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Leverage and Asset Prices: An Experiment.

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Abstract

This is the first paper to test the asset pricing implication of leverage in a laboratory. We show that as theory predicts, leverage increases asset prices: when an asset can be used as collateral (i.e., when the asset can be bought on margin), its price goes up. This increase is significant, and quantitatively close to what theory predicts. However, important deviations from the theory arise in the laboratory. First, the demand for the asset shifts when it can be used as a collateral, even though agents do not exhaust their purchasing power when collateralized borrowing is not allowed. Second, the spread between collateralizable and non-collateralizable assets does not increase during crises in contrast to what theory predicts.

Keywords: Leverage, Asset Pricing, Experimental Economics.

JEL Codes: A10, C90, G12

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Introduction

The recent financial crisis has made clear the impact that leverage has on financial system stability. The crisis was preceded by years in which the amount of leverage in the financial system, both at the institution and at the asset level, increased dramatically. The crises poster-children, AIG and Lehman, as well as the systemic banking troubles in the US and Europe clearly illustrate the risks margin calls pose for the financial system's liquidity and solvency. As a result, recent academic work has focused on the role of leverage in a financial economy.[1]

An important strand of this literature has focused on the asset pricing implication of leverage. Two papers develop a formal theory of asset pricing: Fostel and Geanakoplos (2008) in a general equilibrium model with incomplete markets, and Garleanu and Pedersen (2011) in a CAPM model.[2] These papers show that in a world where agents are heterogeneous and markets incomplete, the ability to use an asset as a collateral (i.e., buying on margin) increases its price in equilibrium.

The reason for the increase in price is that when assets can be used as collateral to borrow money, their prices not only reflect future cash flows, but also their efficiency as liquidity providers. Fostel and Geanakoplos (2008) show that the price of any asset can be decomposed into two parts: its payoff value and its collateral value. The payoff value reflects the asset owner's valuation of the future stream of payments, i.e., it is the value attached to the asset due to its investment role. The collateral value reflects the asset owner's valuation of the fact that the assets can also be used as collateral to borrow money. The asset collateral role is priced in equilibrium, and, as a result, it creates deviations from Law of One Price: two assets with identical payoffs are priced differently if they have different collateral values. An example of such deviation is the so-called "CDS-basis," which became more severe during the recent crisis. An investor buying a corporate bond and its CDS creates a synthetic risk-free position if held to maturity. However, the price of this synthetic instrument is usually below that of a treasury, an apparent arbitrage opportunity that can be explained by the fact that treasuries can be used more easily as collateral than the synthetic instrument.

[1]See for instance, Acharya and Viswanathan (2011), Adrian and Shin (2010), Araujo et al. (Forthcoming), Brunnermeier and Pedersen (2009), Cao (2010), Fostel and Geanakoplos (2008, 2011 and forthcoming), Garleanu and Pedersen (2011), Geanakoplos (2010), Gromb and Vayanos (Forthcoming) and Simsek (2010).

[2]Hindi (1994) studied the pricing implication of leverage in a partial-equilibrium setup with exogenous leverage.

Theory also predicts that leverage allows gains from trade to be realized: when leverage is possible the asset is held in equilibrium by those agents who value it the most. Moreover, as a result of bad news, the spread between assets that can be bought on margin and those that cannot should increase in equilibrium. Fostel and Geanakoplos (2008) called this Flight to Collateral: when the crisis hits, assets that can be used as collateral see their price drop by less than assets that cannot.

Our paper is the first to test the asset pricing implications of leverage in a controlled laboratory environment. To this purpose, we build a model in which markets are incomplete and agents are heterogenous, that is amenable to experimental implementation. In our model, agents can trade an asset among themselves. They have heterogenous asset valuations: some agents value the asset more than others in some state of nature. We compare two economies, which are identical except that in one, the asset can be used as collateral and in the other, it cannot. When the asset can be used as collateral, its collateral value is positive, and its price is higher than when it cannot.

The laboratory results confirm the theory's mains predictions. When the asset can be used a collateral, its price increases. This increase is significant, and quantitatively close to what theory predicts. That is, subjects are willing to pay more when the asset can be used as collateral despite payoffs in all states of world are the same. Moreover, as theory suggests, leverage allows gains from trade to be realized in the laboratory. When leverage is possible, agents who value the asset the most end up holding more of it.

However, important deviations from the theory arise in the laboratory. First, the demand for the asset shifts when it can be used as a collateral, even though agents do not exhaust their purchasing power when collateralized borrowing is not allowed. That is, at the aggregate level, collateralized borrowing create a sort of "money illusion." Allowing agents to buy on margin shifts their demand for the asset even when they do not spend all their cash holding when buying on margin is not allowed. This suggests that leverage creates some sort of "price illusion:" subjects do not fully internalize that when buying on margin, not only the cash they put down is lower, but the future net payoff from the asset goes down, as the loan on the asset needs to be repaid. Second, Flight to Collateral does not arise in the laboratory. In the paper, we show that this stems from the behavior of the empirical supply function.

Section 1 develops the theoretical model. Section 2 describes the experiment design and the experimental procedures. Section 3 presents the results. Section 4 concludes.

1 Theory

1.1 The Model

We develop a model of leverage and asset prices that is amenable to laboratory implementation. The model retains the main features of the standard models in the literature (Geanakoplos 1997 and 2003, and Fostel and Geanakoplos 2008): market incompleteness and agent heterogeneity. As in these earlier models, a spread between collateralizable and non-collateralized asset prices arises in equilibrium, and there is flight to collateral when bad news are more likely. Our model is novel because it contains three features that make it implementable in the laboratory, and which are not present together in the previous literature: there are only two types (as opposed to a continuum) of agents, agents are risk neutral, and there is no consumption at time 0.

1.1.1 Time and Assets

We consider a two-period economy, with time $t = 0, 1$. At time 1, there are two states of the nature, $s = High$ and $s = Low$, which occur with probability q and $1 - q$ respectively. In the economy, there is a continuum of risk-neutral agents, of two different types indexed by $i = O, P$, which we will characterize later.

There are two assets in the economy, cash and a risky asset Y (from now on "the asset") with payoff in units of cash. The payoff of the risky asset is described in Figure 1. In state Low, the risky asset pays D_{Low}, which is the same for all agents' types, whereas in state $High$ it pays D^i_{High}, which differs across types. Nevertheless, for both type i, it is always true that $D_{Low} < D^i_{High}$, that is, the payoff in the high state of the world is always higher than the payoff in the low state of the world.

1.1.2 Agents

At $t = 0$, agents of type i have an endowment of m^i units of cash and of a^i units of the asset. Agents' payoff in each state $s = High, Low$ is given by a linear payoff function:

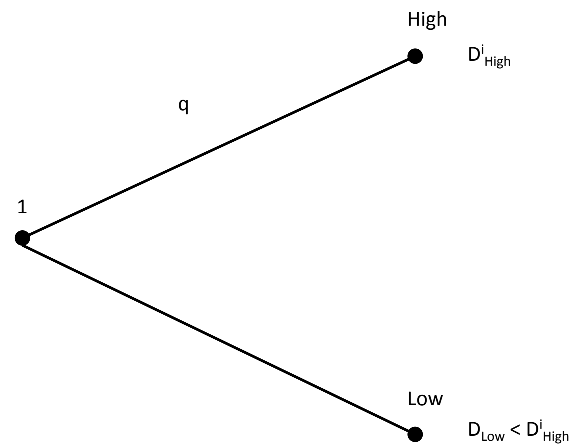

Figure 1: Asset Payoffs.

