Leverage, Asset Prices, and Default in the Laboratory

Marco Cipriani, Federal Reserve Bank of New York

The views expressed in this presentation are those of the presenter and not necessarily those of the Federal Reserve Bank of New York or The Federal Reserve System

The Tenth International Workshop on Theoretical and Experimental Macroeconomics, Bank of Canada, June 2019

Introduction

- Theory tradition in General Equilibrium focusing **on collateralized borrowing, leverage, and its effect on asset prices**
  - Geanakoplos (Econometrics Society, 1997), Geanakoplos-Zame (Cowles Foundation WP, 1997), Fostel-Geanakoplos (Econometrica, 2005)
  - Collateralized borrowing↔security-based leverage: using assets as collateral to borrow money

- **Experimental finance agenda that tests these models in the laboratory**

Two Predictions

- Assets with identical payoffs are **priced differently if their collateral capacities are different**
  - Collateral is priced
  - Collateral generates deviations from the law of one price

- When assets used as collateral are financial, **collateral requirements are set so high that default never occurs**
  - **financial assets**: dividends are independent of ownership and asset does not provide direct utility (stock, bond)

➢ I will present two experimental papers testing these predictions in the laboratory

Two Papers

➢ *"Collateral Constraints and the Law of One price: An Experiment" (JF, 2018):* we study whether differences in collateral capacities generates deviations from the Law of One Price

➢ *"Endogenous Leverage and Default in the Laboratory:"* we study whether collateral constraints are higher and default rates lower when assets used as collateral are financial

- ❖ In both papers, we develop a model of collateral equilibrium, amenable to laboratory implementation
- ❖ Common features: incomplete markets, collateralized borrowing
- ❖ We bring the model to the lab and gather experimental data

Outline

1. Introduction
2. **Model 1: "Collateral Constraints and the Law of One Price: an Experiment"**
3. Experiment 1
4. Model 2: "Endogenous Leverage and Default in the Laboratory"
5. Experiment 2
6. Conclusion

Model 1: Setup

- Time $t = 0, 1$
- Two states of nature, $s = High$ and $s = Low$, with probability q and 1-q
- Two risky assets, Y and Z, and cash (numeraire)
- Two types of agents, each of mass 1, Buyers and Sellers
  - $i = B, S$
  - Risk neutral (in this presentation!)
  - No discounting
- Initial cash endowment, m^i
- Initial asset endowments, ${a_Y}^i$ and ${a_Z}^i$

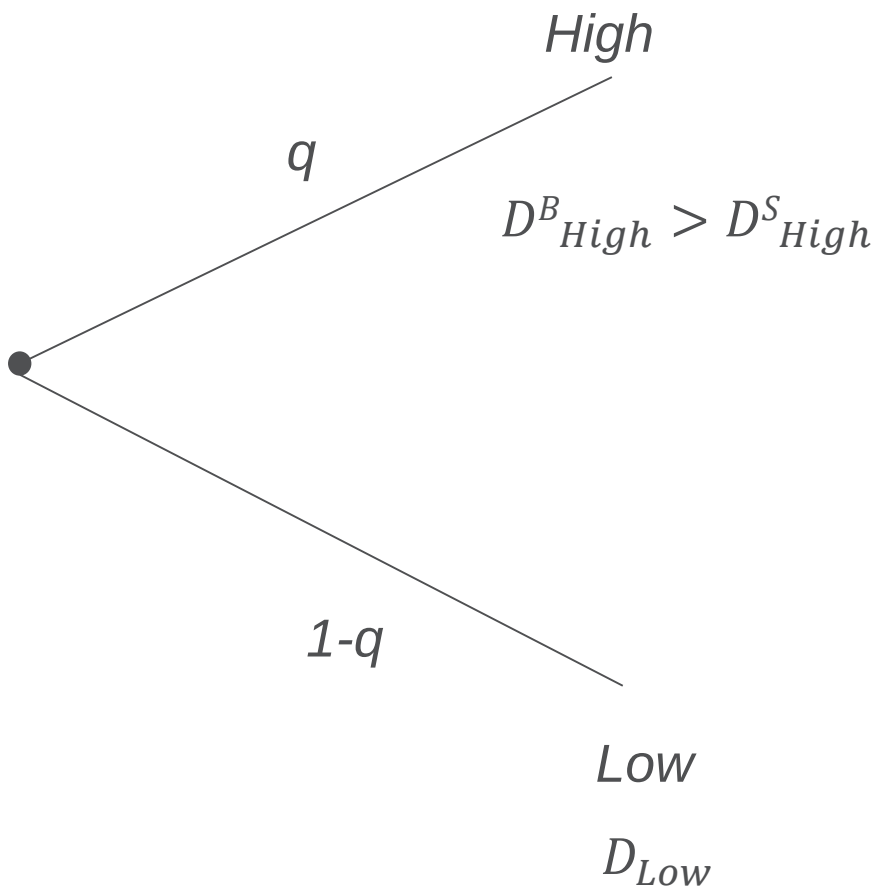
Model 1: Setup

- **The two assets have identical cash payoff**

- In state Low, the payoff is the same for Buyers and Sellers: $\boldsymbol{D^i_{Low}}$

- Gains from trade. In state Higher, Buyers' payoff is higher than Sellers': $\boldsymbol{D^B_{High} > D^S_{High} > D_{Low}}$

- p_Y and p_Z are the prices of Y and Z at 0



Model 1: The Collateralized Debt Contract

- Buyers can only borrow through a collateralized debt contract indexed by $j \in J$
  - Non-contingent promise to pay j ("the promise") at time 1 *backed by one unit of asset Y as collateral*

➢ **Only asset Y can be used as collateral**

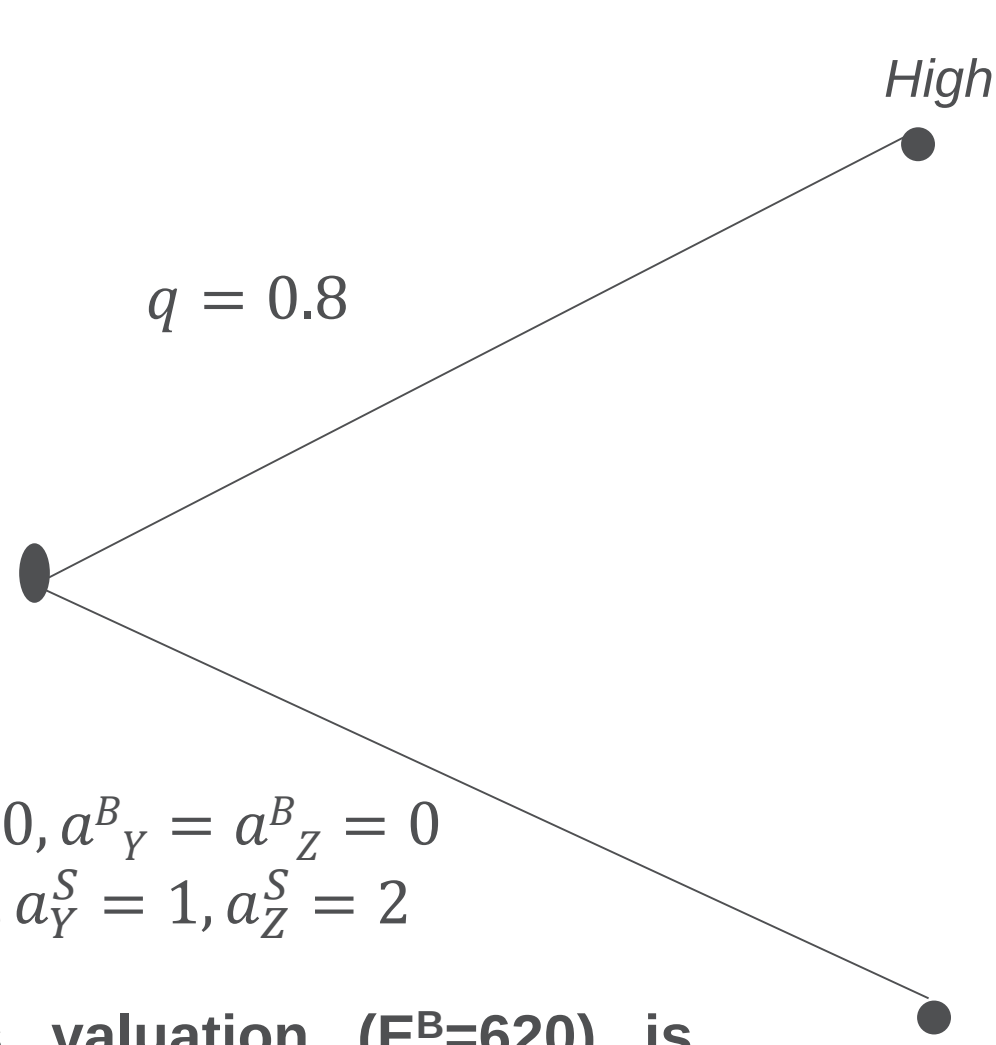
- For each debt contract j, there is an associated price, b_j

