Betting and Belief: Prediction Markets and Attribution of Climate Change

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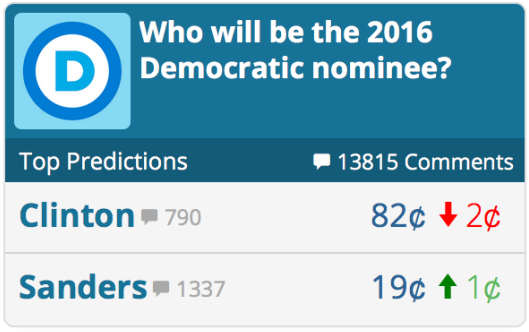
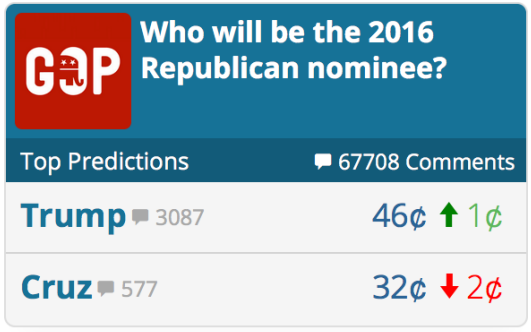
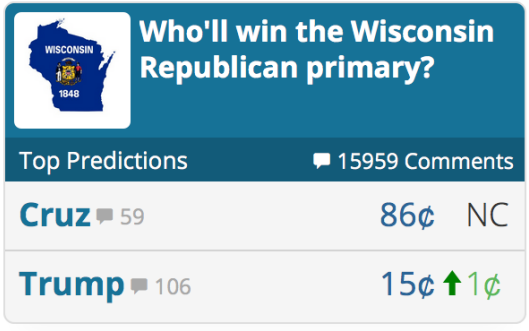
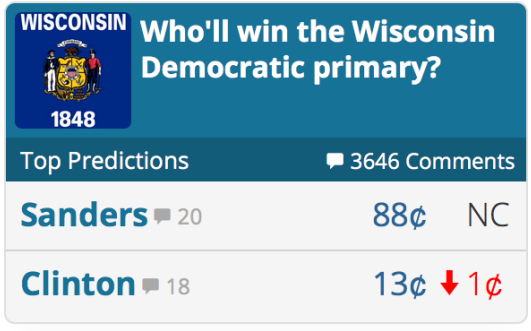
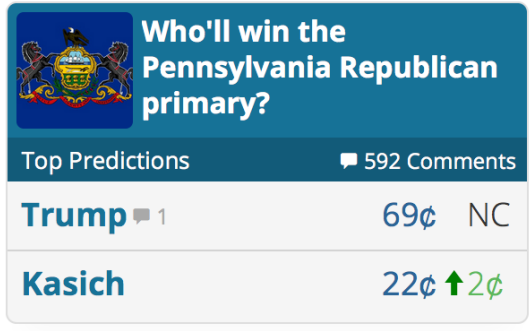
Prediction Markets











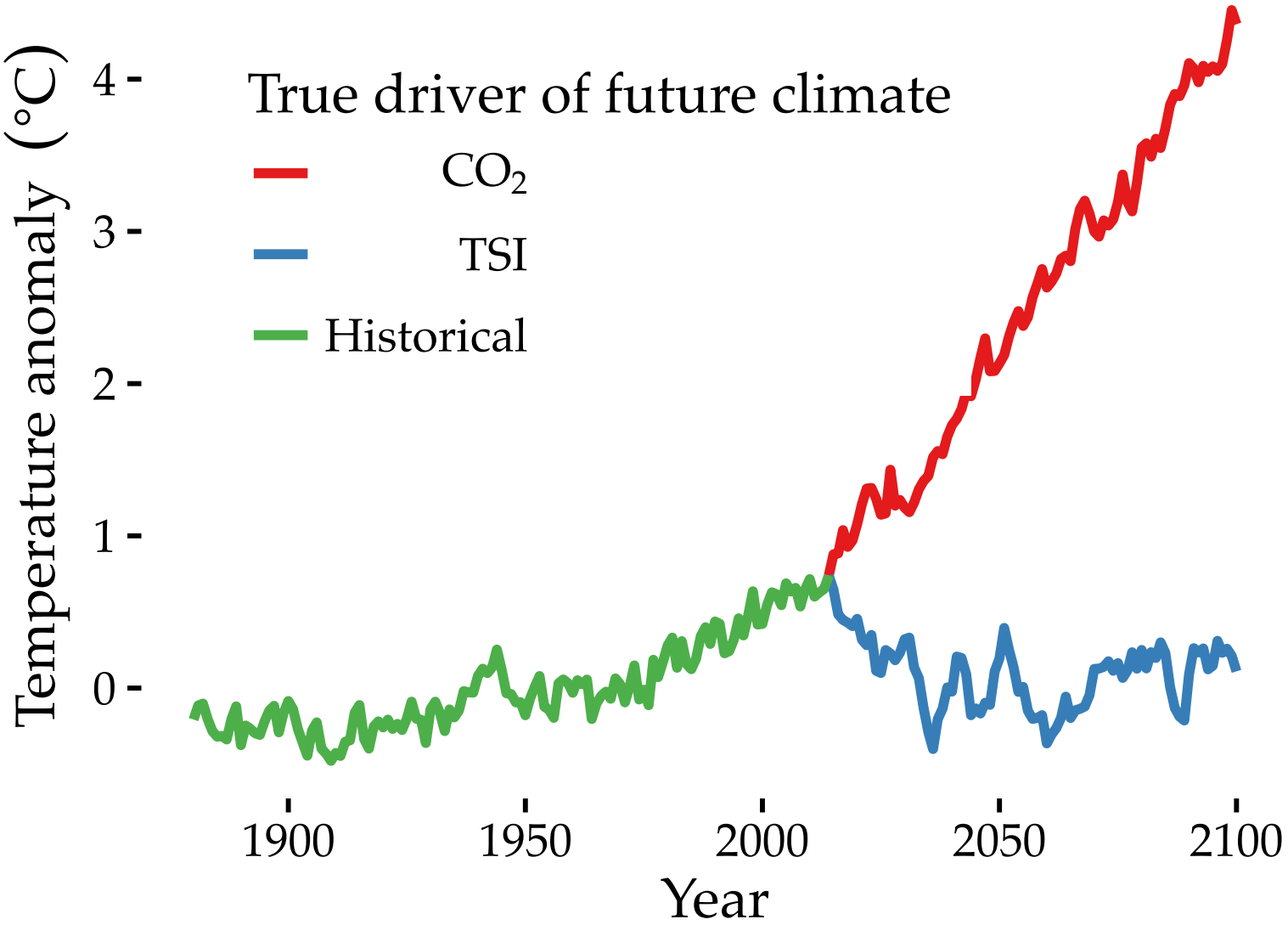
Climate Change and Prediction Markets

- Scientific consensus on anthropogenic climate change increased.
- BUT, beliefs about climate change did not evolve much within public.
- Prediction markets: participants can "put their money where their mouths are."
- High prediction accuracy, efficient information aggregation.
- Do they also change beliefs?

Prediction Market Simulation

- *Whether, and under what social and climate conditions, might prediction markets be useful for increasing convergence of climate beliefs?*
- Prediction markets focus on near term events such as elections months away, so difficult to extrapolate to climate case.
- Investigating unobservable beliefs of traders.
- So, simulation modeling informed by climate and economic theory.

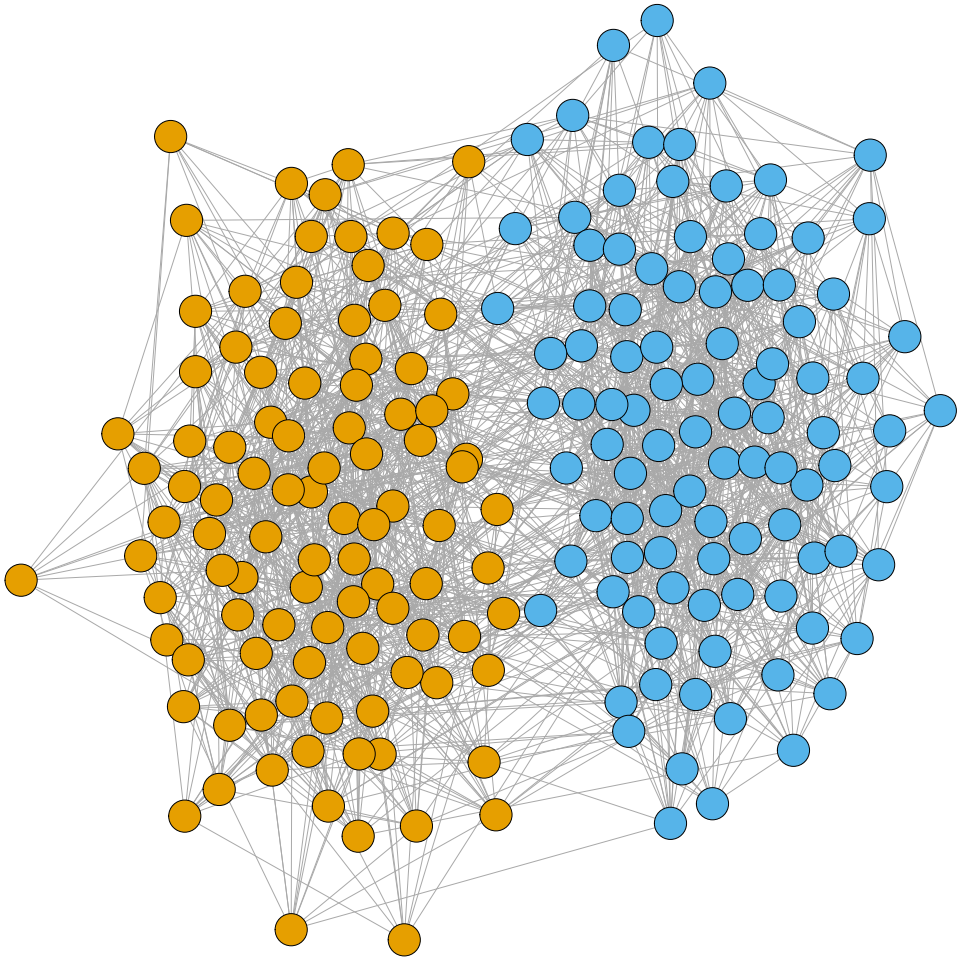
Two Alternate Realities



Trader Beliefs

- At initialization approximately half of traders use true data-generating model to make predictions.
- Traders using true model not necessarily perfectly accurate.
- Although correct *functional form* of model, still need to calibrate on limited noisy data.