$$u^i_s(\bullet) = w + D^i_s y - \varphi. \tag{1}$$

In equation (1), w denotes final cash holdings, y refers to final asset holdings, $D^i_s y$ represents the asset payoffs in state s, and φ is debt repayment.[3] The expected payoff to agent of type i is given by

$$U^i = qu^i_{High} + (1-q)u^i_{Low}. \tag{2}$$

As we mention above, in this model, agents are heterogeneous as they disagree on what the asset pays in the high state. Following Fostel and Geanakoplos (2008), we consider two types of agents: Optimists and Pessimists, denoted by $i = O, P$. Each type of agent has mass 1. Optimists believe that the asset pays more in state $High$ than Pessimists do, that, is $D^O_{High} > D^P_{High}$. The difference in payoff may be interpreted as Optimists and Pessimists owning different technologies that affect the

[3] We introduce the debt repayment φ in the payoff function to mimic the way payoffs are explained to the subjects in the laboratory. One could re-write the model having φ in the budget constraint, and having only final cash holdings net of repayment in the payoff function.

asset's productivity. For instance, the asset could be interpreted as equity, where Optimists and Pessimists are entrepreneurs with different abilities. In Fostel and Geanakoplos (2008) heterogeneity is modeled as differences in subjective probabilities over the states of the world. In contrast, here, in order to make the experiment easier to implement in the laboratory, heterogeneity is modeled as differences in the asset payoff in the high state of the world.[4] What is really crucial for our results is to have some sort of heterogeneity.[5]

The purpose of this paper is to study the asset pricing implications of collateralized borrowing, in a laboratory financial market. In order to do so, we study two different economies: first, the No-Leverage economy–from now on the NL-economy–where agents cannot borrow. Second, the Leverage economy–from now on the L-economy–where agents are allowed to borrow using the asset as a collateral.

We will now present the theoretical models of the NL and L-economy that we bring to the laboratory.

1.1.3 The NL-Economy

In the NL-economy agents cannot borrow, and therefore $\varphi = 0$. Taking as given the asset price, agents choose asset holdings y and cash holdings w in order to maximize the payoff function (2) subject to their budget constraint:

$$w + py \leq m^i + pa^i. \tag{3}$$

An equilibrium in the NL-economy is given by asset price p, cash holdings w, and asset holdings y such that asset market clears and that agents maximize their payoff function (2) subject to the budget constraint (3).

[4]This is similar to how gains from trade arise in the double auction literature, see, e.g., Smith (1962), Plott and Sunder (1982), and subsequent papers.

[5]Obviously, our model could be re-written as a model with heterogeneous priors and three states of nature, where the assets pays D_{Low}, D^P_{High}, and D^0_{High}. Optimists would give probability q to the state paying D^O_{High} and 0 to the state paying D^P_{High}, whereas Pessimists would do the opposite.

1.1.4 The L-Economy

In the L-economy agents can borrow from a bank using the asset Y as collateral.[6] Agents cannot borrow unless they post the asset as collateral. We assume that the maximum amount agents can borrow per unit of the asset is D_{Low}, that is, the asset payoff in the low state. In other words, the minimum downpayment to purchase one unit of the asset is $p - D_{Low}$. This condition guarantees that there can never be default in equilibrium, as the loan is equal to the asset payoff in state Low. This borrowing constraint is sometimes referred to as *Value at Risk* equal to zero ($VaR = 0$), and it is widely used in the literature (see, e.g., Fostel and Geanakoplos, 2008).

Agents take the asset price p as given and choose asset holdings y, cash holdings w, and borrowing φ in order to maximize (2) subject to the borrowing constraint (4) and budget constraint (5):

$$\varphi \leq D_{Low} y, \tag{4}$$

$$w + py \leq m^i + pa^i + \varphi. \tag{5}$$

An equilibrium in the L-economy is given by asset price p, cash holdings w, asset holdings y, and borrowing φ at $t = 0$ such that the asset market clears and that agents maximize their payoff function (2) subject to constraints (4) and (5).

The degree of leverage at the security level is measured by the Loan-to-Value ratio, defined as:

$$LTV = \frac{\varphi}{py}, \tag{6}$$

which measures how much an agent can borrow using one unit of asset as collateral as a proportion of the asset price. The Loan-to-Value ratio measures how effective the asset is as collateral, that is, as a liquidity provider that allows agents to borrow. We will show in the remainder of the section that this role as collateral has profound asset prices implications. In particular, the price of the asset will be higher in the L-economy than in the NL-economy.

[6] Since we are not modeling the credit market, we will assume that the interest rate set by the bank is zero. That is, the amount borrowed at time 0, φ, is also the amount to be repaid at time 1.

1.2 Equilibrium Analysis

1.2.1 Parameter Choice: The Bullish Market

In order to study the asset pricing implications of collateralized borrowing, we calculate the equilibria in both the L and NL-economy. Note that even for this simple model of collateral economy, one cannot solve for the equilibrium price and quantities analytically. For this reason, we solved the model numerically for the set of parameters presented in Table 1. These parameter values were chosen so that the economy is amenable to laboratory implementation. We further discuss this choice in Section 1.3.1 below.

Table 1: Parameter Values in the Bullish Market

$Parameters$	$Values$
D_{Low}	100
D^O_{High}	750
D^P_{High}	250
q	0.6
m^O	$15,000$
m^P	0
a^O	0
a^P	100

Under this parametrization, the asset's payoff in the low state is $D_{Low} = 100$; in the high state is $D^O_{High} = 750$ for the Optimists and $D^P_{High} = 250$ for the Pessimists. The probability of the state of the world being High is $q = 0.6$. Optimists have initial cash endowments $m^O = 15,000$, whereas pessimists have no cash. In contrast, Pessimists have initial asset endowments, $a^O = 100$, whereas Optimists have no asset endowment. Note that since Optimists have all the cash endowment and Pessimists have all the asset endowment, Optimists are on the demand side of the market, and Pessimists on the supply side.[7] In the remainder of the paper, we will refer to this combination of parameters as the *Bullish market*,[8] since under this parametrization, the High state is more likely than the Low state.

[7]Dividing subjects into sellers and buyers simplifies the laboratory implementation considerably (see, for instance, in the double auction litterature, Smith, 1962).

[8]Note that as a convention, we will use the world "market" to refer to the parametrization (Bullish vs. Bearish) and the word "economy" to refer to whether agents are allowed to leverage on the asset (that is, buy on margin) or not (L and NL-economy).

1.2.2 NL-Economy

The equilibrium values are presented in the left column of Table 2. The equilibrium asset price is 190.

Table 2: The Equilibrium in the Bullish Market

	NL-economy		L-economy	
Price	190		250	
	Spread: 60			
	Optimists	Pessimists	Optimists	Pessimists
y	78.95	21.05	100	0
φ	0	0	10,000	0
w	0	15,000	0	25,000
u_U	59,212	20,262	65,000	25,000
u_D	7,895	17,105	0	25,000

Individual decisions are described in the lower part of the table. In equilibrium, the Optimists use all their cash to buy all the assets they can afford; this happens because their expected value of the asset ($0.4(100) + 0.6(750) = 490$) is higher than the price, and the solution to their optimization problem is a corner solution. As a result, they invest their wealth of $15,000$ in buying all the assets they can afford without borrowing–that is, 78.95 units–at the unit price of 190. As a result, their final cash holdings are zero.

In contrast, the solution to the Pessimists's optimization problem is not a corner solution: at a price of 190 they are indifferent between holding cash and holding the asset (as their expected value, $0.4(100) + 0.6(250)$, equals the price). In equilibrium, they end up with 21.05 units of Y and $15,000$ of cash.[9]

Figure 2 shows the Pessimists' supply schedule, and the Optimists' demand. The supply (gray line) is a step function that becomes horizontal at the Pessimists' expected value (190). The demand (black line) is a decreasing function of the price, determined by the Optimists' budget constraints.[10] Demand intersects supply at the

[9]In the experiment, we will not assume that the asset is perfectly divisible, hence we will use as a theoretical benchmark the closest integer approximation.