- Buyers borrow from a financial institution (a bank)

➢ The maximum amount they can promise per unit of collateral is $j = D_{Low}$ (no default)

➢ Assumption: $b_j = j$ (risk-free rate equals 0)

Model 1: Parameterization



$D^B_{High} = 750$
$D^S_{High} = 250$

$q = 0.8$

$m^B = 400, a^B_Y = a^B_Z = 0$
$m^S = 0, a^S_Y = 1, a^S_Z = 2$

$D_{Low} = 100$

- **Buyers valuation (E^B=620) is greater than Sellers' valuation (E^S=220)**

Model 1: Equilibrium

	Eq
Buyers' Final Holdings of Assets Y	**1**
Buyers' Final Holdings of Assets Z	**0.98**
Buyers' Final Cash	**0**
$Promise, j = Borrowing, b_j$	**100**

- Gains from trade are **not** fully realized: Buyers buy all asset Y but share asset Z with Sellers

- Buyers use all their cash as downpayment
- They borrow the maximum using Y as collateral ($b_j = j$=100)

Model 1: Equilibrium

	Eq.
p_Y	**285**
p_z	**220**
$Spread$	**65**

- Y and Z have different prices
- **A deviation from the Law of One Price**

- p_z equals Sellers' valuation (220)
- p_y is such that Buyers' marginal payoffs of investing in either asset are the same

$$\frac{E^B(Z)}{p_Z} = \frac{0.8 * 750 + 0.2 * 100}{220} = \frac{E^B(Y - 100)}{p_Y - 100} = \frac{0.8 * (750 - 100)}{285 - 100} = 2.82$$

Outline

1. Introduction
2. Model 1: “Collateral Constraints and the Law of One Price: an Experiment”
3. **Experiment 1**
4. Model 2: “Endogenous Leverage and Default in the Laboratory”
5. Experiment 2
6. Conclusion

Experiment 1: The Design

- 7 sessions: 12 students in 6 sessions; 16 in one.
- Each session: 10 independent paid rounds
- At the beginning of the sessions, half students were assigned to be Buyers, half to be Sellers
- Each round: two-asset double auction, lasting 160 seconds
  - Subjects traded both assets at the same time
  - **Buy offer for asset Y**: both the price and the amount to be borrowed

Round

1 of 1

Remainig time [sec]: 107

Your experimental ID is: 2

You are a Buyer

Cash: 150

Number of SQUARES: 0

Number of CIRCLES: 1

Total Cash Transfers: 0

Chance of Final Value High: 80%

Widget Value High: 750

Widget Value Low: 100

Open Circle Offers

Buy		Sell	
My offers	Price	My offers	Price
			300

Cancel Cancel

Open Square Offers

Buy			Sell	
My offers	Price	Cash Transfer	My offers	Price
*	200	100		300

Cancel Cancel

PLACE OFFER

Price

Cash Transfer

(Buy Square Offers Only)

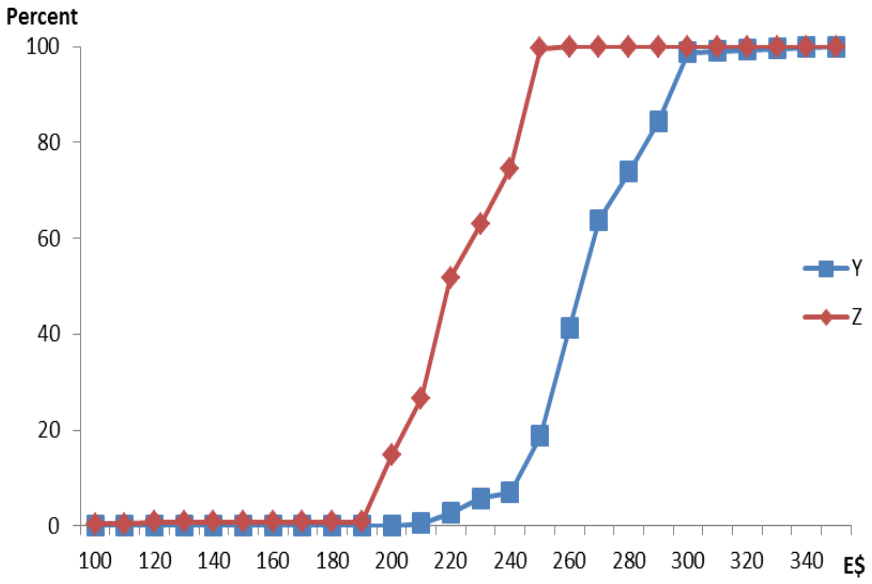
Offer to Buy Circle Offer to Buy Square

Past Trades

My trade	Widget	Price	Cash Transfer
*	Circle	250	

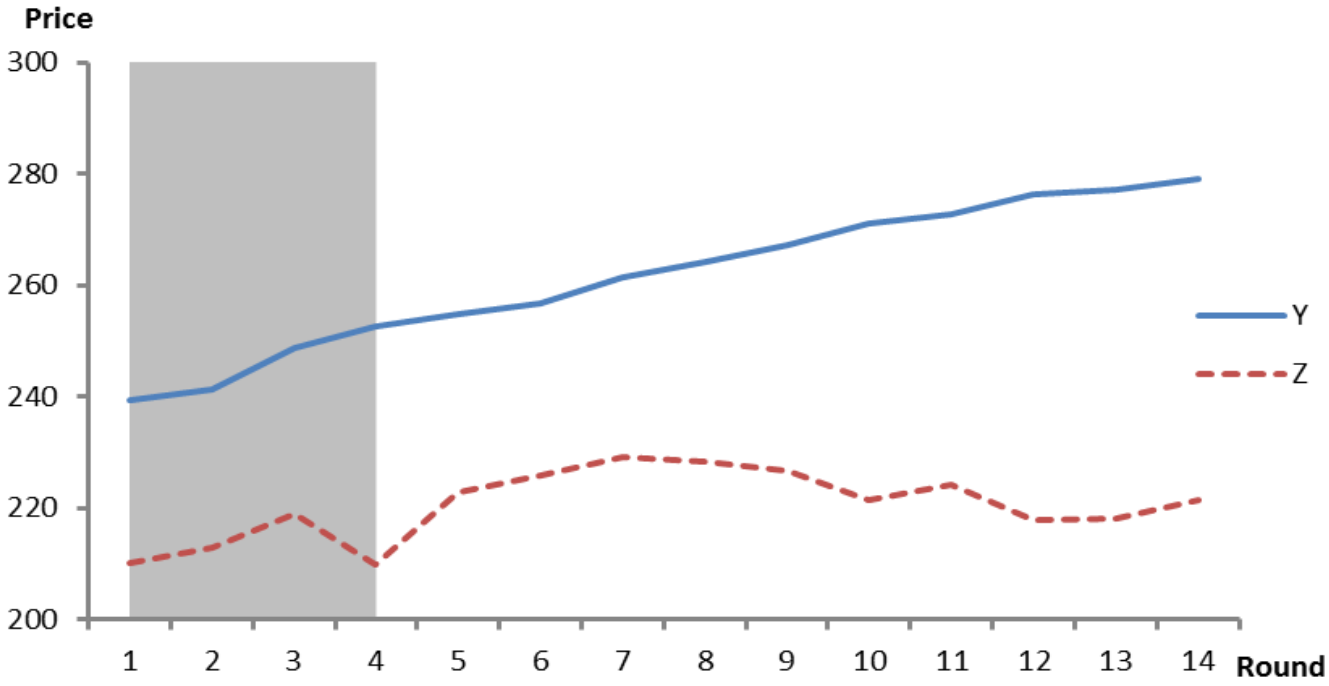
Experiment 1: Prices and Deviation from the Law of One Price

	Y	Z	Spread
All Sessions	268	224	45
Predicted	285	220	65



- The average price of asset Y is higher than that of asset Z
- The difference is statistically significant (p=0.08)
- We observe a deviation from the Law of One Price in the laboratory!