Social Network

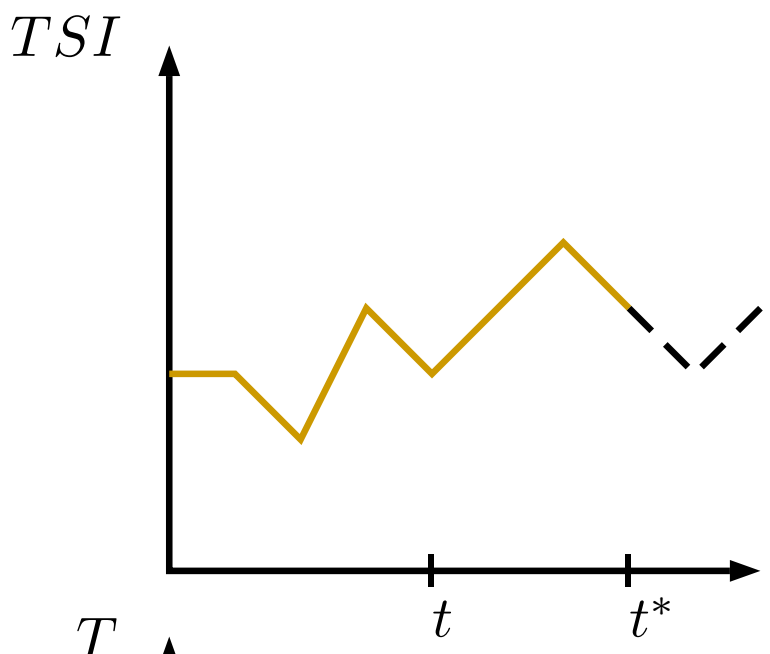


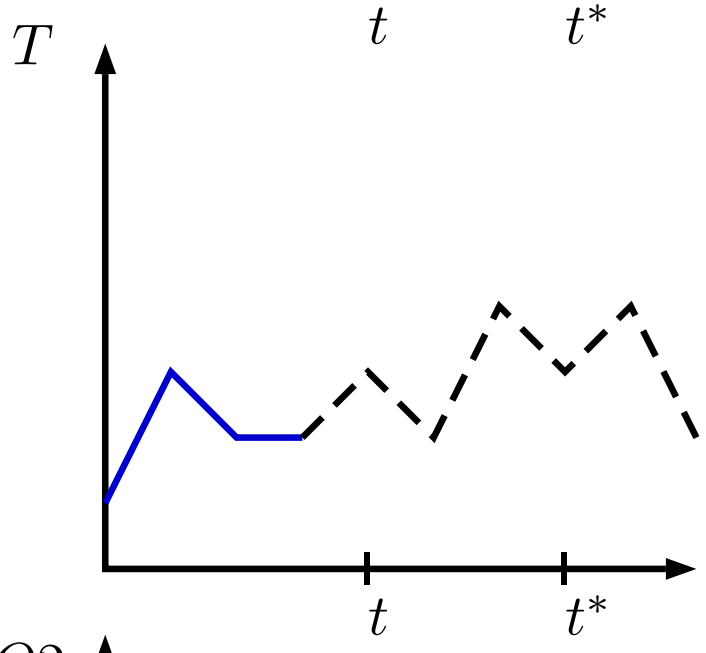
Model

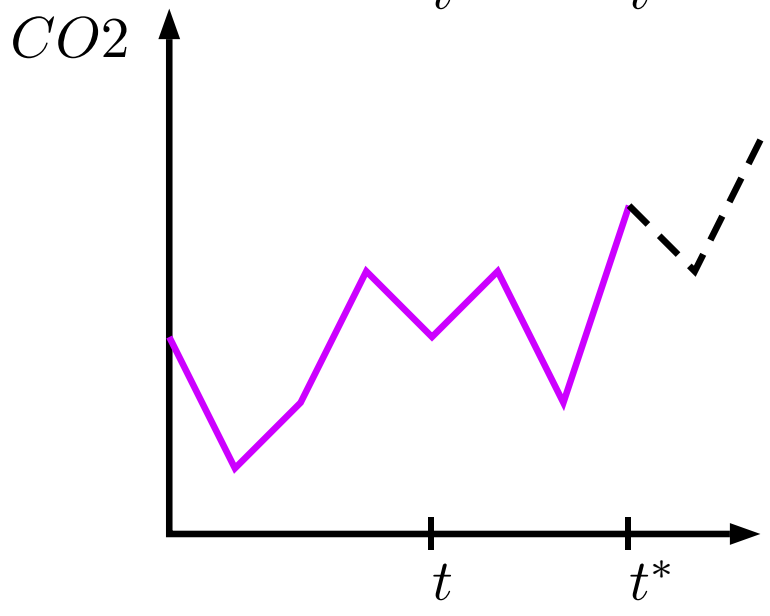
1. Trader agents estimate forecasting model.
2. Make predictions for climate for 6 yrs from now to assign expected value to temp securities.
3. Trade.
4. Payoffs for owners of security that was correct.
5. Decide whether to adopt neighbors model based on cumulative earnings.