[10]The demand drops to zero when the price reaches the Optimists' expected value (490). In our parametrization, this region of the demand curve, however, is irrelevant for the determination of equilibrium price and quantities.

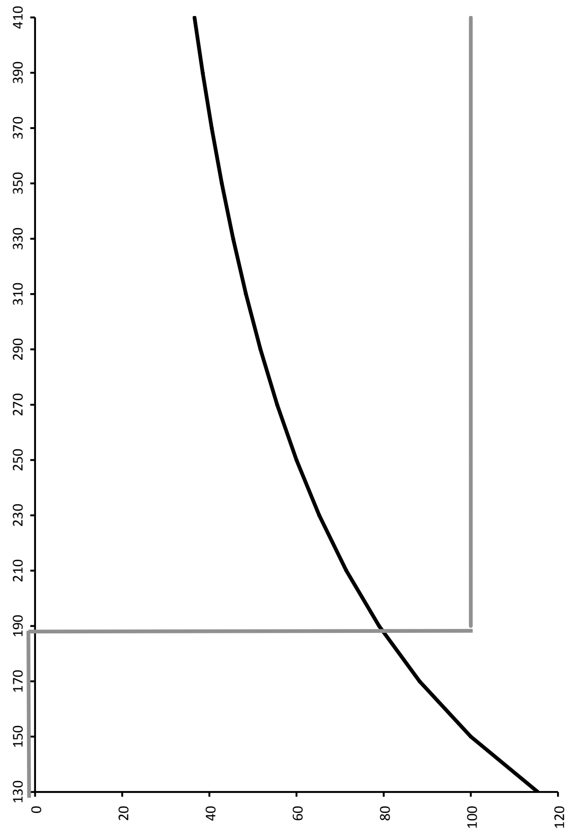

Figure 2: Supply (grey) and Demand (black) in the Bullish NL-economy.

horizontal segment of the supply schedule. As a result, in equilibrium, Pessimists' expected value determines the price, whereas Optimists' budget constraint pins down the quantity traded.

In equilibrium, assets change hands from Pessimists (who value them less) to Optimists (who value them more), thereby realizing gains from trade in the economy. However, due to the Optimists' inability to borrow, gains from trade are not fully exploited. Indeed, in equilibrium Pessimists hold a strictly positive quantity of the asset and share it with Optimists.

Finally, the payoff resulting from the equilibrium allocation are $59,212$ in state High and $7,895$ in state Low for Optimists; $20,262$ in state High and $17,105$ in state Low for Pessimists.

1.2.3 L-economy

The equilibrium values are presented in the right column of Table 2. In equilibrium, the asset price is 250.

Individual decisions are described in the lower part of the table. Since Optimists' expected value (490) is greater than the equilibrium price, they buy as many units of the risky asset as they can afford (100 units) on margin. That is, for each unit of the asset that they purchase, they borrow the maximum amount allowed, 100 per unit of the asset, and pay a downpayment of 150 to cover the unit price of 250. Hence, Optimists borrow $10,000$ using the assets as collateral and use their initial wealth to cover the total downpayment, i.e., $100(250 - 100) = 15,000$. They do not save any of their initial cash endowment and leverage to the maximum extent. As a result, the equilibrium asset loan-to-value is $LTV = \frac{\phi}{py} = \frac{10{,}000}{250(100)} = 0.4$. Borrowing allows the Optimists to hold all the assets in equilibrium.

The solution to Pessimists' optimization problem is also a corner solution, since their expected value of the asset (190) is now lower than the price. As a result, they sell all their endowment of the risky asset at a price of 250 and receive $100(250) = 25,000$ in cash.

In this equilibrium, unlike in the previous one, Optimists determine the price through their budget and borrowing constraints. This happens because collateralized borrowing reduces the downpayment to be paid at time 0, from p to $p - \varphi$, thereby shifting demand upward with respect the NL-economy. The supply side of the market is not affected by the change in credit conditions since in this economy the supply of credit is exogenous and perfectly elastic. As a result, as Figure 3 shows, demand (black line) now intersects supply (gray line) on the vertical segment of the supply curve and, in equilibrium, the price is solely demand determined.

Note that unlike in the NL-economy, gains from trade are fully realized in equilibrium: all the assets change hands from the Pessimists to the Optimists. In equilibrium the payoff are $65,000$ in state High and 0 in state Low for Optimists; $25,000$ in both states for Pessimists.

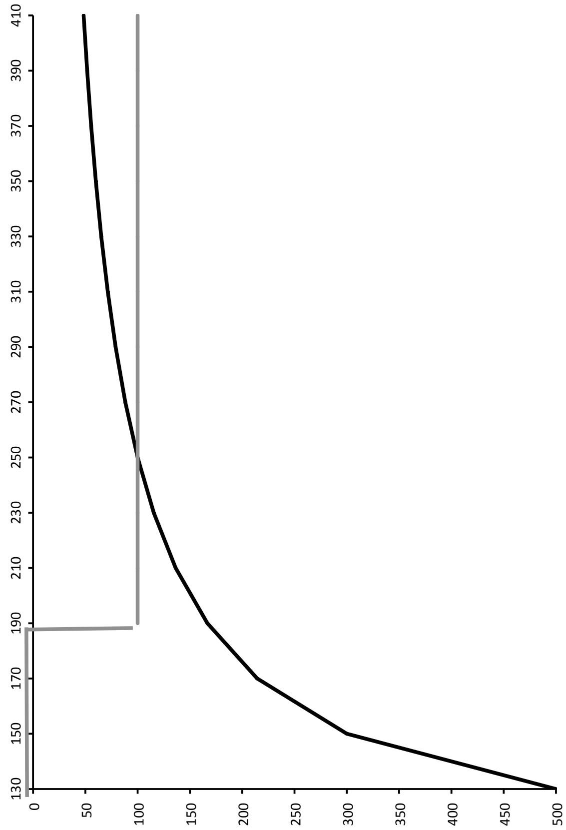

Figure 3: Supply (grey) and Demand (black) in the Bullish L-economy.

1.3 Leverage and Asset Prices

1.3.1 The Spread in Prices

The important feature of our model is that the equilibrium price is higher in the L-economy than in the NL-economy. As we have seen in Sections 1.2.2 and 1.2.3, $p_L = 250 > p_{NL} = 190$, generating a spread of $s = 60$. That is, two assets with identical payoffs (i.e., the risky asset in the L-economy and the risky asset in the NL-economy) have different prices in equilibrium. How does this happen?

In the economy without leverage, even if the Optimists value the asset more than the Pessimists do, they cannot afford to buy all the existing supply; as a result, part of the asset supply ends up in the hands of the less enthusiastic investors (the

Pessimists), lowering its price in equilibrium. In contrast when leverage is possible, Optimists can afford to buy the whole asset supply. The asset price is determined only by the Optimists' combined purchasing power (i.e., by their budget and borrowing constraints). Since the asset price does not reflect Pessimists' expectations, it will be higher.