Experiment 1: Prices Across Rounds



- The price of asset Z is roughly constant across rounds
- The price of asset Y increases across rounds

❖ Buyers discover the value of collateral

Experiment 1: Is the Spread due to Collateral?

A. In the theory, collateral is priced because Buyers value borrowing
   - In the experiment, average borrowing per unit of asset Y is 86
   - In 70% of transactions Buyers borrowed the maximum (100)

B. In the theory, Buyers value borrowing because they are constrained
   - In the experiment, the proportion of constrained Buyers at the end of each round is 82%

C. Since Buyers value collateral, they are do not try to arbitrage away price differences
   - In the experiment, the proportion of times a Buyer buys Y even though Z is available at a lower price is 50% in practice rounds vs. 68% in the last 4 rounds

Outline

1. Introduction

2. **Model 1: "Collateral Constraints and the Law of One Price: an Experiment"**
3. Experiment 1
   - *Results: collateral is priced in the laboratory and generates deviation from the law of one price*
   - *The laboratory data are consistent with the mechanism generating collateral value in the theory*

4. **Model 2: "Endogenous Leverage and Default in the Laboratory"**
5. Experiment 2

3. Conclusion

"Endogenous Leverage and Default in the Laboratory"

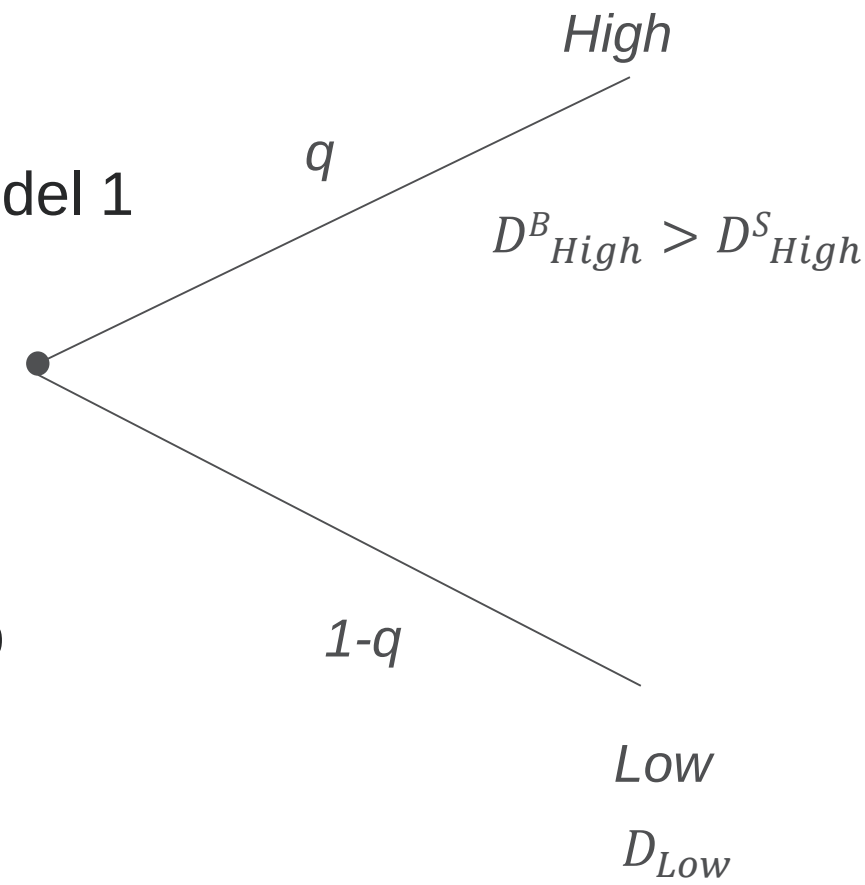
- In a binomial economy where **all assets are financial, collateral requirements are set so that default never occurs** (Fostel and Geanakoplos, ECMA 2015)
  - **financial assets**: dividends are independent of ownership and asset does not provide direct utility (stock, bond)
  - **non financial assets**: ownership affects productivity (firm)

- Model 2: same as Model I but with endogenous leverage:
  - No bank (agents lend and borrow)
  - No maximum promise of 100
  - Two versions (two "economies"): Non Financial Asset (NFA) and Financial Asset Economy (NFA)

- We contrast experimental outcomes

Model 2: The Non Financial Asset Economy (NFA)

- I will first describe an economy with non financial assets
- Same binomial structure as in Model 1
- One risky asset: asset Y
- Asset Y is non financial:
  - It pays according to ownership
  - $\boldsymbol{D^B_{High} > D^S_{High} > D_{Low}}$
- Leverage is endogenous



Model 2: Endogenous Leverage

- Agents can only borrow (and lend) through collateralized debt contracts indexed by $j \in J$
  - Non-contingent promise to pay j ("the promise") at time 1 *backed by* one unit of asset Y *as collateral*
  - The promise j can be above 100

- **Agents borrow and lend among each other using collateralized debt contract**
  - They do not borrow from a Bank
  - For each debt contract j, there is an associated **equilibrium price**, b_j
  - An agent can borrow b_j today by selling the collateralized debt contract j

Model 2: Delivery of the Debt Contract and Default

- The debt contract is a non-recourse contract
- A borrower will never repay more than the value of the collateral to them (no one can force them to)
- Actual delivery in state $s = \{High, Low\}$:

$$Delivery(j) = min\{j, D_s\}$$

- **There is default in state s if:**

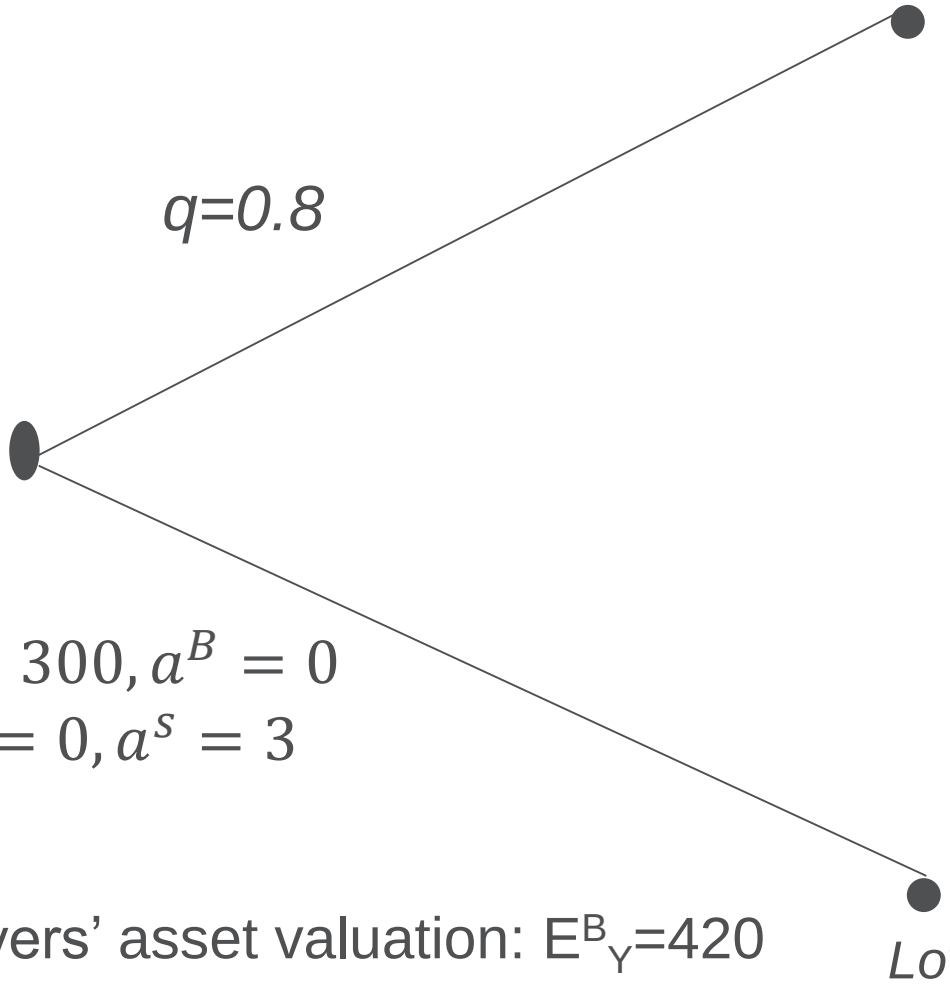
$$\mathbf{j > D_s}$$

Traditional GE Model versus Collateral GE Model

- Traditional GE model:
  - One period economy: only one debt contract (zero-coupon bond), with associated equilibrium price (and interest rate)

- Collateral GE model with endogenous leverage:
  - Each debt contract j, backed by one unit of asset Y as collateral, is a **different financial contract**
    - **Why?** each contract j has a different level of collateralization (collateral per unit of cash is $\frac{1}{j}$)
  - There is one market for each debt contract j
  - That's why at each debt contract j is associated a price b_j and an interest rate

Model 2: The NFA Economy Parameterization

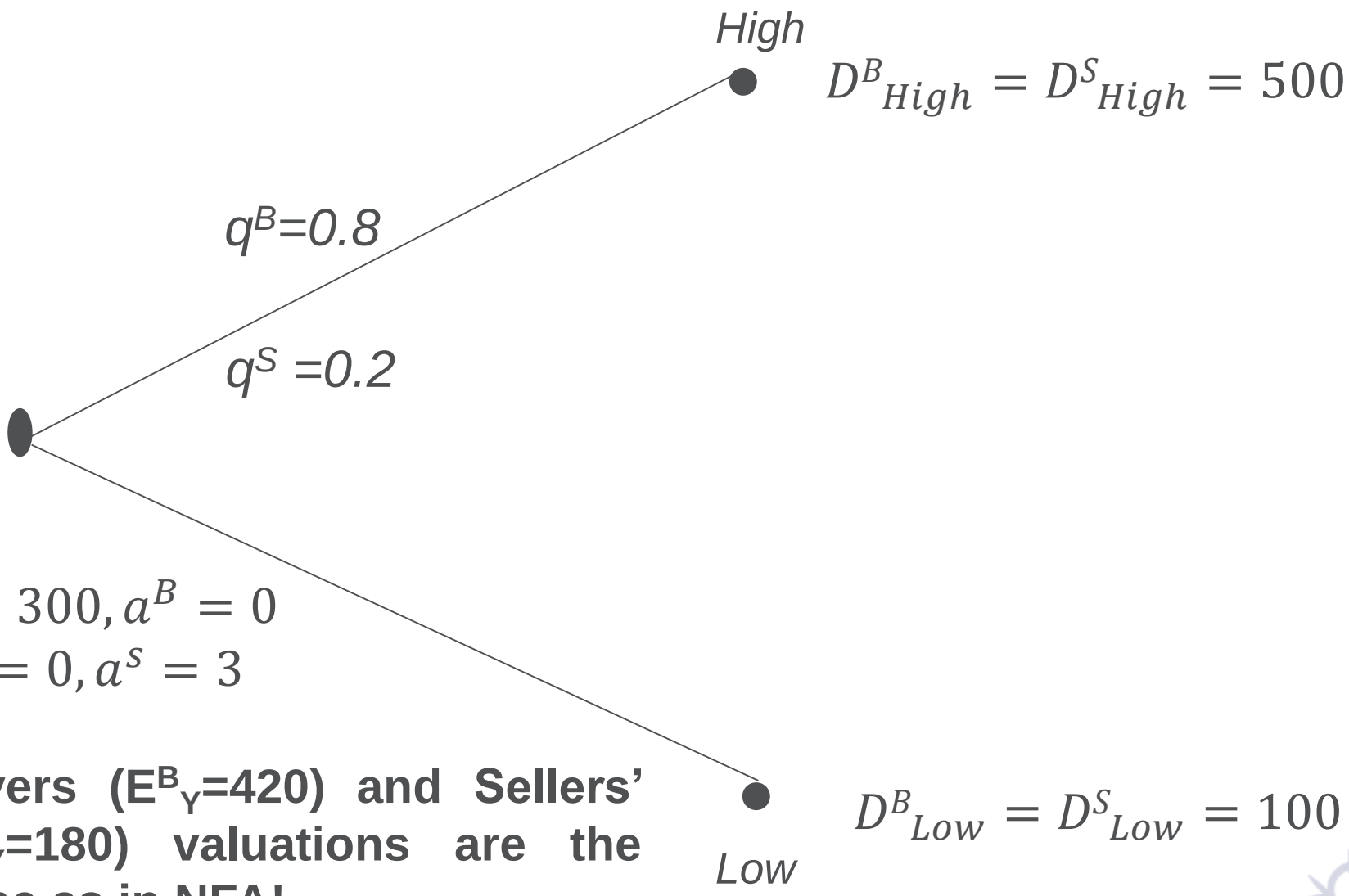


- Buyers' asset valuation: E^B_Y=420
- Sellers' asset valuation: E^S_Y=180

The Financial Asset Economy (FA-economy)

- In the **Financial Asset Economy (FA)** the asset used as collateral is financial
  - *It pays the same to Buyers and Sellers in all states of the world*
- Gains from trade: beliefs are heterogeneous
  - *Buyers assign higher probability to state High than Sellers*
- Everything else is the same as in the NFA-economy
  - *Asset valuations for both Buyers (420) and Sellers (180) are the same as in the NFA-economy*
- **Equilibrium predictions on leverage, prices, and default are very different**

Model 2: The FA Economy Parameterization



- **Buyers (E^B_Y=420) and Sellers' (E^S_Y=180) valuations are the same as in NFA!**

Model 2: Equilibrium

	NFA	FA
Buyers' Final Assets	3	3
Downpayment, d	100	100
Asset price, p	420	200

- In both parameterization, gains from trade are fully realized
- Buyers use all their cash as downpayment
  - Downpayment per asset: d=100
- But: the price of the risky asset is higher in NFA than in FA
  - Only in NFA does competition among Buyers make the price equal to Buyers' valuation

Model 2: Equilibrium

	NFA	FA
$Asset\ price, p$	420	200
$Borrowing, b_j$	320	100
$Promise, j$	375	100

- **In NFA, one debt contract is traded with promise $\mathbf{j = 375}$**
  - Delivery of the debt contract: 375 in High and 100 in Low
  - Price of the debt contract equals its expected delivery
    - $b_j = E(delivery\ to\ Sellers) = 375 * 0.8 + 100 * 0.2 = 320$
  - Default in state Low

- **In FA, one debt contract is traded with promise $\mathbf{j = 100}$**
  - Delivery of the debt contract: 100 in both states of nature
  - **No default**
  - Price of the debt contract $b_j = 100$

Model 2: Equilibrium in NFA vs FA

- Agents' asset valuations are the same in both economies

But

- The promise is lower in FA than in NFA
- **There is no default in FA; there is default in NFA**

- Gains from trade are realized in both economy

- (Borrowing, interest rate, and price are lower in FA)

Model 2: Intuition

- In both the FA and NFA economy, for any price lower than 420, Buyers would like to increase their holding of the risky assets

