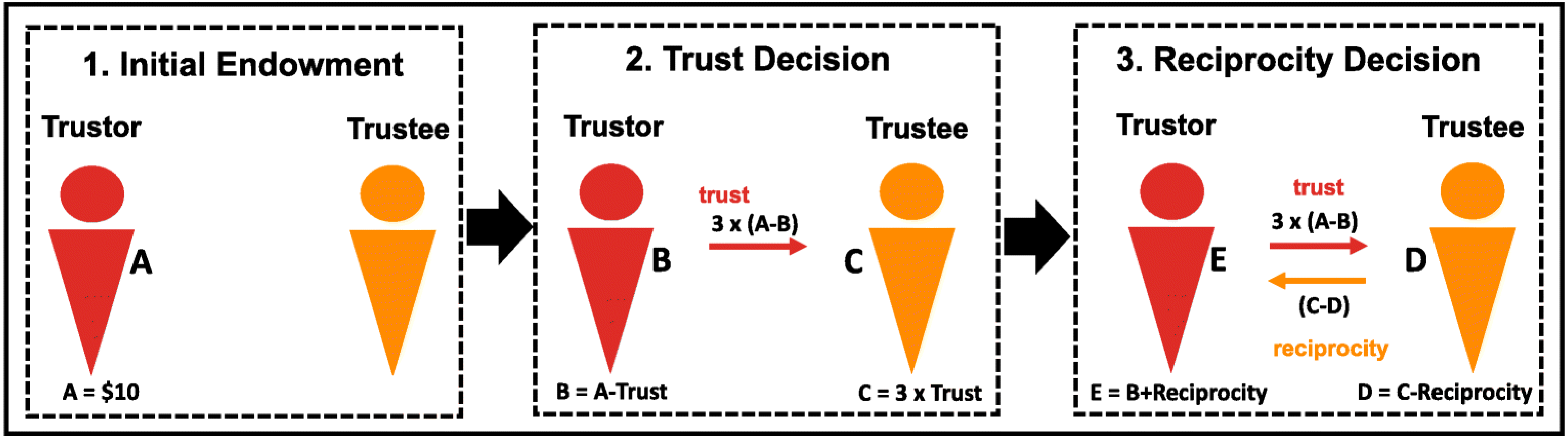
- Trend of implementing AI technologies in business
- New Challenges: Deeper understanding of AI behaviors within a social context



Trust Game

- Non-zero-sum game
- Quantifiable measure of trust and trustworthiness
- One-sided incentive problem

One-Round Trust Game



https://link.springer.com/article/10.3758/s13415-018-00654-3

Objectives

Explore the possibilities and conditions to mimic social behaviors of humans: trust and be trustworthy

Develop trusting and cooperative behavior purely from an interactive trial-and-error learning

Build decision support systems: Artificial agents can leverage social intelligence to achieve better outcomes