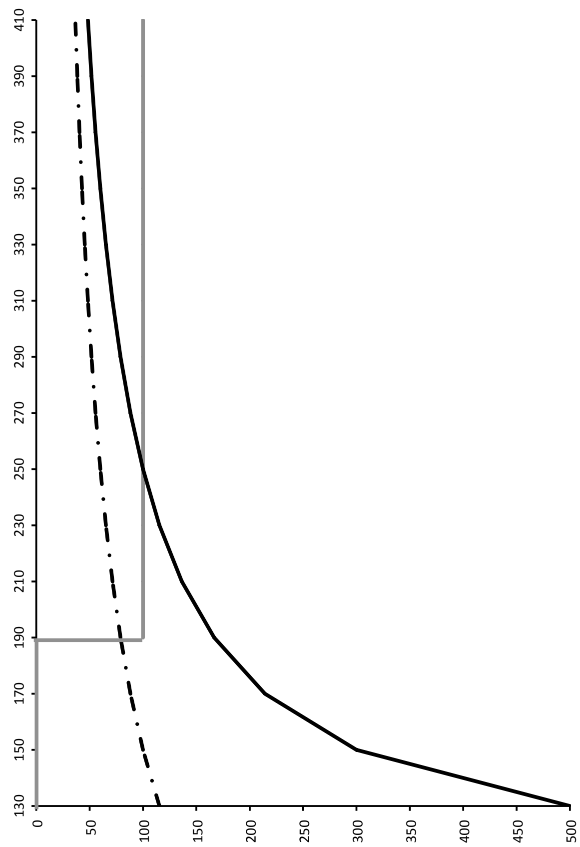

Figure 4: Supply (grey) and Demand (NL-economy: dotted black; L-economy: solid black) in the Bullish Market.

The effect of leverage on the equilibrium price can be seen in Figure 4, which combines Figures 2 and 3, that is, the supply and demand in the L and NL-economy. The gray line is the supply function, which, as we already mentioned, is the same for both economies. The ability to borrow against the asset, however, does affect the demand: the demand in the L-economy (black line) is always higher than in the $NL-$economy (black dotted line). As mentioned before, the downpayment is reduced by the amount borrowed per unit of asset. This can be seen from equations (3), (4) and (5). In both L and NL economies, Optimists chose zero cash holdings provided that the price is less than 490 (their expected value); from their budget constraint (equation 3), we have that the demand in the NL-economy is given by

$$p = \frac{m^i}{y}, \tag{7}$$

whereas from equations (4) and (5) the demand in the L-economy is given by

$$(p - D_{Low}) = \frac{m^i}{y}, \tag{8}$$

hence explaining the shift in demand.

Note that the wedge between demands is the only factor generating the spread between prices in the two economies. Because of this gap, demand intersects supply in two different segments of the supply function. In the $NL-$economy, the intersection occurs when supply is flat, and as a result Optimists and Pessimists share the asset, and Pessimists' expecations determine its price. In the $L-$economy, the curves intersect when supply is vertical at 100; as a result, only Optimists hold the assets and their constraints determine the price.[11]

Notice, that the effect of collateralized borrowing is different from the effect of an increase in the cash endowment m^i. This is so because the loan repayment affects the actual asset payoffs in the final period. That is, because of buying on margin, the net asset payoff is $D^i_{High} - D_{Low}$ in state High and 0 in state Low. To put it differently, Optimists when buying one unit of asset on margin are effectively buying the Arrow security that pays 1 in the High state.

When is the spread positive across the L and NL-economy? When the set of agents determining the price is different across economies. As explained before, in the NL-economy the Pessimists determine the price, whereas in the L-economy the price is determined by the Optimists. A spread would not have been generated in equilibrium if the set of agents determining the price in the two economies were the same. This can happen under two circumstances: i) when Optimists have a large cash endowment m^0 so that they afford to buy all the assets even in the NL-economy, and ii) if the borrowing constraint is very tight (i.e., D_{Low}, which is the maximum agents

[11] In the $NL-$economy the price needs to be equal to Pessimists' expected value for them to be willing to hold (some units of) it; in the $L-$economy, the price needs to be greater than Pessimists' valuation for them to be willing to sell (all of) it.

can borrow, is small), so that even if the Optimists borrow as much as they can, they are still not able to afford all the supply of the asset. The choice of parameters described in Table 1 ensures that the set of agents determining the price is different across economies.

1.3.2 Payoff Value and Collateral Value

How can we interpret the spread between the L and the NL-economy? In NL-economy, Pessimists determine the price in equilibrium. Since they are risk neutral, the price equals the asset's expected value according to Pessimists, 190.

In the L-economy, Optimists price the asset. Its price in equilibrium, however, is lower than the Optimists' expected value (490). Why is it so?

In order to explain this result, we apply the pricing formula developed by Fostel and Geanakoplos (2008) to our economy. Fostel and Geanakoplos (2008) first showed that in an economy with collateralized borrowing, assets have a dual role: they are not only investment opportunities (i.e., they give a right to a future cash flow), but also allow investors to borrow money (i.e., they provide a technology to transfer wealth across time). That is, their price can be decomposed into two parts: the Payoff Value, which reflects the asset future cash flow, and the Collateral Value, which reflects the premium agents are willing to pay to hold an asset that can be used as a collateral.

Let us first define the Payoff Value. As we saw, Optimists use all their cash to buy the asset on margin, thereby synthetically creating a new asset, the Arrow security that pays 1 in the state High. As a result, the marginal payoff of a unit of cash today is given by the return of the Arrow security Up $(0.6(750-100))$ divided by the downpayment $(250-100)$. Denote by η_O, the marginal payoff to an Optimist of a unit of cash at time 0. Then $\eta_O = \frac{0.6(750-100)}{250-100} = 2.6$, which is greater than one. Hence, the appropriate discount factor for the cash flow at time 1 for the Optimist is not 1, but $\frac{1}{\eta_O} = 0.38$. The asset's Payoff Value for an Optimist is therefore given by

$$PV = \frac{E_O(Y)}{\eta_O} = \frac{490}{2.6} = 188.5. \tag{9}$$

The second role of the asset is that of a provider of liquidity, which defines the asset's Collateral Value. For each asset, an Optimist can borrow 100 units of cash.

As we saw before, Optimists invest cash in the Arrow Security Up, whose expected return is $(\frac{0.6(750-100)}{(250-100)} - 1) = \eta_O - 1 = 1.6$. The resulting expected cash flow (100(1.6)) is to be discounted as before by $\frac{1}{\eta_O} = 0.38$. Hence, the asset's Collateral Value for an Optimist is given by

$$CV = \frac{100 * \eta_O - 1}{\eta_O} = \frac{100 * 1.6}{2.6} = 61.5. \tag{10}$$

Hence the price of the asset in the L-economy is given by

$$p = PV + CV = 188.5 + 61.6 = 250, \tag{11}$$

which equals the asset's price in equilibrium (see Table 1). Note that the Payoff Value in the L-economy is lower than that in the NL-economyfootnoteSince Pessimists are not constrained, their marginal payoff of money is one, $\eta_P = 1$. Hence, the Payoff Value coincides with the Pessimists' expected value, 190. Nevertheless, because of presence of the Collateral Value, there is a positive spread between the two economies.

Finally, in our model, two assets with the same payoffs in all states of the world have different prices. We can interpret this as a deviation from the Law of One Price. Note, however, that in our model, we do not have two assets with the same payoffs and different prices in equilibrium in the *same* economy (as the Law of One Price is defined). Nevertheless, the L and the NL-economy only differ because in one the asset can be used as collateral, whereas in the other it cannot. Indeed, in the Appendix, we show how a deviation from the Law of One Price would arise in a two-asset economy with the same parameter values as in the Bullish market where the two assets have different collateral capacity. In the laboratory, we implemented the NL and L-economy sequentially, as opposed to the two-asset economy, because doing otherwise would have been experimentally very difficult.[12]

1.4 The Bearish Market

In this section, we consider a parametrization identical to the Bullish market, except that q is lowered to 0.4. We refer to this as the *Bearish Market*, as the probability of

[12] As we describe in the Procedures (Section 2) and in the Instructions (see Addendum available on request), the game implemented in the laboratory is already very complicated, especially the explanation of how buying on margin works. An extension to a two-asset case, in which only one asset can be bought on margin, would have been extremely difficult to explain to the subjects.

state High is now lower than that of state Low.

Table 3 shows the equilibrium outcomes when $q = 0.4$ for both the NL and $L-$economy.