- In NFA, the equilibrium price is indeed 420 and
  - Buyers borrow 320 per asset in order to finance their purchase (using 100 as downpayment)

- **Why does this not happen in FA?**

- In FA, **for any j>100**, Buyers and Sellers value the lending contract differently
  - Why? Buyers attach a lower probability (0.2) to default than Seller do (0.8); Buyers believe they will pay Sellers more than Sellers believe they will be paid
  - They only contract at which they are willing to trade is j=100 (default does not occur)

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5. **Experiment 2**
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Experiment 2: The Design

- 5 sessions: 12 students per sessions
- In each session, **two treatments** were played:
  - The Financial Asset Economy Treatment (*FA-Treatment*)
  - The Non Financial Asset Economy Treatment (*NFA-Treatment*)
- In each treatment of each session, **8 paid rounds** are played
- At the beginning of the sessions, half students were assigned to be Buyers, half to be Sellers
- Double Auction: each round, subjects traded the risky asset in a **continuous-time limit-order** market (200 seconds per round)

Implementation Challenge I: The Collateral Requirement

- In the theoretical model, there a several debt markets:
  - A market for each debt contract j
  - *These debt markets are linked through the collateral requirement to the market for the risky asset*

- Hard to set-up a double auction with trading in any market j, while assuring that the collateral constraint is satisfied

- Our Solution: link the credit and asset market in the double auction
  - Subjects post orders that determine their simultaneous position in both the asset and the credit market

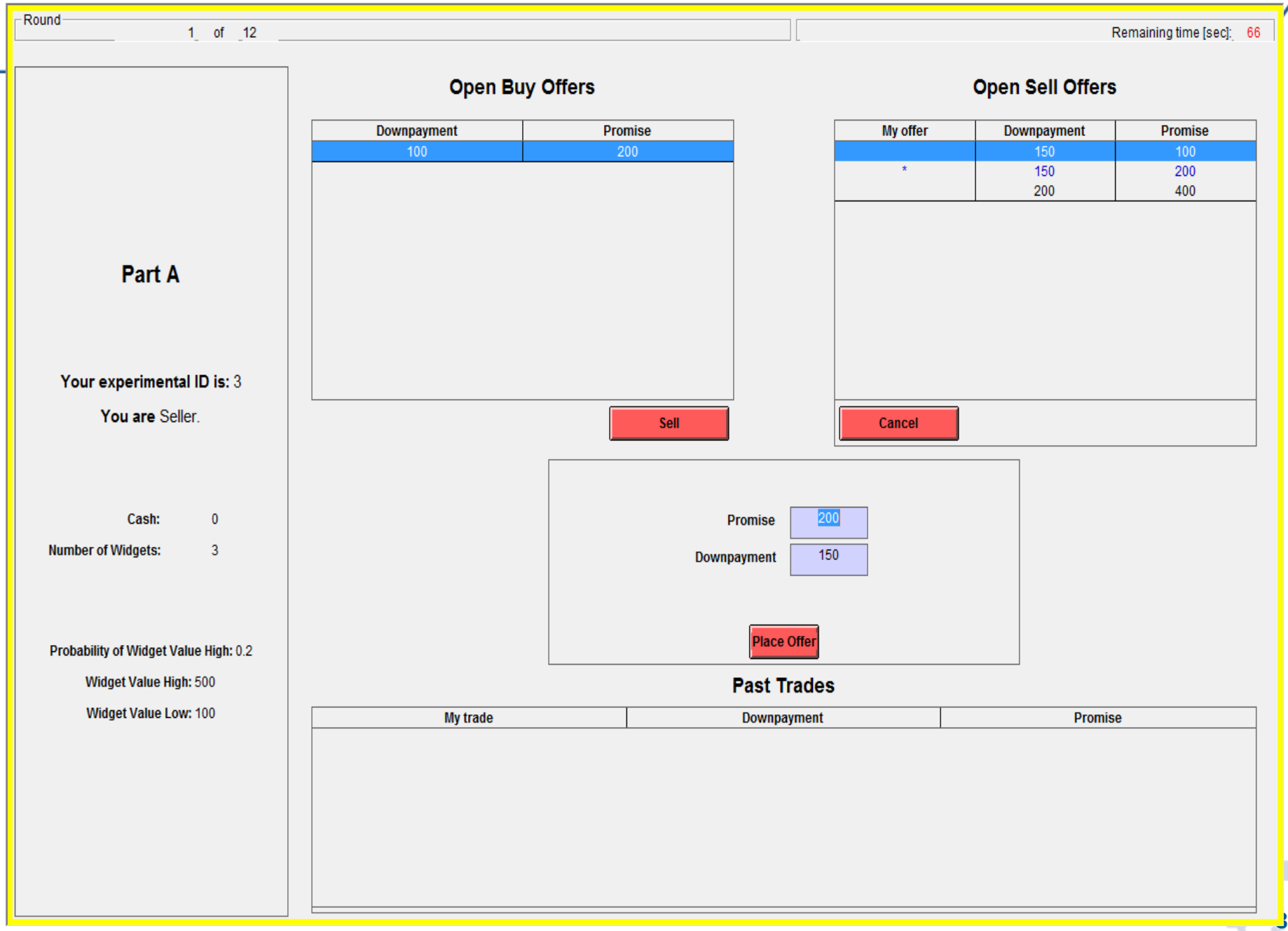
Implementation Challenge I: The Collateral Requirement

- A Buy or Sell offers specifies:
  - a Down-payment **(d)**: the amount a Buyer (Seller) is willing to pay (receive) at the time of the trade
  - a Promise **(j):** the amount a Buyer (Seller) is willing to pay (receive) at the end of the round

- An order is executed when a Buyer accepts a Sell Offer or a Sellers accepts a Buy Offer

➢ **In the laboratory, we observe the Downpayment, the Promise, and Default**

  ➢ **But we do not observe prices**: the price of the risky asset, the price of the bond contract and the interest rate


Round
1 of 12
Remaining time [sec]: 66
Part A
Your experimental ID is: 3
You are Seller.
Cash: 0
Number of Widgets: 3
Probability of Widget Value High: 0.2
Widget Value High: 500
Widget Value Low: 100
Open Buy Offers
Downpayment
Promise
100
200
Sell
Open Sell Offers
My offer
Downpayment
Promise
150
100
*
150
200
200
400
Cancel
Promise
200
Downpayment
150
Place Offer
Past Trades
My trade
Downpayment
Promise

Implementation Challenge II: Heterogeneous Beliefs

- **Most of the double-auction experiments on asset markets involve non-financial assets (in order to generate gains from trade)**

- In the FA treatment, we create gains from trade **through heterogeneous beliefs**: Buyers are Sellers attach a different probability to state High

➢ How to implement heterogeneous beliefs in the laboratory (and maintain control over them)?

- general disfavor toward lying to subjects in experimental economics

Implementation Challenge II: Heterogeneous Beliefs

- Our Solution: we allowed the state of the world to be different for Buyers and Sellers

Ball Number	1	2	3	4	5
Buyers	Low	High	High	High	High
Sellers	Low	Low	Low	Low	High

- At the end of the round, Buyers' and Sellers' payoffs were computed according the state of world realized for them
  - That is, each subject's payoff was computed **as if** the state of the world of **all** subjects were equal to their own

- This procedure was fully explained to subjects

Experiment 2: Proportion of Contracts that Default

	State High	
	NFA	FA
All Sessions	0	0
Predicted	0	0

- State High: in both treatments, there is **almost no default**

- State Low: the proportion of contracts that default is **higher in the NFA** than in the FA-treatment (p=0.06)