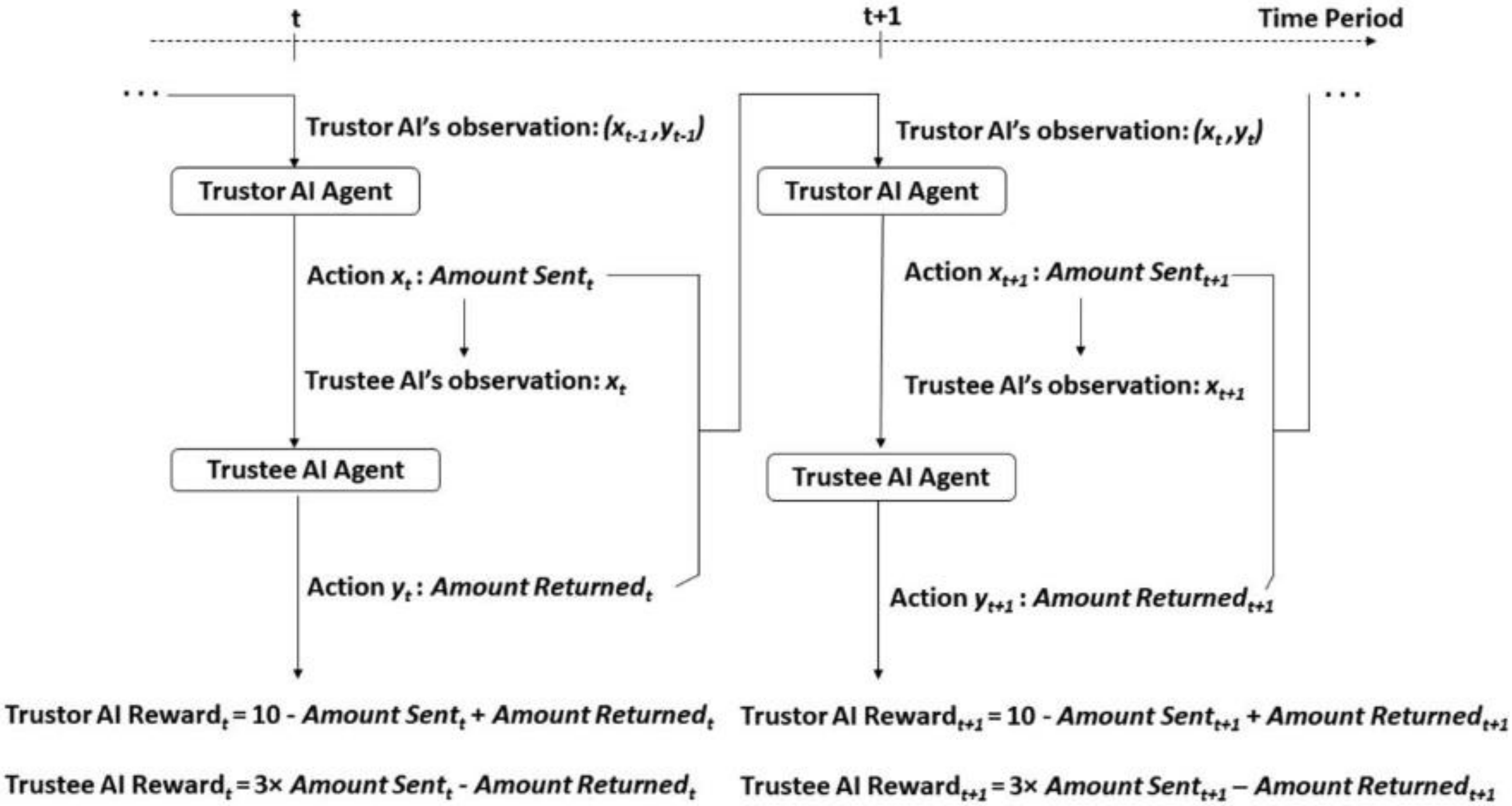
Methodology

- Deep-Q-network (DQN): Deep reinforcement learning method
  - ➢Build the artificial agents: Trustor and trustee
  - ➢Optimize actions through interactions with the environment in order to maximize the expected cumulative reward
  - ➢ε-greedy policy

- Analysis: Randomization test, polynomial regressions on the length of memory and the discount rate; Robustness check

X. Wang *et al.*, "Deep Reinforcement Learning: A Survey," in *IEEE Transactions on Neural Networks and Learning Systems*, vol. 35, no. 4, pp. 5064-5078, April 2024, doi: 10.1109/TNNLS.2022.3207346.