Table 3: The Equilibrium in the Bearish Market

	NL-economy		L-economy	
Price	160		250	
	Spread: 90			
	Optimists	Pessimists	Optimists	Pessimists
y	93.75	6.25	100	0
φ	0	0	10,000	0
w	0	15,000	0	25,000
u_U	70,312	16,562	65,000	25,000
u_D	9,375	15,625	0	25,000

Note that the equilibrium price of the NL-economy drops from 190 in the Bullish market to 160 in the Bearish market. In contrast, in the $L-$economy, the equilibrium price stays put at 250. As a result, the spread between NL and L-economy increases to 90 from 60 in the Bullish market. The increase in spread after bad news is what Fostel and Geanakoplos (2008) interpreted as *Flight to Collateral:* during a crisis, assets that can be used as a collateral become relatively more valuable.

In the Bearish market, the equilibrium regime is the same as the one described before: that is, in the NL-economy the price is determined by Pessimists, whereas in the $L-$economy it is determined by the Optimists. The supply and demand curves for both the L and NL-economies are showed in Figure 5. In both L and NL-economies, the Optimists' demand function does not shift with respect to the Bullish Market, as their behavior is determined by their budget and borrowing constraints and is not affected by the decrease in probability of the high state of the world.[13] In contrast, the Pessimists' supply function shifts downward, as their expected value of the asset decreases. Because of this downshift in supply, the price in the NL-economy decreases.

[13]Strictly speaking, this is true only for the region of prices below the Optimists' new expected value (360), which, however, is the relevant region for price determination given the Pessimists' supply function.

The question is why the downward shift in price does not occur in the L-economy. In the L-economy the price is only determined by the Optimists, for demand intersects the vertical segment of the supply schedule. Since demand does not change as q changes, the price does not change either. Because the decrease in q lowers the price only in the NL economy, the spread between the L and NL-case increases when we move from the Bullish to the Bearish Market.

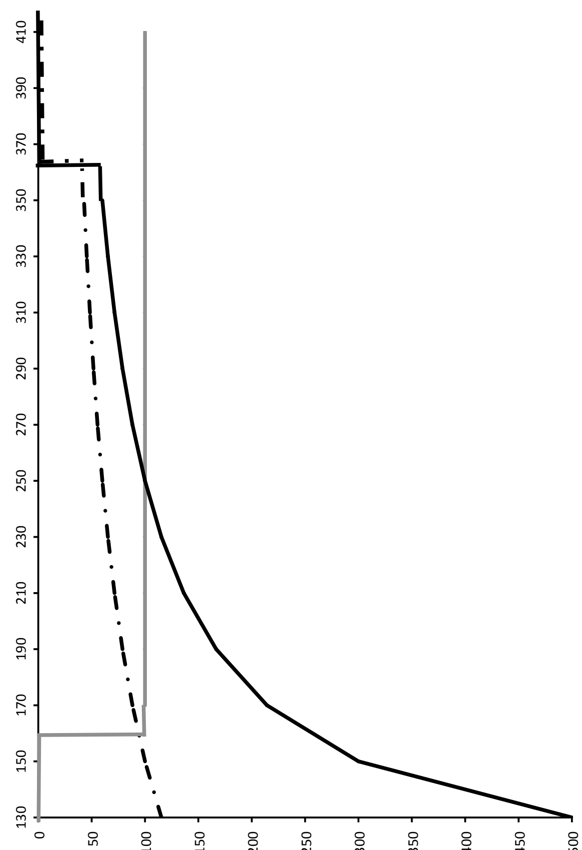

Figure 5: Supply (grey) and Demand (NL: dotted black; L: solid black) in the Bearish Economy.

2 The Experiment

2.1 The Experiment Design

The experiment was run at the Interdisciplinary Center for Economic Science, ICES, at George Mason University. We recruited subjects in all disciplines at George Mason University using the ICES online recruiting system. When the number of students willing to participate was larger than the number needed, we chose the subjects randomly in order to reduce the chance that the students in the experiment knew each other. Subjects had no previous experience with the experiment. The experiment was programmed and conducted with the software z-Tree[14].

The experiment consisted of five sessions. Twelve students participated in each session for a total of 60 students. Each session consisted of four treatments, corresponding to the four economies described in Section 1:

1. The Bullish Market in the Non-Leverage Economy: the *Bull-NL Treatment*.
2. The Bullish Market in the Leverage Economy: the *Bull-L Treatment*.
3. The Bearish Market in the Non-Leverage Economy: the *Bear-NL Treatment*.
4. The Bearish Market in the Leverage: *Bear-L Treatment*.

Note that in each session the same group of students played all the four treatments, thus allowing us to study the difference in behavior across treatments with one-sample statistical techniques.

For each of the five sessions, we ran the experiment over two days. In Sessions 1, 2 and 3, we ran $Bull - NL$ and $Bear - NL$ the first day, and $Bull - L$ and $Bear - L$ the second day. In Sessions 4 and 5, we ran $Bear - L$ and $Bull - L$ in the first day, and $Bear - NL$ and $Bull - NL$ in the second day. Therefore, in Sessions 4 and 5 we inverted both the ordering of $Bull$ vs. $Bear$ and of NL vs. L, thus allowing us to control for order effects in the data.

In each treatment of each session, we ran fifteen rounds of the same economy. The first four rounds of each treatment (both in treatments played in day one and those

[14]See Fischbacher (2007).

played in day two) were used for practice and did not determine students' payments. The experiment lasted on average 2.5 hours each day. Students were paid at the end of the second day. They received on average \$40, including a \$10 show-up fee paid at the end of the first day.

2.2 The Procedures

We first describe the procedures for the $Bull - NL$ treatment in those sessions (1 to 3) when the NL treatment is played first. Later we will describe the procedures for the other treatments and sessions.

1. At the beginning of the experiment, we gave written instructions to all subjects.[15] We read the instructions aloud in order to make the structure of the experiment common knowledge. Then, we gave the subjects time to ask questions, which were answered in private by the experimenters.

2. All payoffs were denominated in an experimental currency called $E\$$. The risky asset was referred to as a "widget." Optimists and Pessimists were referred to as Buyers and Sellers. This was done because, in our economy, Optimists hold all the cash (and have to decide how much to buy) and Pessimists all the assets (and have to decide how much to sell); the terms Buyers and Sellers were easier for subjects to understand as they characterized what their role was in the experiment.[16] Nevertheless, in the remainder of the paper, when describing the empirical results, we will continue use the terminology of the theoretical model (i.e., Optimists and Pessimists).

3. At the beginning of the round, each subject was randomly assigned to be either an Optimist or a Pessimist. In every round, there were six Optimists and six Pessimists. Subjects could see their role in the left corner of their computer (see screen shot in the Addendum, available on request). Subjects had the same role in any given round of all the four treatments they played: that is, if a subject was a Pessimist in the first round of the $Bull - NL$ treatment and an Optimist in the second round, he was also a Pessimist and Optimist in the first and second round of the other three treatments. We did so in order to increase the statistical power of our tests (see footnote 23).

[15] The Instructions are included in an Addendum available on request.

[16] Moreover, we wanted to avoid using the terms "Optimist" and "Pessimist" so as not to bias their behavior.

4. Next, the demand by Optimists and the supply by Pessimists were elicited by presenting them with a list of ten prices and asking them how many units of the asset they wanted to buy (Optimists) or sell (Pessimists) at each price.[17] For each of the 10 prices, Optimists were informed of the maximum number of assets that they could afford to buy. The computer mechanically enforced (weakly) upward sloping supply, and downward sloping demand. That is, if an Optimist demanded x^1 at a price p^1, he was only allowed to demand $x^2 \leq x^1$ at a price $p^2 > p^1$.[18]

5. The list of ten prices was taken from a pre-determined matrix and varied from round to round. Note that the matrix was the same (for each round) across sessions and treatments (i.e., we used the same matrix in the same round of each session and each treatment). We let prices vary slightly from round to round in order to avoid habituation.