$$F^{TSI}_{(t-1)}$$

$$F^{CO2}_{(t-1)}$$

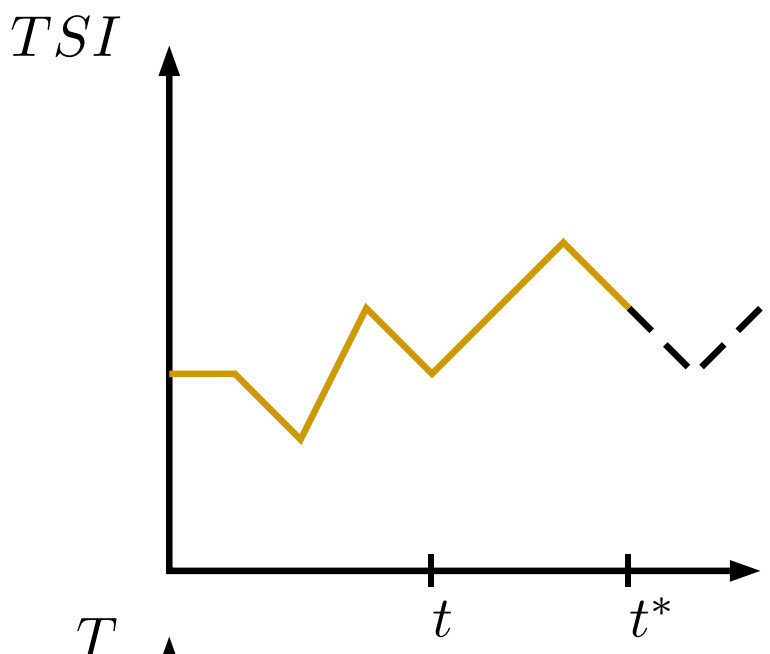


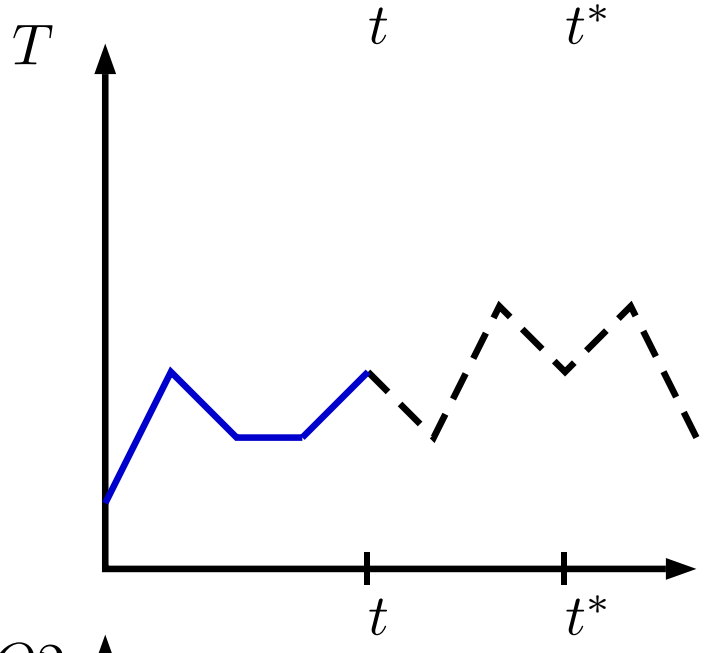


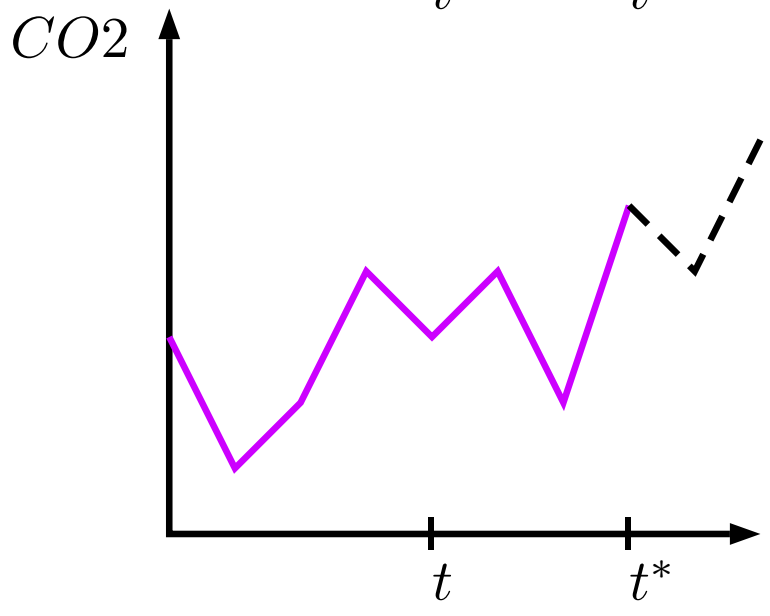


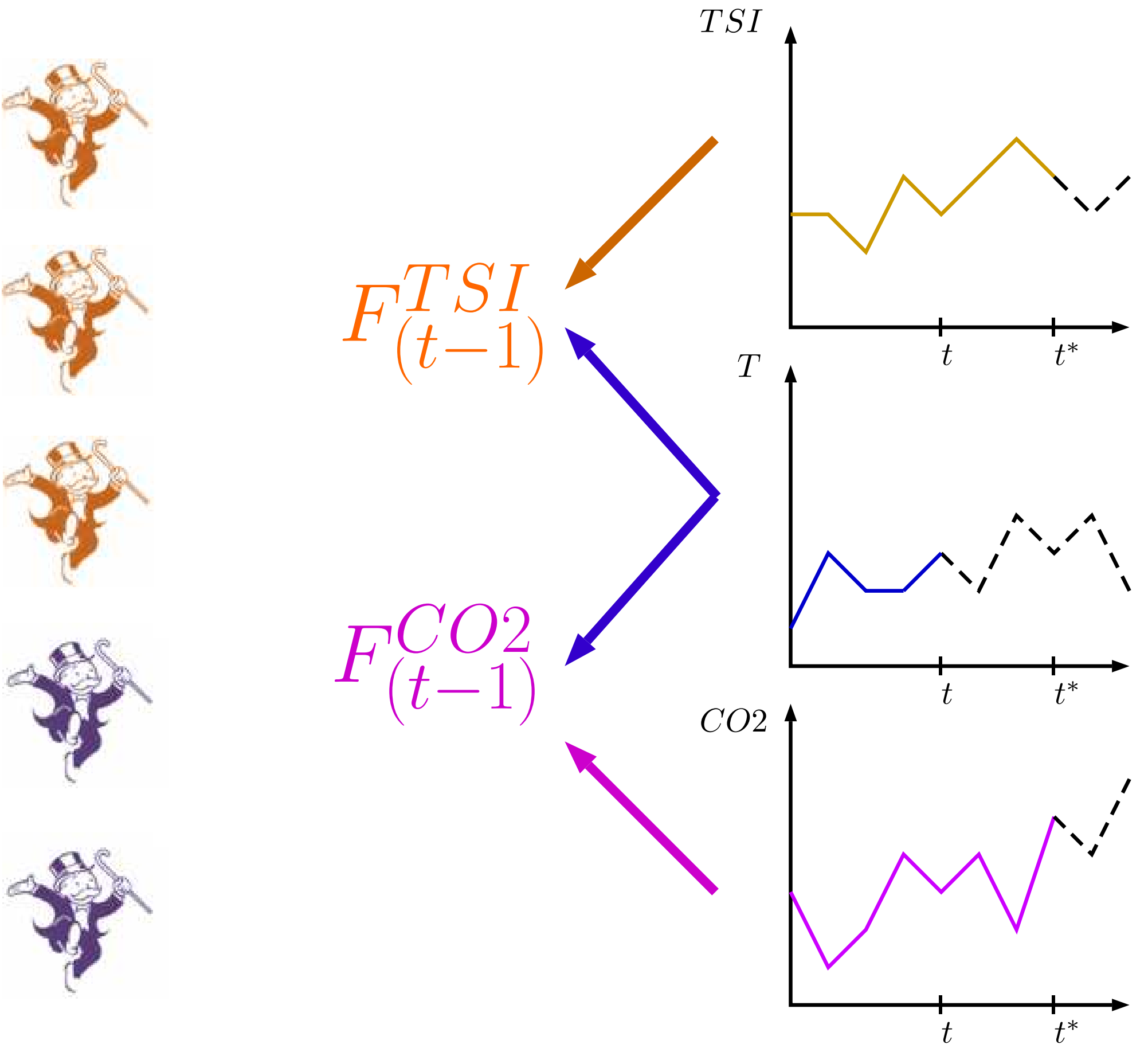
$$F^{TSI}_{(t-1)}$$

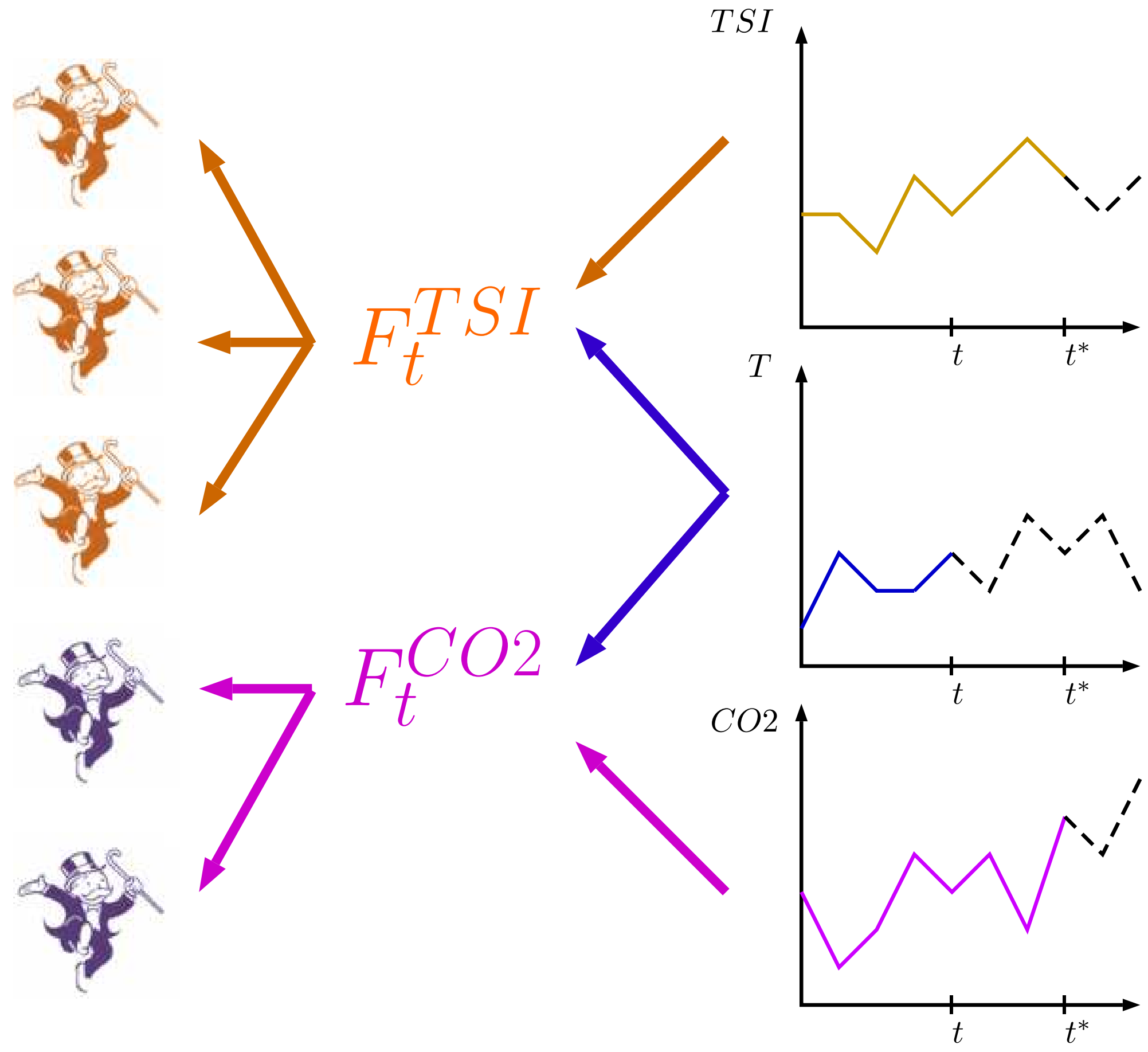
$$F^{CO2}_{(t-1)}$$








TSI
$F^{TSI}_{(t-1)}$
T
$F^{CO2}_{(t-1)}$
CO2
t
t*
t
t*
t
t*


F_t^{TSI}
F_t^{CO2}
TSI
T
$CO2$
t
t^*
t
t^*
t
t^*

1$ if

$T_{t^*} \geq 4$

$T_{t^*} \in [3, 4)$

$T_{t^*} \in [2, 3)$

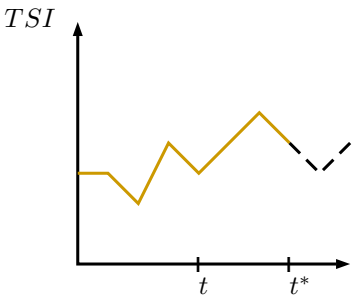
$T_{t^*} \in [1, 2)$

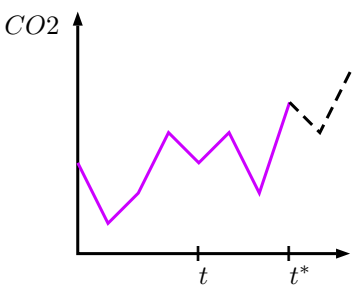
$T_{t^*} \in [0, 1)$

$T_{t^*} < 0$

F_t^{TSI}

F_t^{CO2}





1$ if

$T_{t^*} \geq 4$

$T_{t^*} \in [3, 4)$

$T_{t^*} \in [2, 3)$

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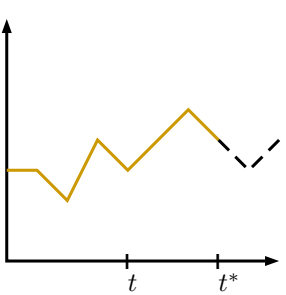
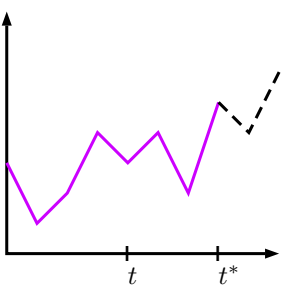
$T_{t^*} \in [0, 1)$