	State Low	
	NFA	FA
All Sessions	0.86	0.42
Predicted	1	0

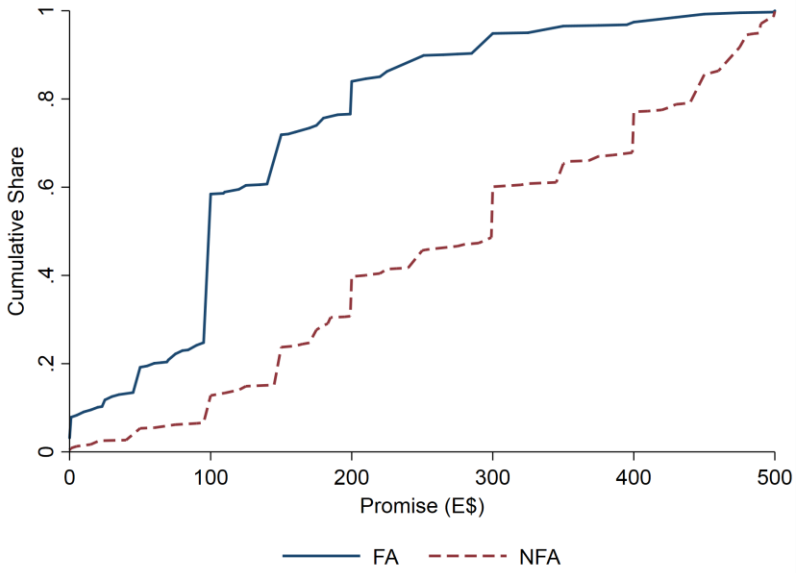
Experiment 2: Sellers' Default Losses in the Low State

	State Low	
	NFA	FA
All Sessions	177	51
Predicted	275	0

- Default loss is **(much) higher in the NFA** than in the FA-treatment
  - Difference between FA and NFA is statistically significant (p=0.06)

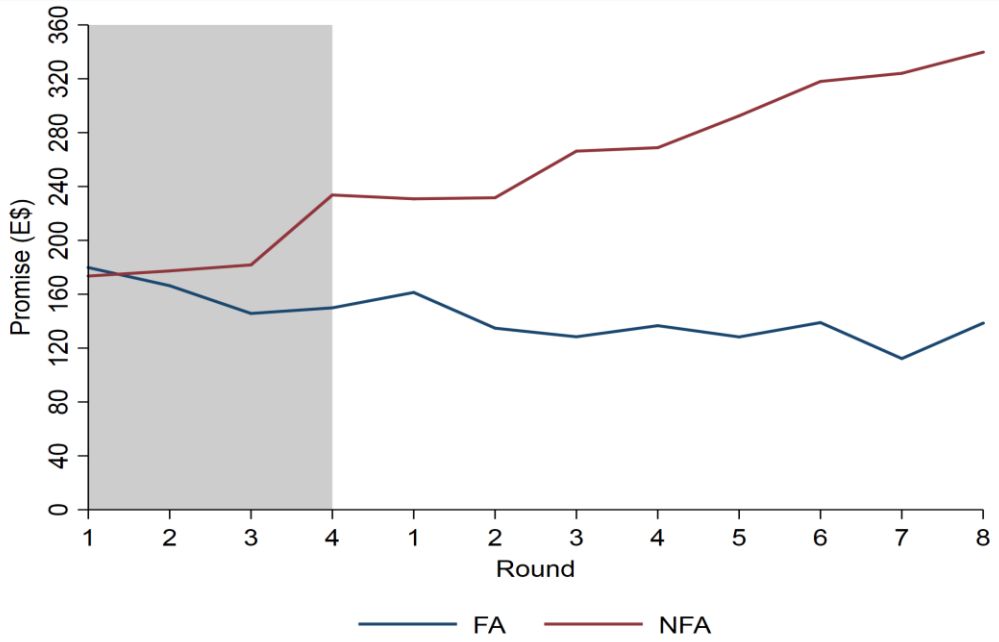
Experiment 2: The Promise j

	NFA	FA
All Sessions	**284**	**135**
Predicted	**375**	**100**



- The promise is **higher in the NFA** than in the FA-treatment
- The difference between FA and NFA is statistically significant (p=0.06)

Experiment 2: Promises Across Rounds



	NFA Treatment				FA Treatment			
	Practice	1-2	3-6	7-8	Practice	1-2	3-6	7-8
Average	185	231	287	332	164	149	133	126
Predicted		**375**				**100**		

- In both treatments, the promise moves closer to its theoretical counterpart as the experiment progresses

Conclusions

- Experimental finance agenda: bring the theoretical GE literature on collateralized borrowing, leverage, and asset prices to the laboratory

- We focus on two theoretical predictions:
  - Collateral is priced and generates deviations from the Law of One Price
  - When assets are financial, collateral requirements are set high enough that default does not occur

➢ The experimental data confirm the theoretical predictions

➢ Laboratory outcomes get closer to the theoretical predictions over the rounds

THANKS!

Useful

Extra slides

Model 1

Model 1: Intuition

- The deviation from the Law of One Price is due to **Collateral Value:**
  - **additional payoff from collateralized borrowing, appropriately discounted**

- Buyers' marginal payoff of investing cash at 0:

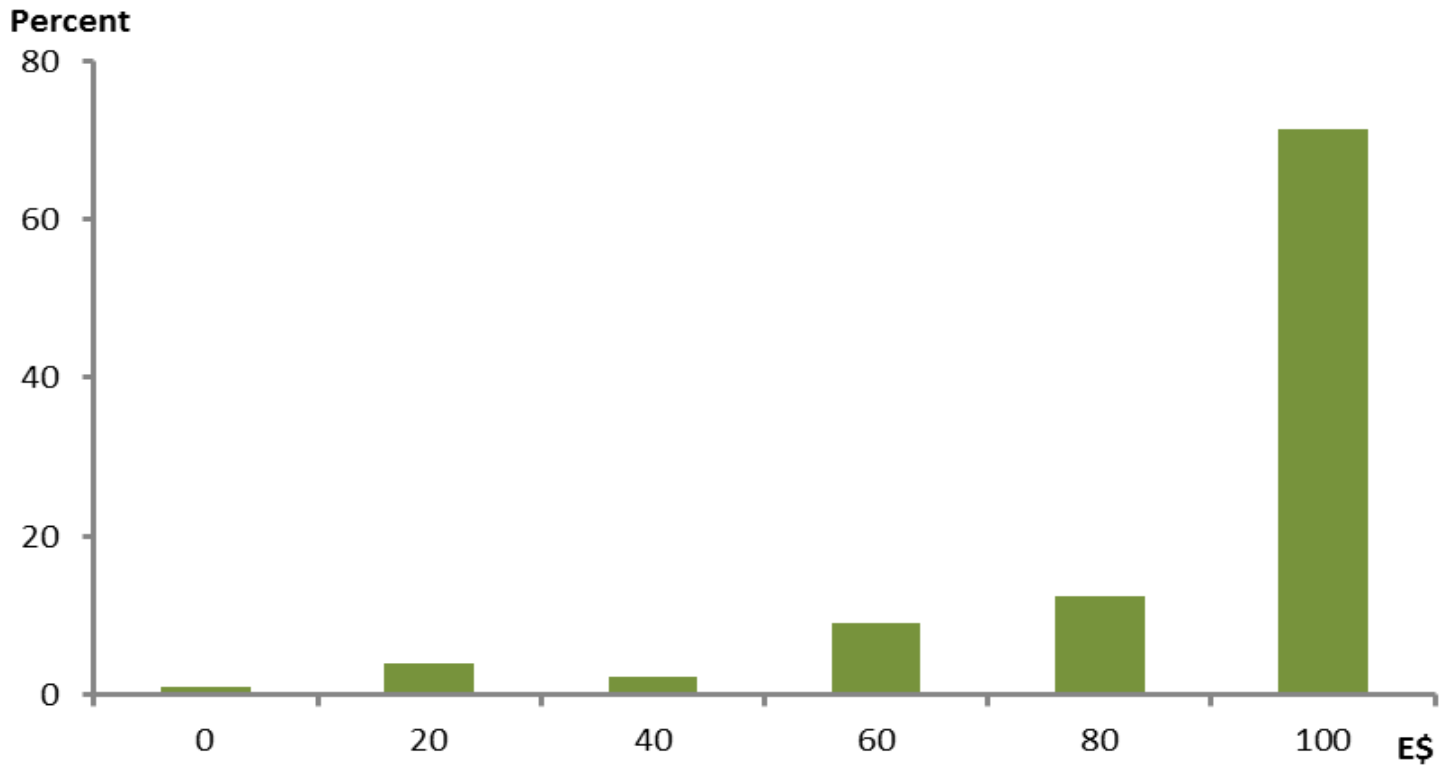
$$\frac{E^B(Z)}{p_Z} = \frac{0.8 * 750 + 0.2 * 100}{220} = \frac{E^B(Y - 100)}{p_Y - 100} = \frac{0.8 * (750 - 100)}{285 - 100} = 2.82$$