6. After all the subjects had made their choices, the computer calculated the price at which trading occurred. The price was determined by minimizing the excess supply over the ten prices for which we elicited subjects' choices. Subjects then learned about the price from the computer screen and the trades were automatically realized. If excess supply was positive (negative) at the equilibrium price, supply (demand) was proportionally reduced for all Optimists (Pessimists).

7. After trading occurred, the state of the world was realized. In front of all the subjects, an experimenter extracted a ball from an urn with 6 red balls and 4 green balls. If the ball extracted was red (green), the state of the world was High (Low). The outcome of the extraction was shown to all subjects.

8. After the state of the world was realized, subjects could see in the computer screen their final per-round payoff. In order to avoid zero-payoff, a $E\$10,000$ bonus was paid to each subject at the end of each round in addition to their payoff.

[17] See screenshot in an Addendum available on request.

[18] Since the payoff is defined in terms of final cash only, no rational agent would chose an inverted demand or supply function. Moreover, without the above choice restriction in the experiment, mistakes by even a small number of subjects could have created inversions in some segments of demand or supply. As a result, there could have been multiple prices, far away from each other, for which the distance between demand and supply is low. Given our price-selection rule, this would have generated large changes in the equilibrium price for small changes in subjects' choices, thus making the equilibrium price less meaningful.

9. After round 1 ended, a new round started. The session continued until all 15 rounds were played. Each round was independent from the previous one: subjects were not allowed to carry over endowments of cash or assets from one round to the next.

After the 15 rounds were played, students were given the instructions for the $Bear-NL$ treatment, which was played right after. We followed the same procedure described in points 1 to 9. In the $Bear-NL$ treatment, we told subjects that the urn had 4 red balls and 6 green balls (so that the probability of the High state of the world was 40 percent).

The same group of students were gathered the following day to play the two L-economy treatments (i.e., the $Bull-L$ treatment and the $Bear-L$ treatment), following the same procedures outlined in points 1 to 9. In the Instructions, subjects were explained in detail how borrowing worked: the maximum amount of borrowing allowed, its effect on subjects' budget constraint and the impact of loan repayment on their final payoff. During the experiment, the Optimists' screenshots indicated how much they needed to borrow to afford a given number of assets at a given price.[19] Finally, after trading decisions were made, the screenshots indicated how much Optimists had borrowed and had to repay at the trading price determined by the computer.

Note that Optimists were not allowed to borrow in order to keep a positive cash balance (i.e., if the price was 300, they would borrow only if they wanted to buy more than $15,000/300 = 50$ assets). This allowed us to simplify the choice problem facing the Optimists, that is, for each price they only had to chose one variable, the number of assets they wanted to buy, which in turns determined the amount of borrowing. The constraint would only bias Optimists' behavior only if they valued warehousing cash per se (i.e., if they were willing to borrow in order to keep a positive cash balance). Such a bias would reduce the amount borrowed in the laboratory, making the behavior in the L-treatment closer to that in the NL-treatment. Obviously, the presence of this bias would be a departure from rationality, since with a zero interest rate, subjects should be indifferent between warehousing cash and not. We believe that such a bias was likely to be small, both because

[19]For each price, Optimists were told how many assets they could afford if: a) they did not want to borrow, b) if they wanted to borrow the maximum of 100 per asset, c) if they wanted to borrow only 30 per asset, and d) if they wanted to borrow only 60 per asset. In the Instructions, Optimists were told that this information was for reference only, and that they were not restricted to borrow the quantities indicated in the screen.

the cash warehoused would be repaid immediately at the end of the round, and because in a collateralized borrowing economy, the only way subjects could borrow was by buying assets anyway. And indeed, as we will comment in the following section, Optimists' demand shift significantly from the NL to the L-treatment. Given the complexity of the experiment, we thought that enforcing such a small level of rationality in order to dramatically reduce the subjects' choice set was worthwhile.

After the end of the second treatment of the second day of the experiment, five rounds were extracted out of the last 11 rounds of each treatment (the first four rounds were for practice only). Payoffs were summed up and converted into US$ at the rate of $E\$20,000$ per US$. Identical procedures were followed in Sessions 4 and 5, with the exception that the sequence in which the treatments were played was altered.

Notice that our procedure to determine the equilibrium price is different from that of a double auction or of a call auction since we elicited the whole demand and supply schedule for each subject and in each round, with a methodology reminiscent of the "strategy method." We did so because eliciting the whole demand and supply schedules is crucial for our understanding of the mechanism generating a spread between the equilibrium prices in the L and the NL-treatment. Additionally, if we had chosen to run a double auction, we would have had to implement a multiple-unit double auction as opposed to a standard one.[20] Doing so, would have been very difficult in our economy. In particular, in the L-treatment, the departure from the multiple unit-double auction would have been severe, as subjects would have had to choose prices, quantities and borrowing per asset at the same time.

In the remainder of the paper we will confront the equilibrium price and quantities of the theoretical model with those that arise in the laboratory. Note that having a finite number of subjects does not modify the equilibrium, as long as they behave as price takers, which is a reasonable assumption given the large number of subjects in each session of the experiment.

[20] This is the case since subjects could not have traded 100 units of the asset in a reasonable amount of time. Note that the reason why we parametrized the model with large cash and asset endowments is to generate differences in behavior across treatments that are detectable in the laboratory. For instance, with our parameter values, if subjects had only 10 units of the asset and $1,500$ in cash, optimists equilibrium holding in the L and NL-economies would have been 9 and 10 units respectively. As a result, even small amount of noise would have masked the effect of leverage in the laboratory.

3 Results

3.1 The Bullish Market

We start by analyzing the equilibrium results in the Bullish market, comparing the equilibrium prices in the Leverage (L) and in the Non-Leverage (NL) treatments. Table 4 shows the average equilibrium prices across the five sessions of the experiment and in each session separately.[21]

Table 4: Average Equilibrium Prices in the Bullish Market

	Average	S1	S2	S3	S4	S5
NL	216	213	210	219	210	228
L	254	241	263	260	241	263
Spread	38	28	54	42	32	35

As theory predicts, across and in each session, the average equilibrium price is higher in the L versus the NL-treatment, with an average spread of 38 across sessions. The difference in prices is statistically significant ($p - value = 0.001$),[22] and robust to order effects. Moreover, it is consistent even across rounds of the experiment: as shown in Table 5, out of 55 rounds (11 for each session), the spread between the L and the NL-treatment is zero in only 14, and it is never negative.

Table 5: Per-round Equilibrium Prices across Sessions in the Bullish Market

[21] As we mentioned above, subjects were paid only on their earnings in the last 11 rounds. Therefore, in the analysis, we restrict ourselves to the last 11 rounds of data. The results for all 15 rounds are reported in the Appendix, and are in line with the results reported here.

[22] We regressed the per-round changes in the equilibrium price between L and NL-economy against a constant (remember that, in each round of the two treatments, the same subjects act as Optimists and Pessimists, and face the same price vector). We tested whether the regression constant is significantly different from zero, correcting the standard errors with by-session clustering and obtaining the p-value reported in the main text of the paper. Note that we obtain a similar result if we run a non-parametric sign test on per-round price differences (p-value=0.000).