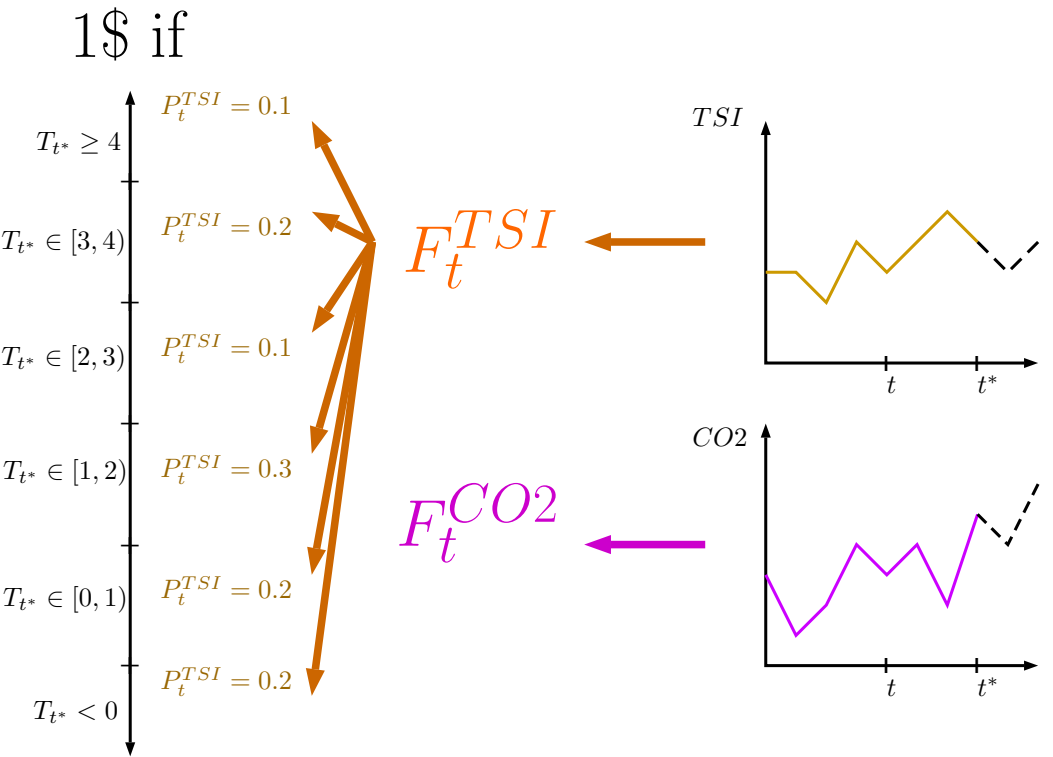
$T_{t^*} < 0$

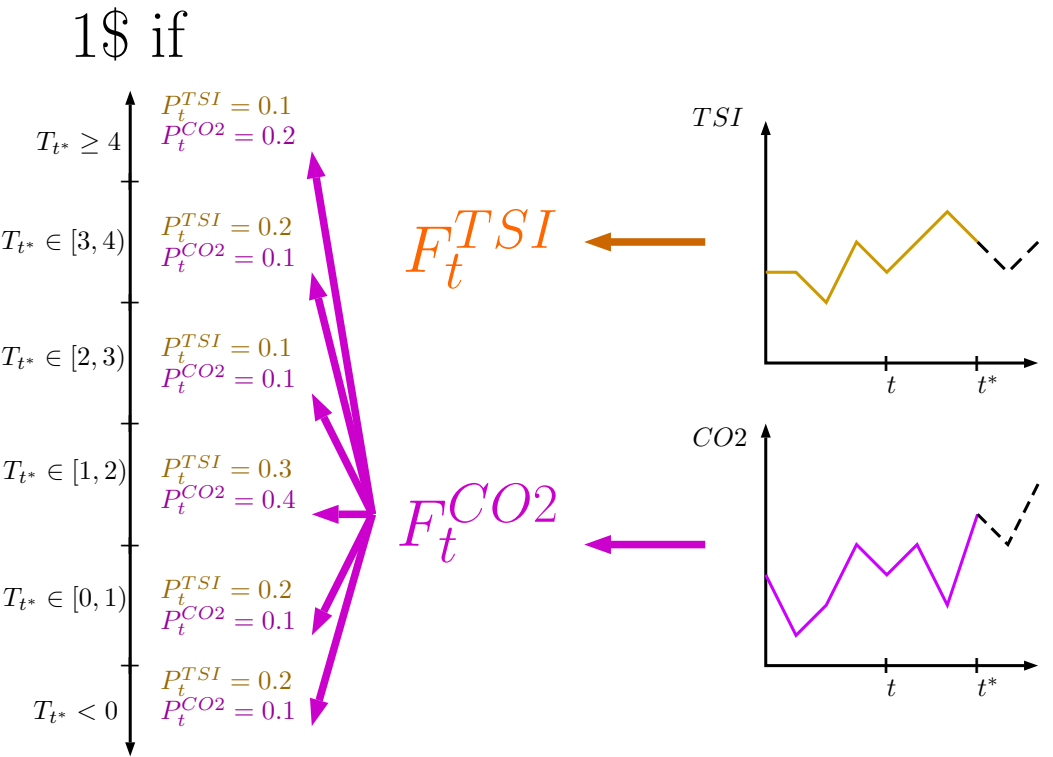
F_t^{TSI}

F_t^{CO2}






1$ if
$T_{t^*} \geq 4$
$T_{t^*} \in [3,4)$
$T_{t^*} \in [2,3)$
$T_{t^*} \in [1,2)$
$T_{t^*} \in [0,1)$
$T_{t^*} < 0$
$P_t^{TSI} = 0.1$
$P_t^{TSI} = 0.2$
$P_t^{TSI} = 0.1$
$P_t^{TSI} = 0.3$
$P_t^{TSI} = 0.2$
$P_t^{TSI} = 0.2$
F_t^{TSI}
F_t^{CO2}
TSI
$CO2$
t
t^*
t
t^*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$T_{t^*} < 0$
$P_t^{TSI} = 0.1$ $P_t^{CO2} = 0.2$
$P_t^{TSI} = 0.2$ $P_t^{CO2} = 0.1$
$P_t^{TSI} = 0.1$ $P_t^{CO2} = 0.1$
$P_t^{TSI} = 0.3$ $P_t^{CO2} = 0.4$
$P_t^{TSI} = 0.2$ $P_t^{CO2} = 0.1$
$P_t^{TSI} = 0.2$ $P_t^{CO2} = 0.1$
F_t^{TSI}
F_t^{CO2}
TSI
$CO2$
t
t^*
t
t^*

1$ if

$T_{t^*} \geq 4$ $P_t^{TSI} = 0.1$ $P_t^{CO2} = 0.2$

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$T_{t^*} < 0$ $P_t^{TSI} = 0.2$ $P_t^{CO2} = 0.1$

Sell

Buy

1$ if

$T_{t^*} \geq 4$

$P_t^{TSI} = 0.1$
$P_t^{CO2} = 0.2$

$T_{t^*} \in [3, 4)$

$P_t^{TSI} = 0.2$
$P_t^{CO2} = 0.1$

Sell

Buy

$T_{t^*} \in [2, 3)$

$P_t^{TSI} = 0.1$
$P_t^{CO2} = 0.1$

$T_{t^*} \in [1, 2)$

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$P_t^{CO2} = 0.1$

$T_{t^*} < 0$

$P_t^{TSI} = 0.2$
$P_t^{CO2} = 0.1$

Buy

Sell

1$ if

$T_{t^*} \geq 4$ $P_t^{TSI} = 0.1$ $P_t^{CO2} = 0.2$

$T_{t^*} \in [3, 4)$ $P_t^{TSI} = 0.2$ $P_t^{CO2} = 0.1$

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$T_{t^*} < 0$ $P_t^{TSI} = 0.2$ $P_t^{CO2} = 0.1$

Sell

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$P_t^{TSI} = 0.2$
$P_t^{CO2} = 0.1$

$T_{t^*} < 0$

$P_t^{TSI} = 0.2$
$P_t^{CO2} = 0.1$

Sell

Buy

1$ if

$T_{t^*} \geq 4$ $P_t^{TSI} = 0.1$ $P_t^{CO2} = 0.2$

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$T_{t^*} < 0$ $P_t^{TSI} = 0.2$ $P_t^{CO2} = 0.1$

Order Book

Sell Orders

Buy Orders

1$ if

$T_{t^*} \geq 4$ $P_t^{TSI} = 0.1$ $P_t^{CO2} = 0.2$

$T_{t^*} \in [3, 4)$ $P_t^{TSI} = 0.2$ $P_t^{CO2} = 0.1$

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$T_{t^*} < 0$ $P_t^{TSI} = 0.2$ $P_t^{CO2} = 0.1$

Order Book

Sell Orders

Sell $\{T_{t^*} \in [3, 4)\}$ above 0.3

Buy Orders

Buy $\{T_{t^*} \in [0, 1)\}$ below 0.15

1$ if

$T_{t^*} \geq 4$ $P_t^{TSI} = 0.1$ $P_t^{CO2} = 0.2$

$T_{t^*} \in [3, 4)$ $P_t^{TSI} = 0.2$ $P_t^{CO2} = 0.1$

$T_{t^*} \in [2, 3)$ $P_t^{TSI} = 0.1$ $P_t^{CO2} = 0.1$

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$T_{t^*} \in [0, 1)$ $P_t^{TSI} = 0.2$ $P_t^{CO2} = 0.1$

$T_{t^*} < 0$ $P_t^{TSI} = 0.2$ $P_t^{CO2} = 0.1$

Order Book

Sell Orders

Sell $\{T_{t^*} \in [3, 4)\}$ above 0.3
Sell $\{T_{t^*} \in [3, 4)\}$ above 0.25

Buy Orders

Buy $\{T_{t^*} \in [0, 1)\}$ below 0.15
Buy $\{T_{t^*} \in [3, 4)\}$ below 0.15

1$ if

$T_{t^*} \geq 4$ $P_t^{TSI} = 0.1$ $P_t^{CO2} = 0.2$

$T_{t^*} \in [3, 4)$ $P_t^{TSI} = 0.2$ $P_t^{CO2} = 0.1$

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$T_{t^*} \in [0, 1)$ $P_t^{TSI} = 0.2$ $P_t^{CO2} = 0.1$

$T_{t^*} < 0$ $P_t^{TSI} = 0.2$ $P_t^{CO2} = 0.1$

Order Book

Sell Orders

Sell $\{T_{t^*} \in [3, 4)\}$ above 0.3
Sell $\{T_{t^*} \in [3, 4)\}$ above 0.25
Sell $\{T_{t^*} \geq 4\}$ above 0.2

Buy Orders

Buy $\{T_{t^*} \in [0, 1)\}$ below 0.15
Buy $\{T_{t^*} \in [3, 4)\}$ below 0.15
Buy $\{T_{t^*} \in [0, 1)\}$ below 0.1

1$ if

$T_{t^*} \geq 4$ $P_t^{TSI} = 0.1$ $P_t^{CO2} = 0.2$

$T_{t^*} \in [3, 4)$ $P_t^{TSI} = 0.2$ $P_t^{CO2} = 0.1$

$T_{t^*} \in [2, 3)$ $P_t^{TSI} = 0.1$ $P_t^{CO2} = 0.1$

$T_{t^*} \in [1, 2)$ $P_t^{TSI} = 0.3$ $P_t^{CO2} = 0.4$

$T_{t^*} \in [0, 1)$ $P_t^{TSI} = 0.2$ $P_t^{CO2} = 0.1$

$T_{t^*} < 0$ $P_t^{TSI} = 0.2$ $P_t^{CO2} = 0.1$

Order Book

Sell Orders

Sell $\{T_{t^*} \in [3, 4)\}$ above 0.3
Sell $\{T_{t^*} \in [3, 4)\}$ above 0.25
Sell $\{T_{t^*} \geq 4\}$ above 0.2
Sell $\{T_{t^*} \in [0, 1)\}$ above 0.12

Buy Orders

Buy $\{T_{t^*} \in [0, 1)\}$ below 0.15
Buy $\{T_{t^*} \in [3, 4)\}$ below 0.15
Buy $\{T_{t^*} \in [0, 1)\}$ below 0.1
Buy $\{T_{t^*} < 0\}$ below 0.05

1$ if

$T_{t^*} \geq 4$ $P_t^{TSI} = 0.1$ $P_t^{CO2} = 0.2$

$T_{t^*} \in [3,4)$ $P_t^{TSI} = 0.2$ $P_t^{CO2} = 0.1$

$T_{t^*} \in [2,3)$ $P_t^{TSI} = 0.1$ $P_t^{CO2} = 0.1$

$T_{t^*} \in [1,2)$ $P_t^{TSI} = 0.3$ $P_t^{CO2} = 0.4$

$T_{t^*} \in [0,1)$ $P_t^{TSI} = 0.2$ $P_t^{CO2} = 0.1$

$T_{t^*} < 0$ $P_t^{TSI} = 0.2$ $P_t^{CO2} = 0.1$

Order Book

Sell Orders

Sell $\{T_{t^*} \in [3,4)\}$ above 0.3
Sell $\{T_{t^*} \in [3,4)\}$ above 0.25
Sell $\{T_{t^*} \geq 4\}$ above 0.2
Sell $\{T_{t^*} \in [0,1)\}$ above 0.12

Buy Orders

Buy $\{T_{t^*} \in [0,1)\}$ below 0.15
Buy $\{T_{t^*} \in [3,4)\}$ below 0.15
Buy $\{T_{t^*} \in [0,1)\}$ below 0.1
Buy $\{T_{t^*} < 0\}$ below 0.05

1$ if

$T_{t^*} \geq 4$ $P_t^{TSI} = 0.1$ $P_t^{CO2} = 0.2$

$T_{t^*} \in [3,4)$ $P_t^{TSI} = 0.2$ $P_t^{CO2} = 0.1$

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$T_{t^*} \in [1,2)$ $P_t^{TSI} = 0.3$ $P_t^{CO2} = 0.4$

$T_{t^*} \in [0,1)$ $P_t^{TSI} = 0.2$ $P_t^{CO2} = 0.1$

$T_{t^*} < 0$ $P_t^{TSI} = 0.2$ $P_t^{CO2} = 0.1$

0.12 $

Order Book

Sell Orders

Sell $\{T_{t^*} \in [3,4)\}$ above 0.3
Sell $\{T_{t^*} \in [3,4)\}$ above 0.25
Sell $\{T_{t^*} \geq 4\}$ above 0.2
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Buy Orders