- Buyers' payoff for each unit of cash borrowed, $2.82 - 1 = 1.82$

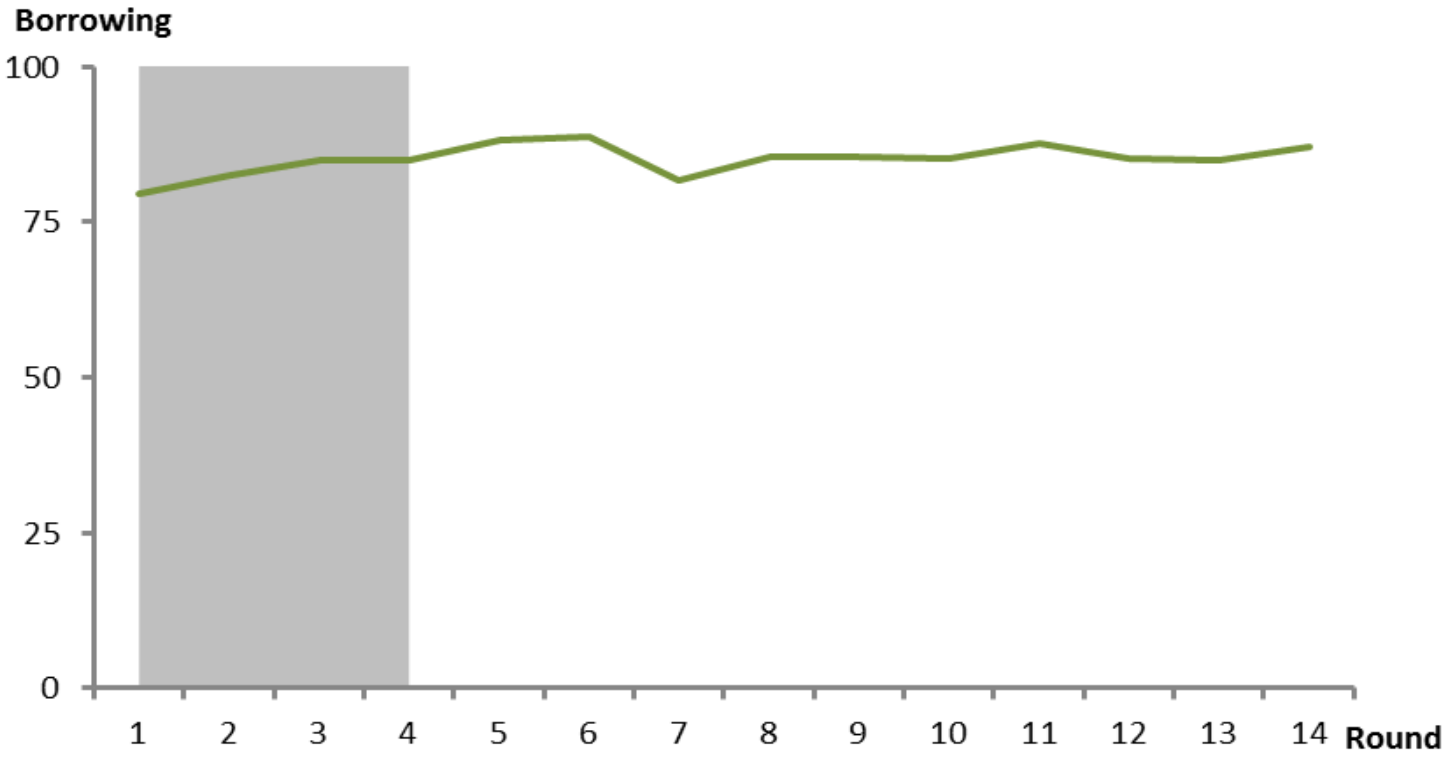
- Collateral Value:

$$CV^Y = 100\frac{1.82}{2.82} = 65 = spread$$

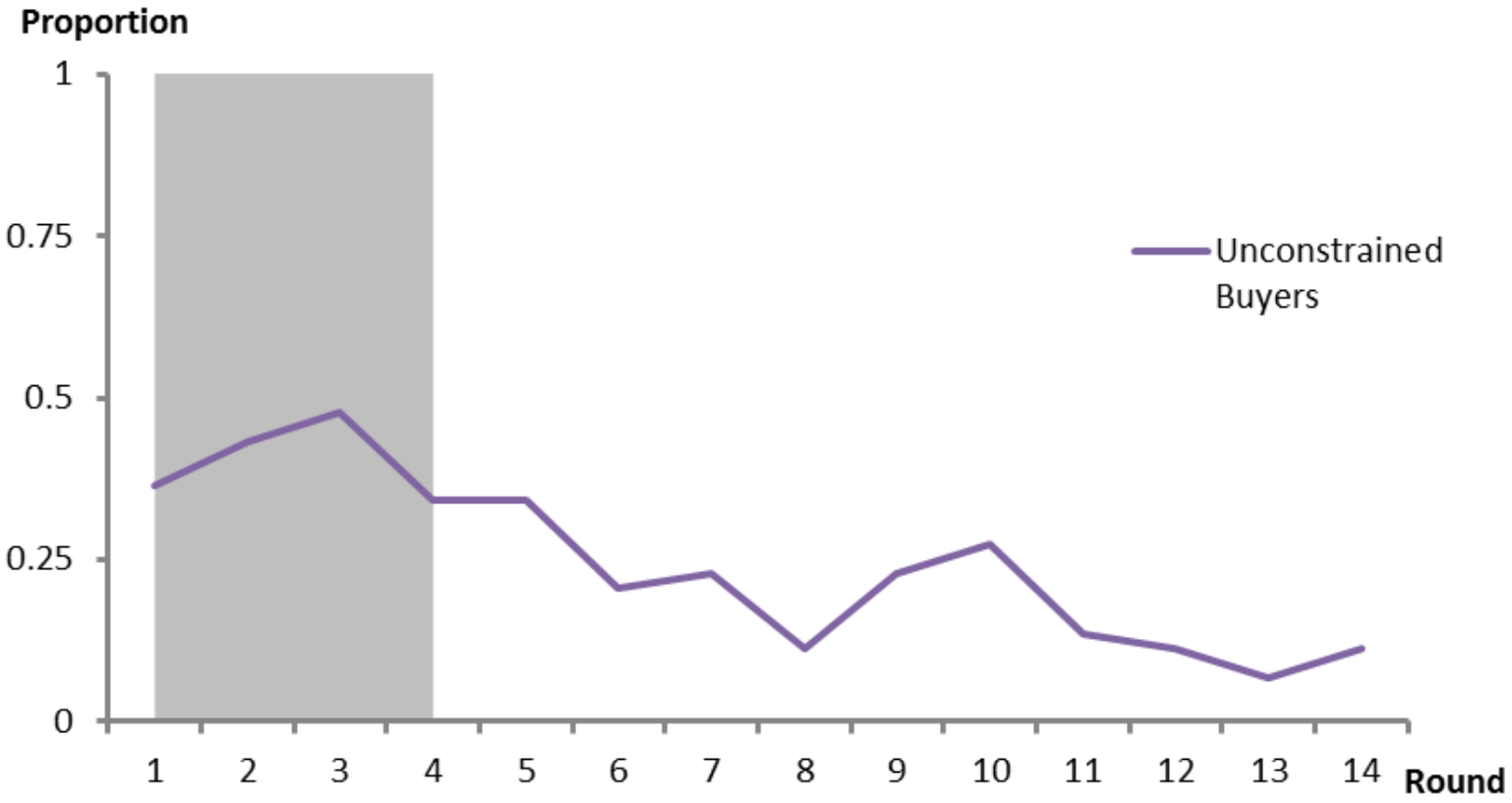
Experiment 1: Borrowing



Experiment 1: Borrowing through the Rounds



Experiment 1: Unconstrained Buyers through the Rounds



Model 2

Experiment 2: Final Asset Holdings

	FA Treatment		NFA Treatment	
	Sellers	Buyers	Sellers	Buyers
All Sessions	0.24	**2.76**	0.03	**2.97**
Predicted	**0**	**3**	**0**	**3**