Round	S1 NL	S1 L	S1 S	S2 NL	S2 L	S2 S	S3 NL	S3 L	S3 S
5	210	240	30	210	300	90	240	300	60
6	220	220	0	200	220	20	200	250	50
7	200	230	30	200	320	120	230	230	0
8	225	255	30	175	255	80	205	225	20
9	195	285	90	195	225	30	225	285	60
10	195	245	50	245	245	0	245	305	60
11	205	235	30	235	295	60	205	235	30
12	240	240	0	240	240	0	210	300	90
13	200	250	50	200	250	50	220	250	30
14	230	230	0	230	290	60	200	230	30
15	225	225	0	175	255	80	225	255	30

Round	S4 NL	S4 L	S4 S	S5 NL	S5 L	S5 S
5	210	240	30	240	300	60
6	200	250	50	220	220	0
7	230	230	0	200	290	90
8	175	255	80	225	225	0
9	195	285	90	225	285	60
10	215	245	30	245	245	0
11	235	235	0	235	235	0
12	240	240	0	240	300	60
13	200	220	20	220	250	30
14	200	230	30	230	290	60
15	205	225	20	225	255	30

Moreover, as predicted by theory, as we move from the NL to L-treatment, the equilibrium level of transactions increases, that is, a larger number of assets is sold by the Pessimists to the Optimists. As Table 6 indicates, the average quantity traded per subject increases from 56 to 69 assets, a difference that is statistically significant and robust to order effects.[23] Therefore, the relaxation of the collateral constraint between NL and L-treatment allows gains from trade to be exploited in the laboratory market to a greater extent.

[23]The p-value is 0.000.

Table 6: Per-Subject Average Transactions in the Bullish Market

	Average	S1	S2	S3	S4	S5
NL	56	57	46	63	64	49
L	69	75	59	70	76	66

Although the experimental results are broadly in line with the theoretical predictions of Section 1, important departures from theory arise:

1. in both NL and L-treatments, the quantities traded per subject (56 in NL and 69 in L) are lower than what theory predicts (78 and 100 respectively);

2. whereas in the L-treatment the average price is very close to its theoretical counterpart, the equilibrium price in the NL-treatment (216) is above the theoretical one (190).

In order to explain these departures, let us first focus on the NL-treatment. Figure 6 shows the theoretical (thick lines) and the empirical (dotted lines) demand (black) and supply (grey) curves in the NL-economy; the empirical curves are averaged across subjects, rounds and sessions. Two observations are in order. First, the empirical demand is to the left of the theoretical one: in particular, the Optimists' demand, although downward sloping, is not determined by the budget constraint as theory predicts. Indeed, as column 1 of Table 7 shows, Optimists' average final cash holdings–which theoretically should be zero–are on average around $E\$3,000$ (out of an initial endowment of $E\$15,000$).

Second, the average empirical supply is a smoother version of the theoretical one. According to the model, Pessimists should sell 0 assets at a price below their expected value ($E\$190$), and sell all their holdings, 100, at a price above its expected value. Instead, in the experiment, Pessimists offer positive quantities for prices below 190 (that is, the empirical supply is to the right of the theoretical one), and supply less than 100 units for prices above 190 (that is, the empirical supply is to the left of the theoretical one). Although supply monotonically increases in the price, it never reaches 100 units.[24]

[24]Note that for a price higher than 250 (Pessimist's value in the High state), supply is very close to 100, which reassures us that Pessimists understood the model. We will discuss more extensively the supply behavior in the next section.

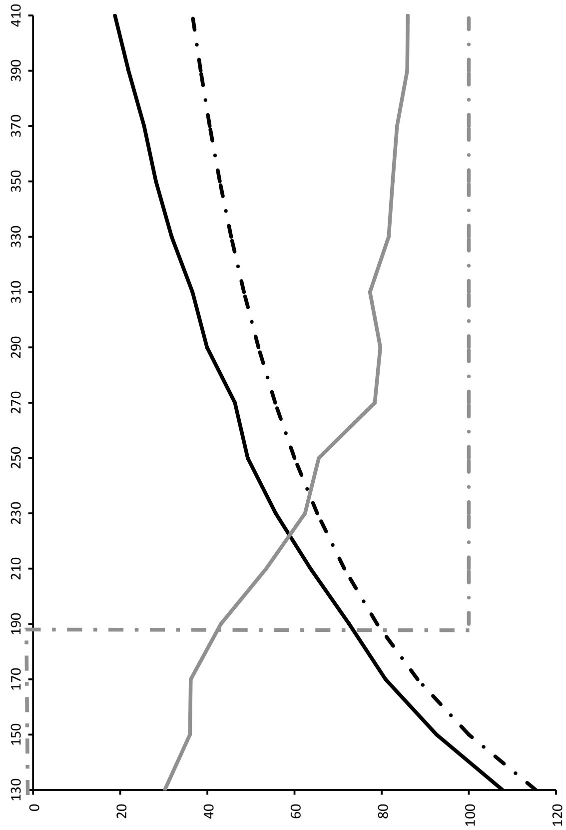

Figure 6: Supply (grey) and Demand (black) in the $Bull - NL$ Treatment. Solid lines are the experimental results; dotted lines the theoretical functions.

Table 7: Optimists' Final Cash Holding and Borrowing in the Bullish Market

	Final Cash	Borrowing per Widget	Aggregate Loan to Value Ratio
NL	$3,065$	-	-
L	$1,555$	45	0.23

Because the empirical supply is a smooth version of the theoretical one, the price is higher than theory predicts, and the quantity traded is lower. The leftward shift in the empirical demand with respect to theory amplifies the effect of the empirical supply on quantities and dampens the effect on prices. Nevertheless, since the departure of supply from the theoretical one is larger than that of the demand, the price in the laboratory is higher than theory predicts.

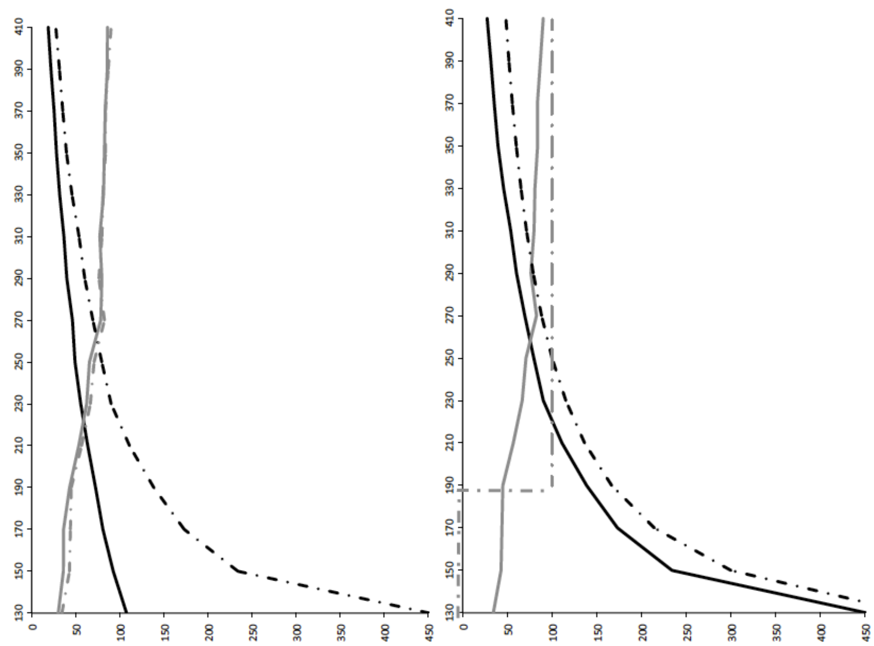

Figure 7: Left: Supply (grey) and Demand (black) in the $Bull - NL$ treatment (Solid lines), and $Bull - L$ treatment (Dotted lines). Right: Supply (grey) and Demand (black) in the $Bull - L$ treatment experimental results (Solid lines), and in the $Bull - L$ model theoretical predictions (dotted lines).