Reinforcement Learning Process



Schematic Neural Network

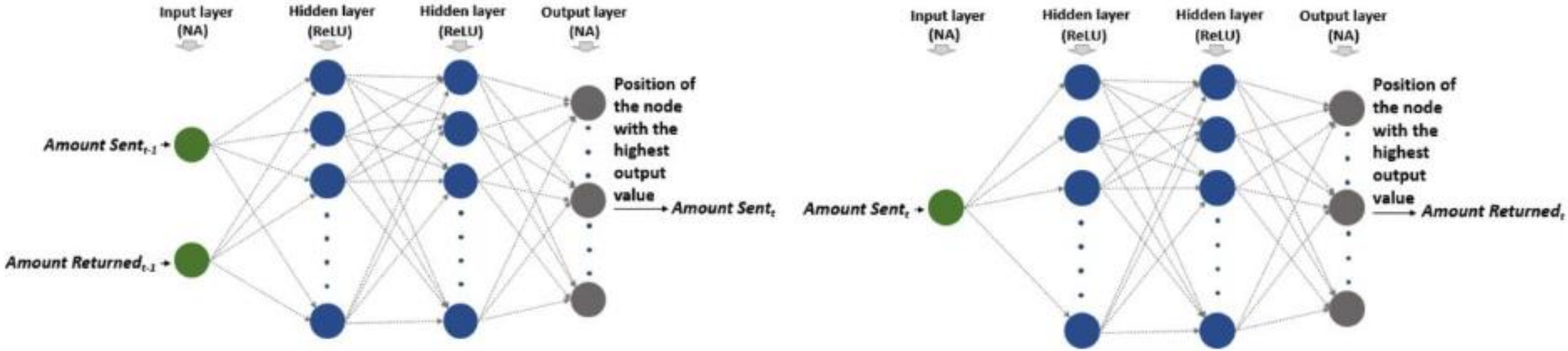


Table A.2. Structural Details of the Neural Network

		Number of nodes in the neural network	
Layer	Activation function	Trustor AI	Trustee AI
Input layer	NA	2	1
Hidden layer 1	ReLU $\max(0, x)$	800	800
Hidden layer 2	ReLU $\max(0, x)$	1,000	1,000
Output layer	NA	11	31

Objective Function

- Bellman Equation:

$$
\begin{aligned}
&Q^*_{trustor}((x_{t-1}, y_{t-1}), x_t) \\
&\quad = \mathbf{E}\{R - x_t + y_t + \gamma \cdot \mathbf{max}_{x_{t+1}} Q^*_{trustor}((x_t, y_t), x_{t+1}) \,|\, (x_{t-1}, y_{t-1}), x_t\}.
\end{aligned}
$$

$$
Q^*_{trustee}(x_t, y_t) = \mathbf{E}\{\alpha x_t - y_t + \gamma \cdot \mathbf{max}_{y_{t+1}} Q^*_{trustee}(x_{t+1}, y_{t+1}) \,|\, x_t, y_t\}
$$

- Minimize the mean-squared error in the Bellman Equation

$$
\begin{aligned}
L(\theta_{trustor}) = \mathbf{E}_{x_{t-1}, y_{t-1}, x_t, y_t}(R - x_t + y_t + \gamma \cdot \mathbf{max}_{x_{t+1}} Q_{trustor}((x_t, y_t), \\
x_{t+1}, \theta^{-1}_{trustor}) - Q_{trustor}((x_{t-1}, y_{t-1}), x_t, \theta_{trustor}))^2,
\end{aligned}
$$

$$
\begin{aligned}
L(\theta_{trustee}) = \mathbf{E}_{x_t, y_t, x_{t+1}}(\alpha x_t - y_t + \gamma \cdot \mathbf{max}_{y_{t+1}} Q_{trustee}(x_{t+1}, y_{t+1}, \theta^{-1}_{trustee}) \\
- Q_{trustee}(x_t, y_t, \theta_{trustee}))^2,
\end{aligned}
$$

Experimental Setting

The same parameter settings as the trust game Berg et al. (1995)

Built 20 trustors and 20 trustees

Training stage for 1,000,000 periods; playing stage for 10,000 periods

The discount rate: $\gamma = 0.75$

Experimental Design

First set of experiments

- Two matching protocols: fixed partners versus random stranger
- 2 x 2 factorial design

Second set of experiments

- The availability and the length of memory
- Discount rate
- Robustness check

Result 1

DQN agents can develop trust and trustworthiness purely from an interactive trial-and-error learning process.