Buy $\{T_{t^*} \in [0,1)\}$ below 0.15
Buy $\{T_{t^*} \in [3,4)\}$ below 0.15
Buy $\{T_{t^*} \in [0,1)\}$ below 0.1
Buy $\{T_{t^*} < 0\}$ below 0.05

1$ if

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$T_{t^*} \in [3,4)$ $P_t^{TSI} = 0.2$ $P_t^{CO2} = 0.1$

$T_{t^*} \in [2,3)$ $P_t^{TSI} = 0.1$ $P_t^{CO2} = 0.1$

$T_{t^*} \in [1,2)$ $P_t^{TSI} = 0.3$ $P_t^{CO2} = 0.4$

$T_{t^*} \in [0,1)$ $P_t^{TSI} = 0.2$ $P_t^{CO2} = 0.1$

$T_{t^*} < 0$ $P_t^{TSI} = 0.2$ $P_t^{CO2} = 0.1$

1 security $\{T_{t^*} \in [0,1)\}$

Order Book

Sell Orders

Sell $\{T_{t^*} \in [3,4)\}$ above 0.3
Sell $\{T_{t^*} \in [3,4)\}$ above 0.25
Sell $\{T_{t^*} \geq 4\}$ above 0.2
Sell $\{T_{t^*} \in [0,1)\}$ above 0.12

Buy Orders

Buy $\{T_{t^*} \in [0,1)\}$ below 0.15
Buy $\{T_{t^*} \in [3,4)\}$ below 0.15
Buy $\{T_{t^*} \in [0,1)\}$ below 0.1
Buy $\{T_{t^*} < 0\}$ below 0.05

1$ if

$T_{t^*} \geq 4$

$P_t^{TSI} = 0.1$
$P_t^{CO2} = 0.2$

$T_{t^*} \in [3,4)$

$P_t^{TSI} = 0.2$
$P_t^{CO2} = 0.1$

$T_{t^*} \in [2,3)$

$P_t^{TSI} = 0.1$
$P_t^{CO2} = 0.1$

$T_{t^*} \in [1,2)$

$P_t^{TSI} = 0.3$
$P_t^{CO2} = 0.4$

$T_{t^*} \in [0,1)$

$P_t^{TSI} = 0.2$
$P_t^{CO2} = 0.1$

$T_{t^*} < 0$

$P_t^{TSI} = 0.2$
$P_t^{CO2} = 0.1$

Order Book

Sell Orders

Sell $\{T_{t^*} \in [3,4)\}$ above 0.3
Sell $\{T_{t^*} \in [3,4)\}$ above 0.25
Sell $\{T_{t^*} \geq 4\}$ above 0.2

Buy Orders

Buy $\{T_{t^*} \in [3,4)\}$ below 0.15
Buy $\{T_{t^*} \in [0,1)\}$ below 0.1
Buy $\{T_{t^*} < 0\}$ below 0.05

1$ if

$T_{t^*} \geq 4$ $P_t^{TSI} = 0.1$ $P_t^{CO2} = 0.2$

$T_{t^*} \in [3, 4)$ $P_t^{TSI} = 0.2$ $P_t^{CO2} = 0.1$

$T_{t^*} \in [2, 3)$ $P_t^{TSI} = 0.1$ $P_t^{CO2} = 0.1$

$T_{t^*} \in [1, 2)$ $P_t^{TSI} = 0.3$ $P_t^{CO2} = 0.4$

$T_{t^*} \in [0, 1)$ $P_t^{TSI} = 0.2$ $P_t^{CO2} = 0.1$

$T_{t^*} < 0$ $P_t^{TSI} = 0.2$ $P_t^{CO2} = 0.1$

Order Book

Sell Orders

Sell $\{T_{t^*} \in [3, 4)\}$ above 0.3
Sell $\{T_{t^*} \in [3, 4)\}$ above 0.25
Sell $\{T_{t^*} \geq 4\}$ above 0.2

Sell $\{T_{t^*} < 0\}$ above 0.15

Buy Orders

Buy $\{T_{t^*} \in [3, 4)\}$ below 0.15
Buy $\{T_{t^*} \in [0, 1)\}$ below 0.1
Buy $\{T_{t^*} < 0\}$ below 0.05

Buy $\{T_{t^*} \in [3, 4)\}$ below 0.05

1$ if

$T_{t^*} \geq 4$

$P_t^{TSI} = 0.1$
$P_t^{CO2} = 0.2$

$T_{t^*} \in [3, 4)$

$P_t^{TSI} = 0.2$
$P_t^{CO2} = 0.1$

$T_{t^*} \in [2, 3)$

$P_t^{TSI} = 0.1$
$P_t^{CO2} = 0.1$

$T_{t^*} \in [1, 2)$

$P_t^{TSI} = 0.3$
$P_t^{CO2} = 0.4$

$T_{t^*} \in [0, 1)$

$P_t^{TSI} = 0.2$
$P_t^{CO2} = 0.1$

$T_{t^*} < 0$

$P_t^{TSI} = 0.2$
$P_t^{CO2} = 0.1$

1$ if

$T_{t^*} \geq 4$

$P_t^{TSI} = 0.1$
$P_t^{CO2} = 0.2$

3 securities of $\{T_{t^*} \in [3,4)\}$
3 securities of $\{T_{t^*} \in [0,1)\}$

$T_{t^*} \in [3,4)$

$P_t^{TSI} = 0.2$
$P_t^{CO2} = 0.1$

5 securities of $\{T_{t^*} \in [2,3)\}$

$T_{t^*} \in [2,3)$

$P_t^{TSI} = 0.1$
$P_t^{CO2} = 0.1$

1 securities of $\{T_{t^*} \in [3,4)\}$
2 securities of $\{T_{t^*} \in [0,1)\}$
5 securities of $\{T_{t^*} \geq 4\}$

$T_{t^*} \in [1,2)$

$P_t^{TSI} = 0.3$
$P_t^{CO2} = 0.4$

No securities

$T_{t^*} \in [0,1)$

$P_t^{TSI} = 0.2$
$P_t^{CO2} = 0.1$

$T_{t^*} < 0$

$P_t^{TSI} = 0.2$
$P_t^{CO2} = 0.1$

1 securities of $\{T_{t^*} \in [3,4)\}$
5 securities of $\{T_{t^*} < 0\}$
5 securities of $\{T_{t^*} \in [1,2)\}$

1$ if

$T_{t^*} \geq 4$ — $P_t^{TSI} = 0.1$, $P_t^{CO2} = 0.2$

3 securities of $\{T_{t^*} \in [3,4)\}$
3 securities of $\{T_{t^*} \in [0,1)\}$

$T_{t^*} \in [3,4)$ — $P_t^{TSI} = 0.2$, $P_t^{CO2} = 0.1$

5 securities of $\{T_{t^*} \in [2,3)\}$

$T_{t^*} \in [2,3)$ — $P_t^{TSI} = 0.1$, $P_t^{CO2} = 0.1$

1 securities of $\{T_{t^*} \in [3,4)\}$
2 securities of $\{T_{t^*} \in [0,1)\}$
5 securities of $\{T_{t^*} \geq 4\}$

$T_{t^*} \in [1,2)$ — $P_t^{TSI} = 0.3$, $P_t^{CO2} = 0.4$

No securities

$T_{t^*} \in [0,1)$ — $P_t^{TSI} = 0.2$, $P_t^{CO2} = 0.1$

$T_{t^*} < 0$ — $P_t^{TSI} = 0.2$, $P_t^{CO2} = 0.1$

1 securities of $\{T_{t^*} \in [3,4)\}$
5 securities of $\{T_{t^*} < 0\}$
5 securities of $\{T_{t^*} \in [1,2)\}$

True Temperature at t^*

$3.12 \in [3,4)$

1$ if

$T_{t^*} \geq 4$ — $P_t^{TSI} = 0.1$, $P_t^{CO2} = 0.2$

3 securities of $\{T_{t^*} \in [3,4)\}$
3 securities of $\{T_{t^*} \in [0,1)\}$
+ 3$

$T_{t^*} \in [3,4)$ — $P_t^{TSI} = 0.2$, $P_t^{CO2} = 0.1$

5 securities of $\{T_{t^*} \in [2,3)\}$

$T_{t^*} \in [2,3)$ — $P_t^{TSI} = 0.1$, $P_t^{CO2} = 0.1$

1 securities of $\{T_{t^*} \in [3,4)\}$
2 securities of $\{T_{t^*} \in [0,1)\}$
5 securities of $\{T_{t^*} \geq 4\}$
+ 1$