- In both treatments, **Buyers end up with almost all the supply of the risky asset Y**
- Gains from trade are realized

Results: Downpayment (d)

d	FA Treatment	NFA Treatment
Average	94	59
Predicted	100	100

- In the theoretical model, the downpayment in both treatments is 100; cash should end up in the hands of Sellers.
- In the FA-treatment it is **very close to the theory**
- In the NFA-treatment, the average downpayment is only 59, significantly different from 100 (p=0.06)

➢ In the NFA treatment, Buyers ended up with (high) positive cash balances at the end of the round.

$Cash^B$	NFA Treatment
Average	126
Predicted	0

❖ Risk aversion with no-recourse loans

Collateral Equilibrium

- Standard equilibrium concept: agents maximize (expected) payoffs given prices, markets clear
- Two departures with respect to standard GE:
  - Agents' payoff in state s
  - Collateral constraint

❖ Number of debt contracts j, $\varphi^i{}_j$

- **Agent buys debt contract (lending), $\varphi^i{}_j > 0$**
  - The agent is lending
- **Agent sells debt contracts, $\varphi^i{}_j < 0$**
  - The agent is borrowing

Collateral Equilibrium

- Payoff in state s

$$final\ cash + y^i D_s + \sum_{j \in J} (\varphi_j^i) min\{j, D_s\}$$

Delivery of Debt Contract j

Repayment due to Net lending (+) or Payment due to Net Borrowing (-)

- Collateral constraint (in addition to budget constraint)

$$\sum_{j \in J} max(-\varphi_j^i, 0) \leq y$$

Number of debt contracts j sold

The Regime in the FA Economy

- The price of asset y (200) is *higher than Sellers'* expected value (180), but *lower than Buyers'* expected value (420)

- Risky Neutrality: Buyers buy all the supply of the asset, which Sellers are willing to sell

- Buyers cannot afford to buy 3 units of asset y in cash
  - They sell three debt contracts j=100, each backed by one unit of the asset
  - Since the contract j=100 never defaults, its price $b_j = 100$
  - For each unit of the asset, Buyers borrow 100 and put down 100 in downpayment.
  - Buyers have enough cash (300) to buy all risky assets (3)

- Note: Buyers are constrained in equilibrium. They would like to buy more units of the asset but they cannot

Some (Vague) Intuition

- In both the FA and NFA economy, for any price lower than 420, Buyers would like to increase their holding of the risky assets

- In NFA, the equilibrium price is indeed 420 and
  - Buyers borrow 320 per asset in order to finance their purchase (using 100 as downpayment)

- **Why does this not happen in FA?**

- In FA, **for any j>100**, Buyers and Sellers value the lending contract differently
  - Why? Buyers attach a lower probability (0.2) to default than Seller do (0.8): Buyers believe they will pay Sellers more than Sellers believe they will be paid
  - They only contract at which they are willing to trade is j=100 (default does not occur)

Why j=100?

- **With j<100**, the interest rate would be 0 (no default)
  - Buyers would be able to buy fewer assets.
  - Since, in equilibrium, Buyers are constrained, they would want to borrow more

- **With j>100**, there would be default
  - Sellers charge an interest rate higher than 0
  - The interest rate reflects Sellers' belief on the likelihood of default (0.8)
  - At that interest rate, Buyers (who attach 0.2 probability to default) are unwilling to borrow

- **j=100 is the only equilibrium!**

The Regime in the NFA Economy

- The price (420) is higher than Sellers' expected value (180), *and equal to Buyers' expected value (420)*
- In equilibrium, Buyers buy all the supply of the asset, which Sellers are willing to sell.
- Buyers cannot afford to buy 3 units of asset y in cash
  - They sell three debt contracts j=375, each backed by one unit of the asset Y
  - The price of the debt contract j=375 equals its expected delivery, $b_j = 320$
  - For each unit of the asset, Buyers borrow 320 and put down 100 in downpayment. The price of the asset is 420
- Note: Buyers are not constrained in equilibrium

Why j=375?

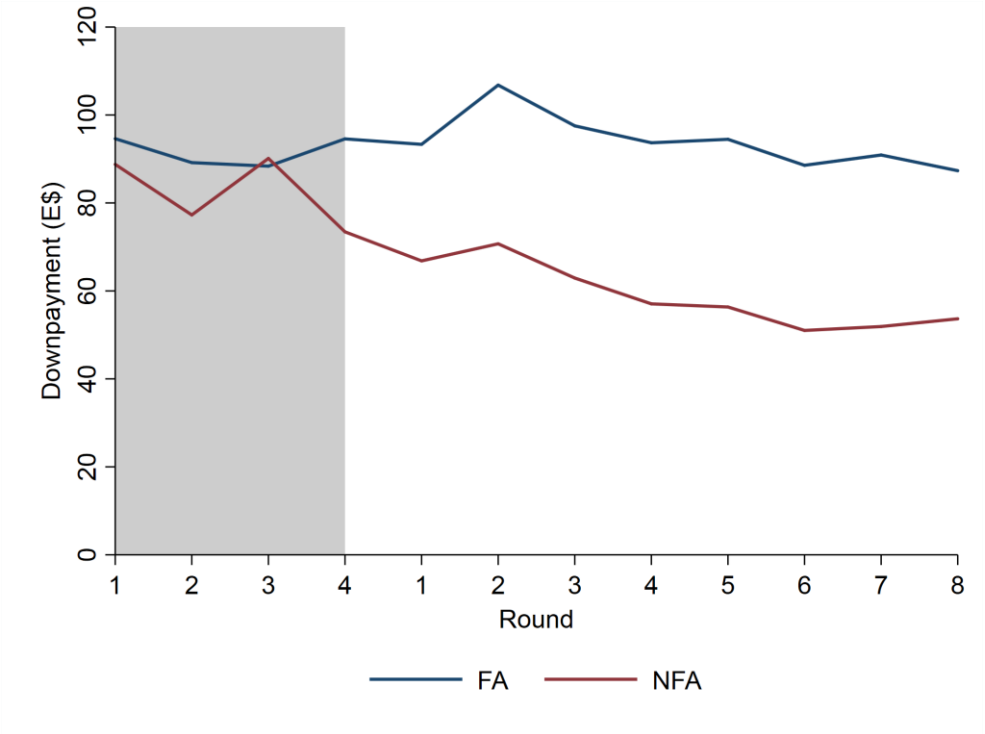
- **With j>375**, borrowing is higher
  - Price cannot be higher (Buyers are not willing to pay more)
  - Either they would save in downpayment, keeping positive cash balances. That cannot be an equilibrium because (risk-neutral) Buyers are paying a positive interest rate on borrowing
  - Or: they would demand more than the asset supply.

- **With j<375**, the price of the risky asset is lower than 420
  - Buyers' expectation is greater than the asset price
  - They want to purchase more of it
  - That cannot be an equilibrium because at the implied interest rate, Buyers would like to increase their borrowing

The Payoff

- Summed the per-trade payoffs in a round
- One round randomly chosen out of the 16 paid rounds
- Bonus added at the end of round to avoid negative payoffs
- Exchange Rate: 35 to 1

Results: Downpayments Across Rounds



	FA-Treatment				NFA-Treatment			
	Practice	1-2	3-6	7-8	Practice	1-2	3-6	7-8
Average	95	101	94	89	80	69	57	**53**
Predicted		100				100		