Table 1. Summary Statistics for the 2 × 2 Factorial Design of AI-Agent Experiments

	Trustor AI agents (N = 20)		Trustee AI agents (N = 20)	
Average over 10,000 playing periods	Amount sent	Transfer rate: $\frac{\text{Amount Sent}}{10}$, %	Amount returned	Return rate: $\frac{\text{Amount Returned}}{3\times\text{Amount Sent}}$, %
Partner training, partner playing	5.45 (2.54)	54.50 (25.44)	6.20 (2.98)	39.77 (15.42)
Partner training, stranger playing	3.78 (2.10)	37.84 (20.99)	3.25 (0.62)	41.12 (46.14)
Cochard et al. (2004) Repeated game (N = 16)	7.47 (NA)	74.70 (NA)	NA (NA)	56.14 (NA)
Cochard et al. (2004) One-shot game (N = 20)	5.00 (NA)	50.00 (NA)	NA (NA)	38.21 (NA)
Berg et al. (1995) One-shot game (N = 28)	5.36 (3.53)	53.57 (35.29)	6.46 (6.19)	37.08 (24.83)

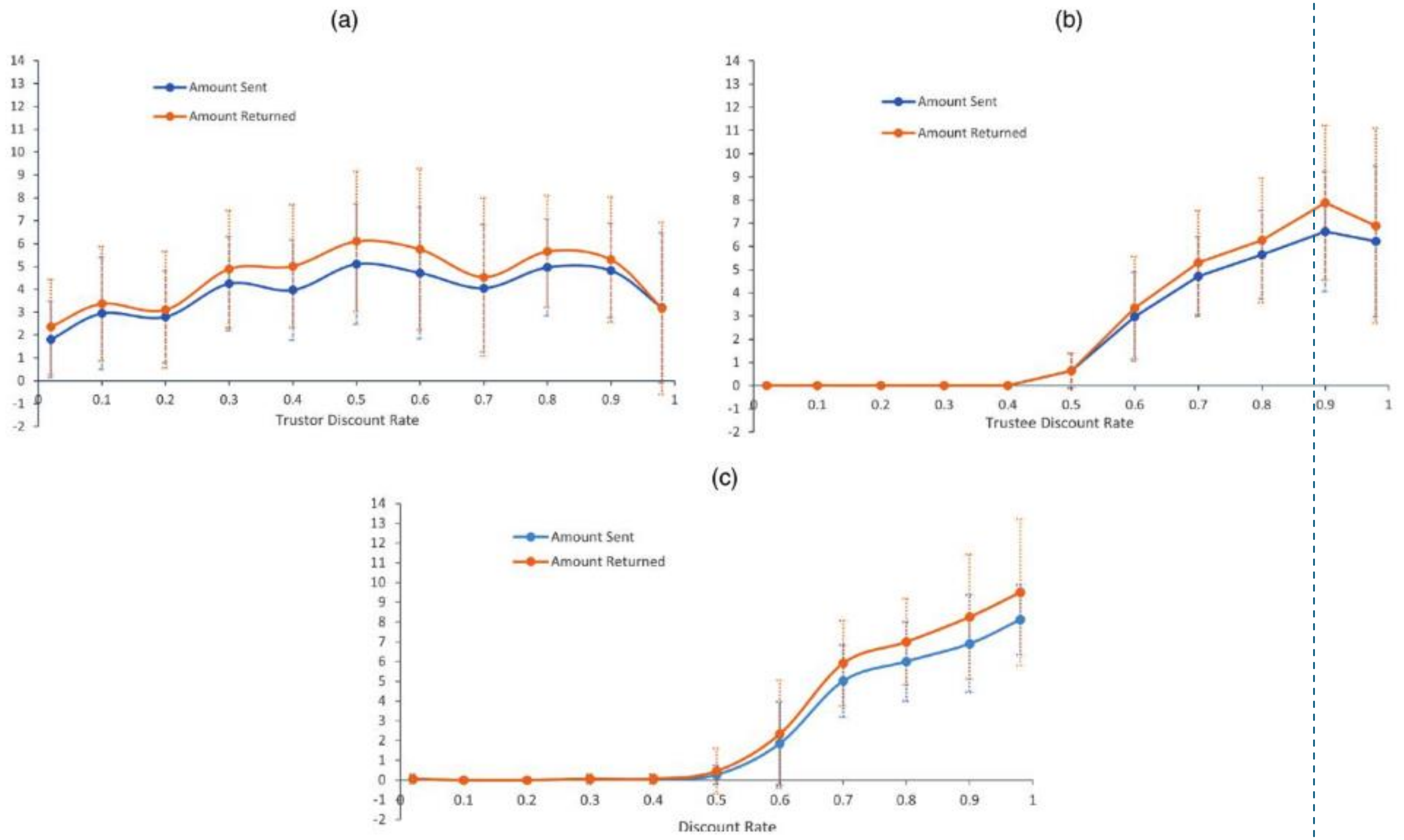
Result 2

Under partner training, memory of past experience by the trustor AI is required for DQN agents to establish trusting and cooperative behaviors.

	Partner playing / Stranger playing	Training stage: Memory	Training stage: No memory
Playing stage	Memory	Baseline: 5.45, 6.20 (2.54, 2.98) / 3.78, 3.25 (2.10, 0.62)	0.00, 0.00 (0.00, 0.00) / 0.00, 0.00 (0.00, 0.00)
	No memory	4.23, 4.05 (1.78, 2.00) / 4.23, 3.40 (1.77, 0.72)	0.00, 0.00 (0.00, 0.00) / 0.00, 0.00 (0.00, 0.00)