$T_{t^*} \in [1,2)$ — $P_t^{TSI} = 0.3$, $P_t^{CO2} = 0.4$

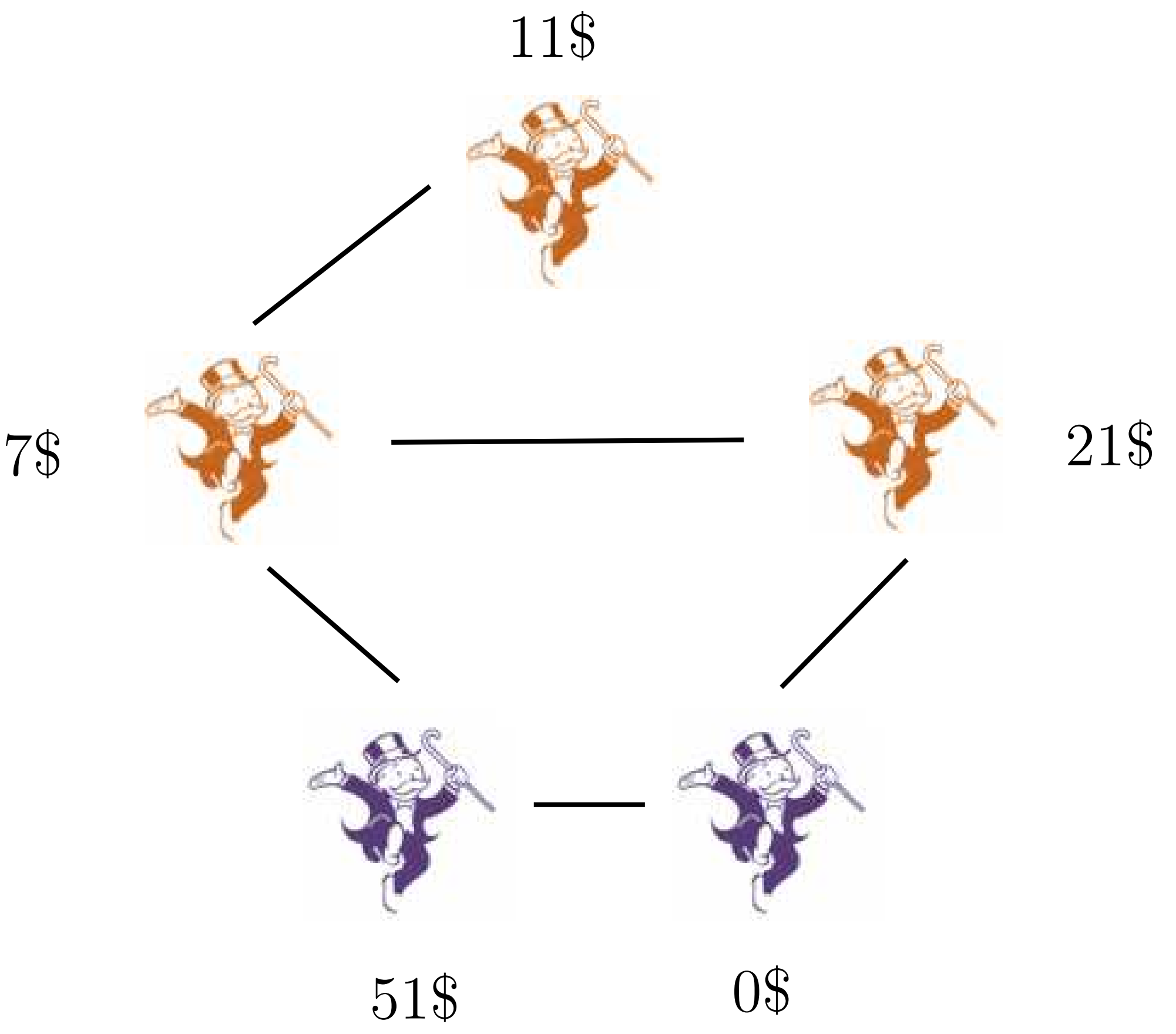
No securities

$T_{t^*} \in [0,1)$ — $P_t^{TSI} = 0.2$, $P_t^{CO2} = 0.1$

$T_{t^*} < 0$ — $P_t^{TSI} = 0.2$, $P_t^{CO2} = 0.1$

1 securities of $\{T_{t^*} \in [3,4)\}$
5 securities of $\{T_{t^*} < 0\}$
5 securities of $\{T_{t^*} \in [1,2)\}$
+ 1$

True Temperature at t^*
$3.12 \in [3,4)$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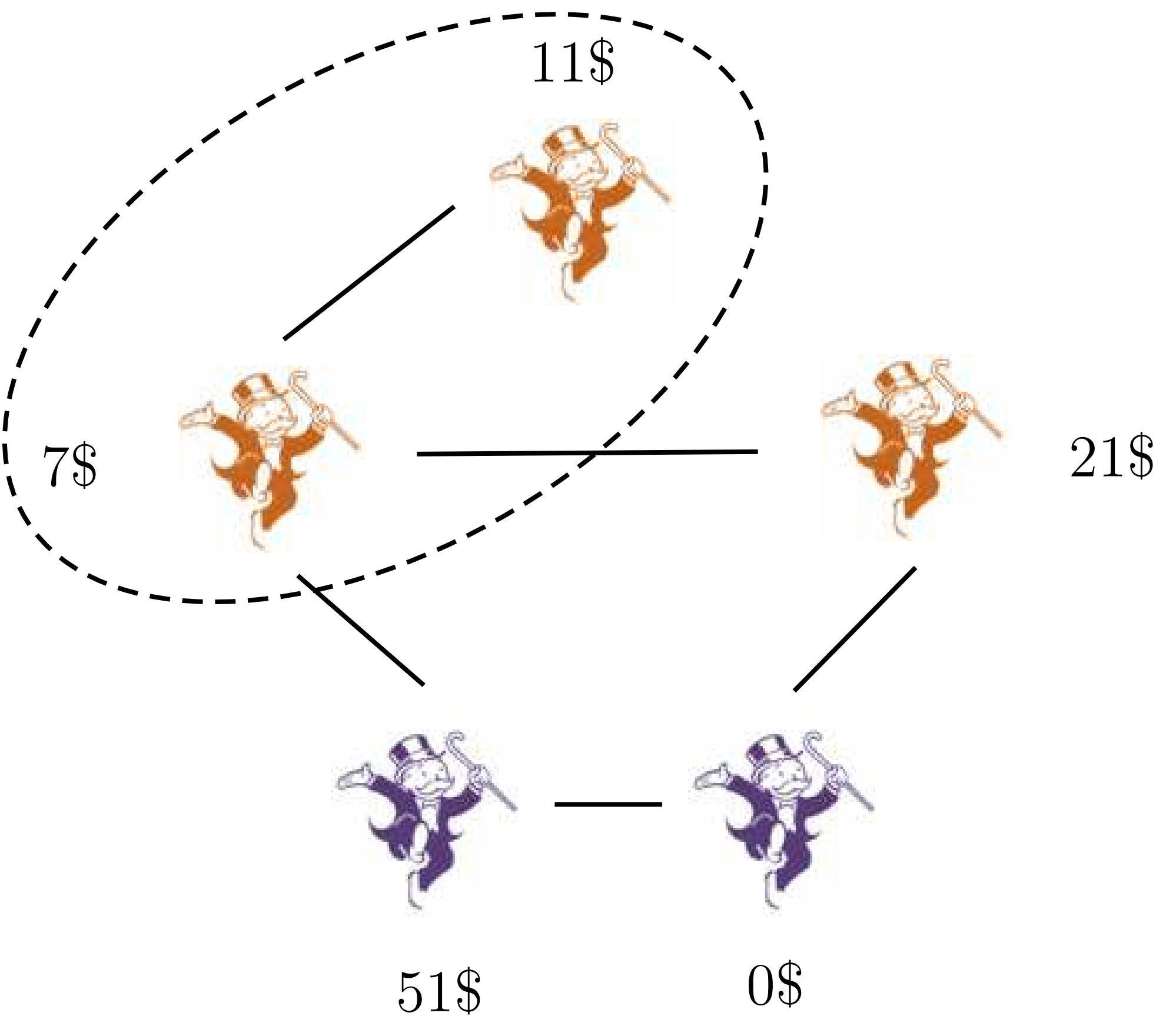
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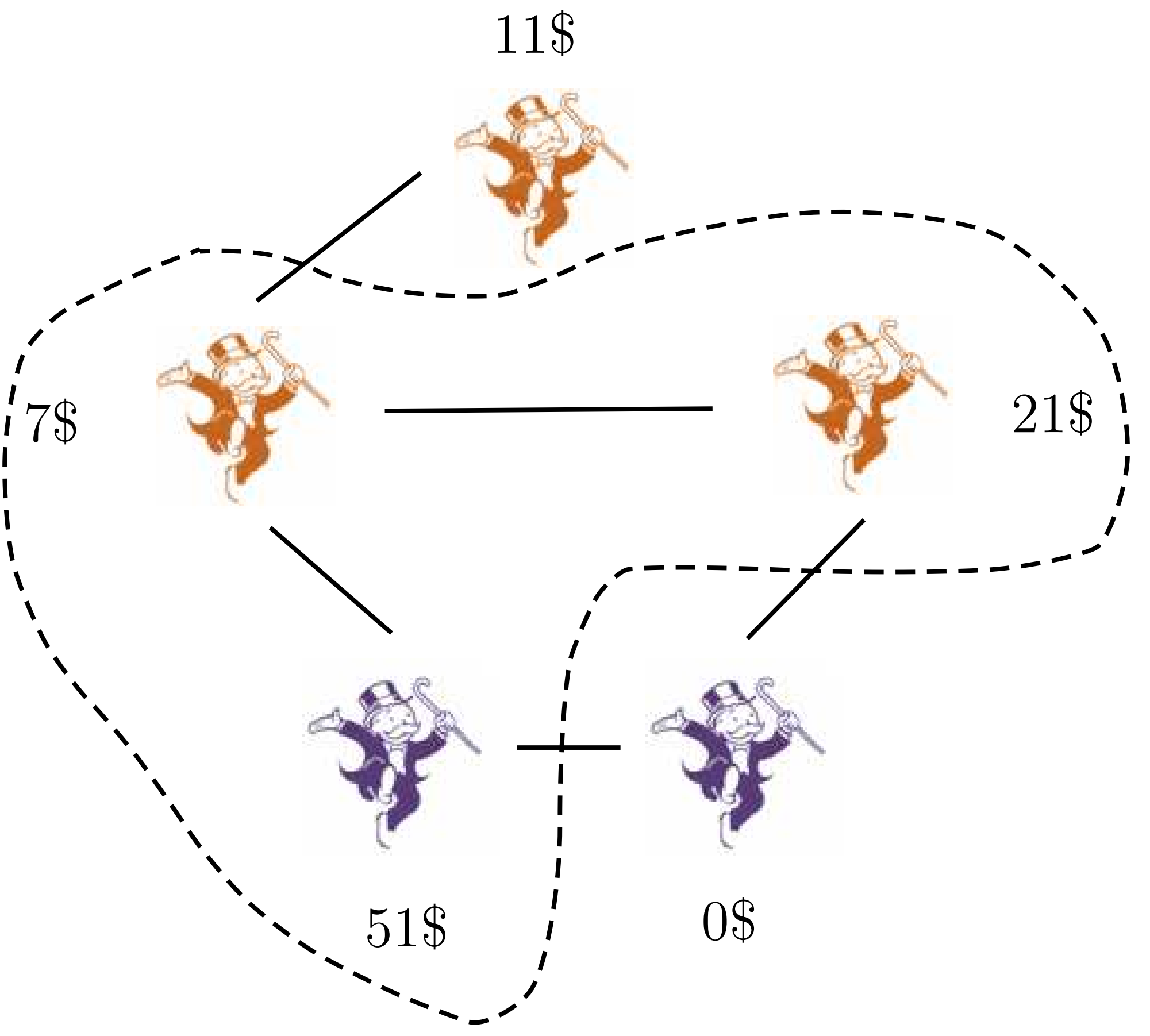
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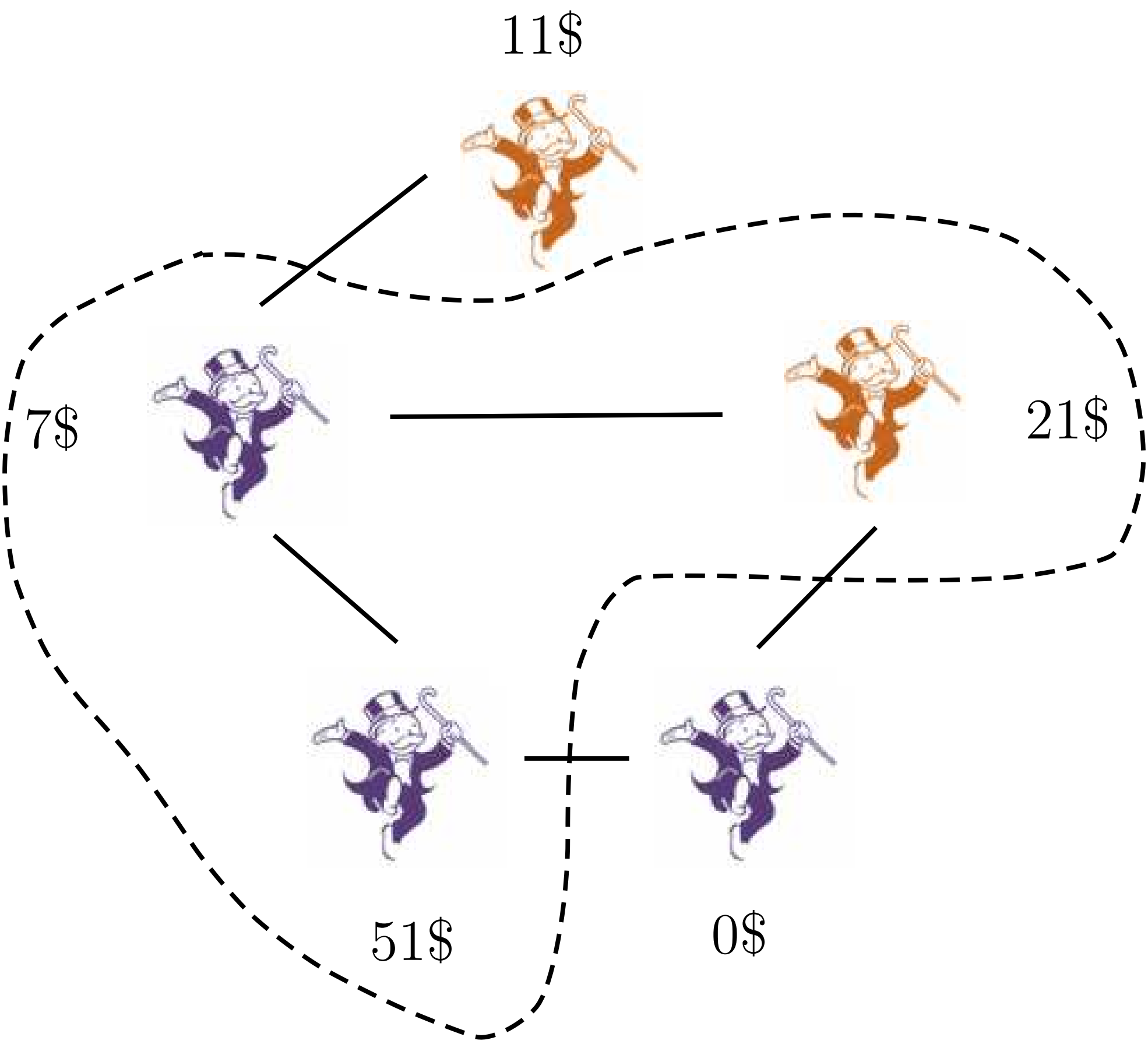
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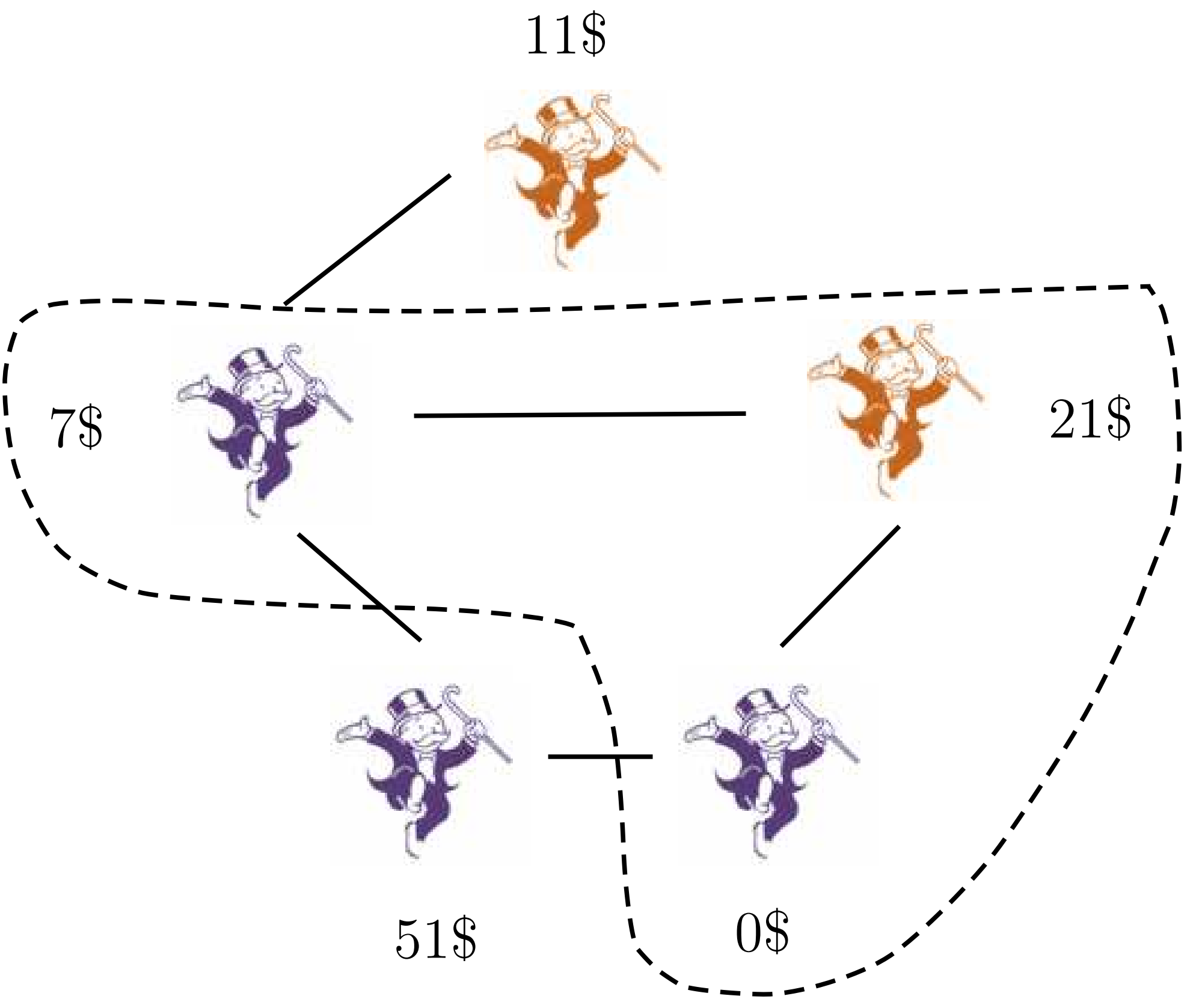
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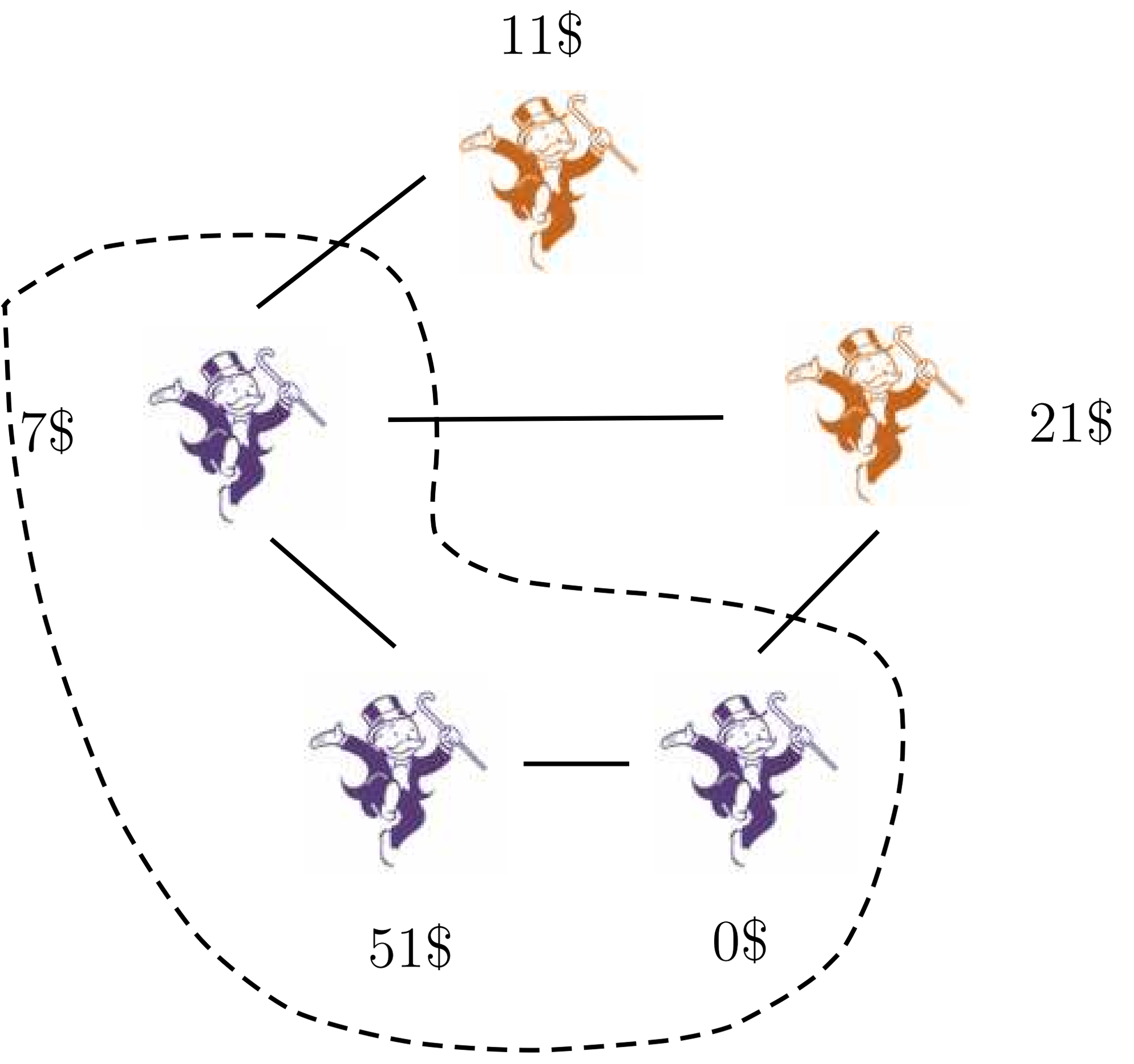
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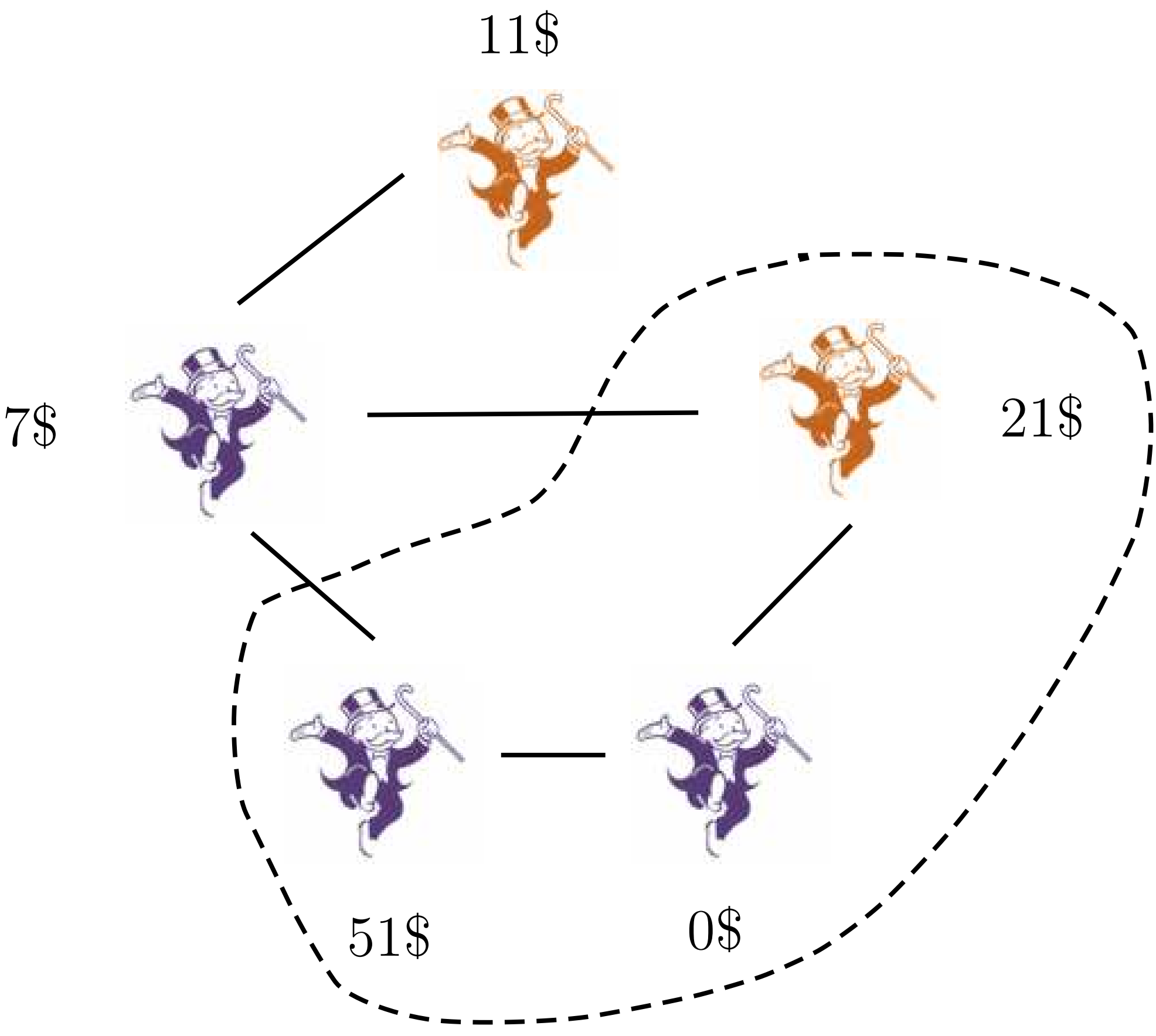
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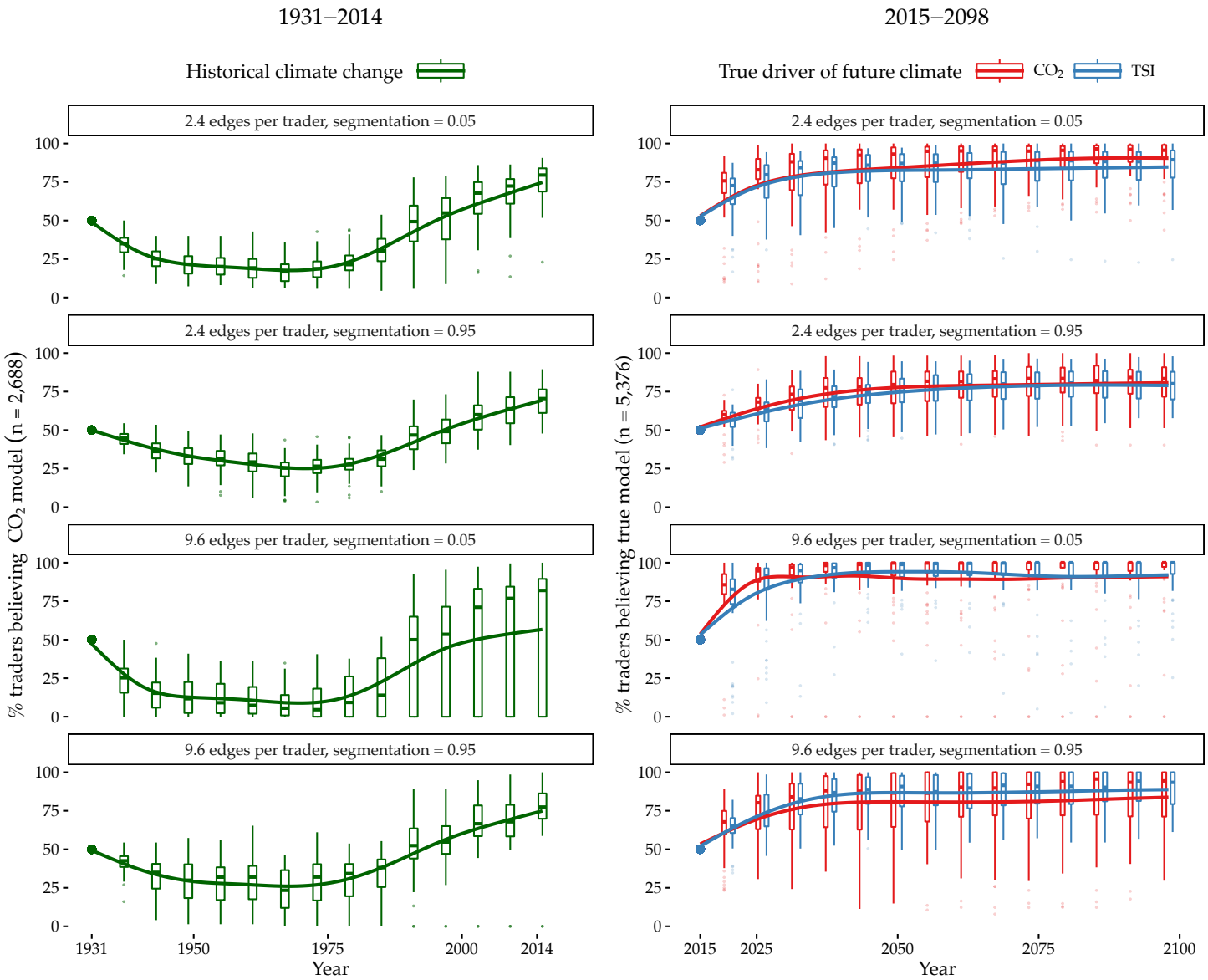
Parameters