Result 3

- The discount rate plays a dominant role in the emergence of cooperative behaviors
- Higher incentives for future rewards, controlled by the discount rate, generally increase their levels of trust and trustworthiness



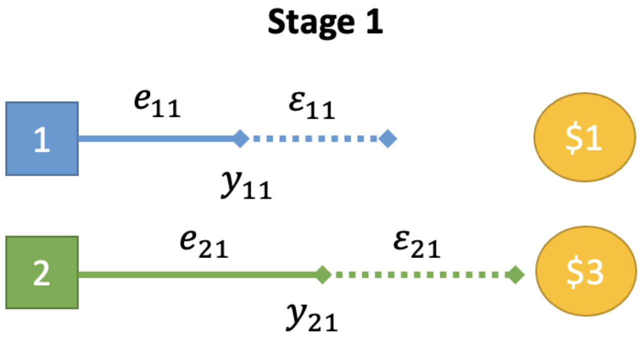
Future Works

- Cooperation with two-sided incentives
- More than two players
- Asymmetric information
- Behavioral uncertainties

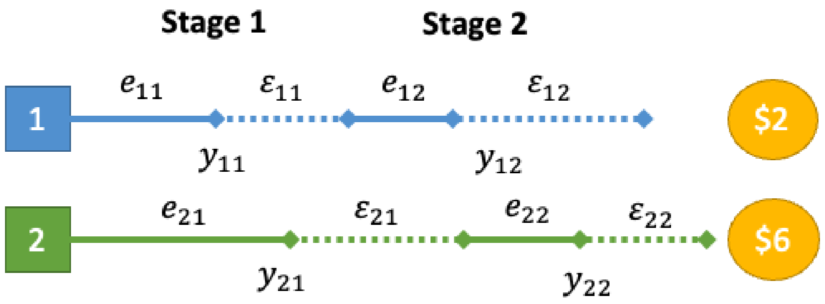
Research in-progress

Exploring Equilibrium for Multi-period Sales Tournament

- Output: $\boldsymbol{y_{it} = e_{it} + \varepsilon_{it}}$, ε_{it} iid, uniformly distributed on the interval $[-q, q]$
- Cost function: $c(e_{it}) = \boldsymbol{k e_{it}^2}$
- 2 contestant, and each contestant can view her own output and that of her competitor after each round



$$\frac{(\boldsymbol{w}^H - \boldsymbol{w}^L)}{4\boldsymbol{kq}}$$



$$\frac{(\boldsymbol{w}^H - \boldsymbol{w}^L)}{3\boldsymbol{kq}}$$

•••

Objectives

- Learning to find the equilibrium: one period and two periods
  - Without data
  - With limited data
- Multi-period sales tournament
  - Exploring the effort equilibrium for more that three periods
  - Insights for incentive strategies

Thank you!