- $ideo \sim \text{Uniform}(0, 1)$
- $n.edge \sim \text{Uniform}(100, 200)$ (mapped into integer)
- $n.traders \sim \text{Uniform}(50, 250)$ (mapped into integer)
- $risk.tak \sim \text{Uniform}(0, 1)$
- $seg \sim \text{Uniform}(0, 1)$
- $true.model \sim \text{Bernoulli}(0.5)$

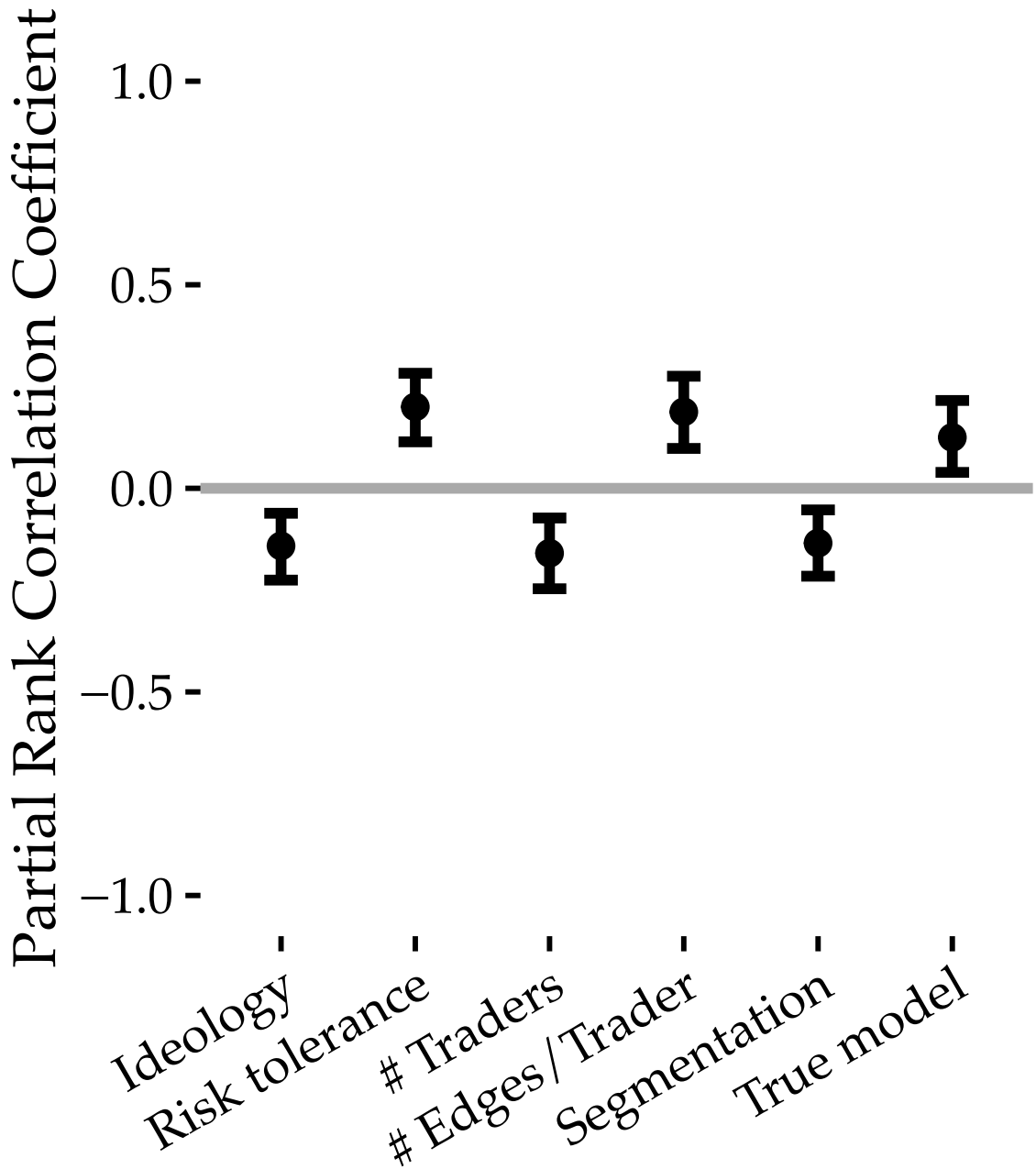
Convergence Over Time



Sensitivity Analysis Design

- Stochasticity in tempertature data, social network structure, and agent decision models.
- 10 full simulations for each of 500 input parameter sets and average.
- Partial rank correlation coefficient analysis on relationship between input matrix, X, and resulting simulated outcome vector of mean belief convergence scores, y.
- Partial correlation: linear relationship between part of variation of X_i and y that are linearly independent of other X_j $(j \neq i)$.
- To allow potentially non-linear relationships y is first rank-transformed.
- 1,000 bootstrapped estimations of PRCC to obtain 95% confidence intervals.

Sensitivity Analysis Results



References