Let us now turn our attention to the L-treatment. The left portion of Figure 7, compares the empirical supply and demand in the L-treatment (solid line) with those of the NL-treatment (dotted line). The right portion instead compares the empirical supply and demand in L-treatment (solid line) with their theoretical counterparts (dotted line).[25]

As the left portion of Figure 7 shows, the empirical supply in the L-treatment overlaps with that in the NL-economy (dotted and solid gray lines overlaps). This is a good check that subjects understood the experiment since the problem that Pessimists face is the same in the two treatments. The empirical demand (solid black line) shifts rightward with respect to that of the NL-treatment (dotted black line), as now subjects are allowed to borrow. This rightward shift is what generates the spread between the prices in the NL and the L-treatments.

[25] That is, in Figure 7, both the left and the right charts show the experimental results for the L-treatment, comparing them with the results in the NL-treatment (left portion), and with the L-treatment theoretical predictions (right portion).

Note however that, as the right portion of Figure 7 shows, the empirical demand is in the L-treatment (solid black line) is still to the left of its theoretical counterpart (dotted black line). That is, subjects do not exhaust all the collateral value of the assets. As the second column of Table 7 shows, each Optimist borrows on average $E\$45$ per unit of the asset he buys, whereas in the theoretical equilibrium they borrow $E\$100$. Nevertheless, because in the region determining the price, the empirical supply is to the left of the theory, the price in the L-treatment is very close to the theoretical one (although the quantity traded is lower).

To summarize the previous discussion, the increase in price due to leverage stems from the fact that Optimists' demand shift to the right when we move from the NL to the L-treatment. This rightward shift in demand is somewhat puzzling. In the NL-treatment, the demand curve was not determined by the Optimists' budget constraint, that is, Optimists were not spending all their cash endowment. One would expect that in such circumstances allowing subjects to borrow should not affect their behavior; instead, we observe the opposite.[26]Two explanations come to mind:

The shift in demand could stem from an aggregation bias. This would be the case if the shift in demand primarily stems from subjects who are at (or close to) the budget constraint in the NL-treatment, and use the leverage technology to buy more assets in the L-treatment. To some extent, this is indeed the case. As figure 8 shows, the Loan to Value in the L-treatment is negatively associated with the Optimists' final cash holdings in the NL-treatment.[27]

The above explanation, however, cannot be the whole story: there are subjects who are far away from the budget constraint in the NL-treatment and still borrow when allowed. One possible interpretation is that some sort of "price illusion" affects their behavior. Subjects do not fully internalize that when buying on margin, not only the cash put down at time 0 is lower (i.e., the downpayment is smaller than the un-leveraged price), but the future net payoff from the asset goes down (as the loan on the asset needs to be repaid). That is, subjects do not realize that when buying on margin, they are effectively buying a different asset, the Arrow security that pays in the high state.

[26]This shift in demand cannot be explained by risk aversion. It is simple to show that under very general conditions on subjects' utility functions, if an Optimist chooses not to use all the available cash in the $NL-$economy, he will also chose not to borrow in the $L-$economy.

[27]The slope of the regression line (in the chart) is negative and significant (p-value 0.01, after correcting for session clusters).

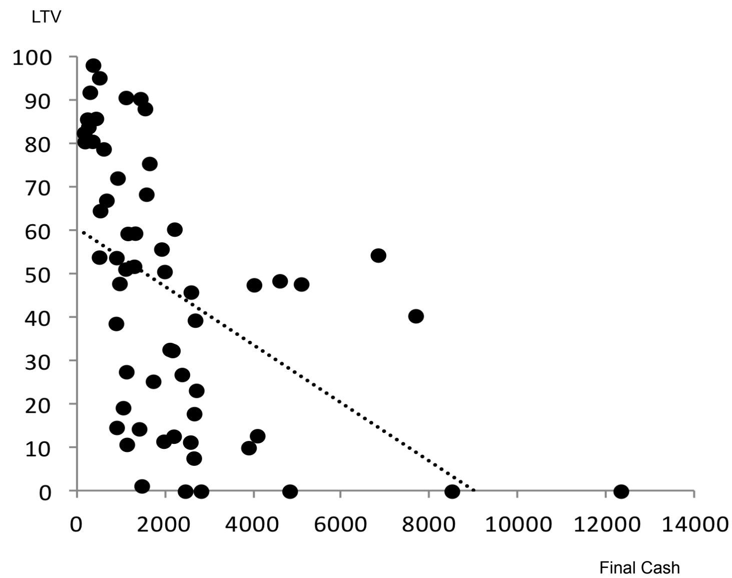

Figure 8: LTV regressed on Final Cash holding in NL-Treatment.

3.2 The Bearish Market

In this section, we analyze the experimental results when we lower the value of q to 0.4 (i.e., in the Bearish Market). Let us recall what the theory predicts should happen by looking at how demand and supply functions move when q goes from 0.6 to 0.4 (as we had showed on Figure 5). In both L and NL-economies, the Optimists' demand function does not shift with respect to the Bullish Market. In contrast, the Pessimists' supply function shifts downward. As we mentioned in the theoretical section of the paper, in the NL-economy because of the downward shift in supply, the price decreases. In the $L-$economy, in contrast, the downward shift in supply leaves equilibrium price unaffected. As a result, the spread between the L and NL economies (i.e., the deviation from the law of one price) increases when we move from the Bullish to the Bearish Market.

Let us now turn our attention to whether the data bear out the theory's predictions. As theory predicts, the empirical supply curve (both in L and in NL-treatments), averaged across rounds and across sessions, shifts rightward, reflecting

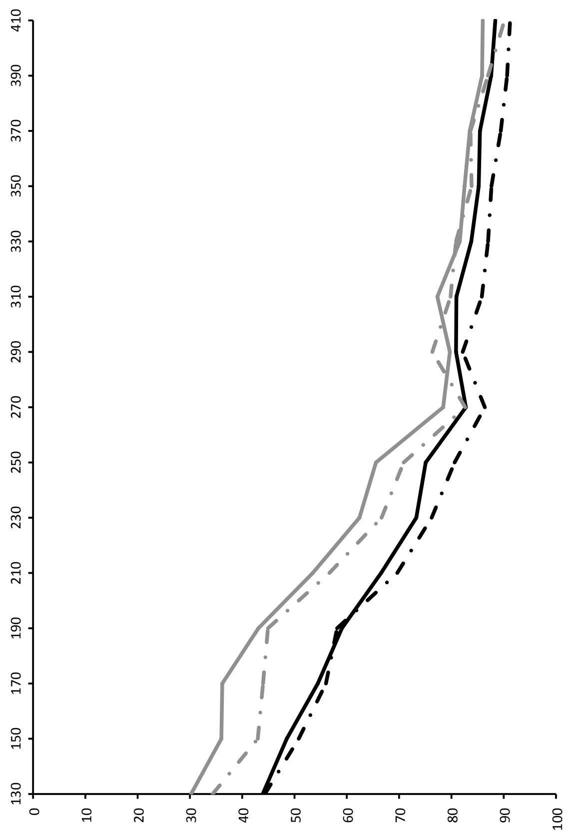

Figure 9: Supply curves in the *Bull* (gray) and *Bear* (black) Treatments. Solid lines are the results in the NL-economies; dotted lines in the L-economies.

the decrease in the asset's expected value (see Figure 9).[28]

In contrast, Optimists' demand does not shift significantly as q changes (i.e., with respect to the Bullish market), in accordance to what theory predicts: i.e., the movement in demand between L and NL-treatment is unaffected by the change in probability (see Figure 10).

Table 8: Average Equilibrium Prices in the Bearish Market Treatments

[28]Moreover, as theory predicts (and as was the case in the Bullish Market), there is no significant difference in the empirical supply curve between the NL and the L-treatment, which is to be expected as subjects face exactly the same decision problem.

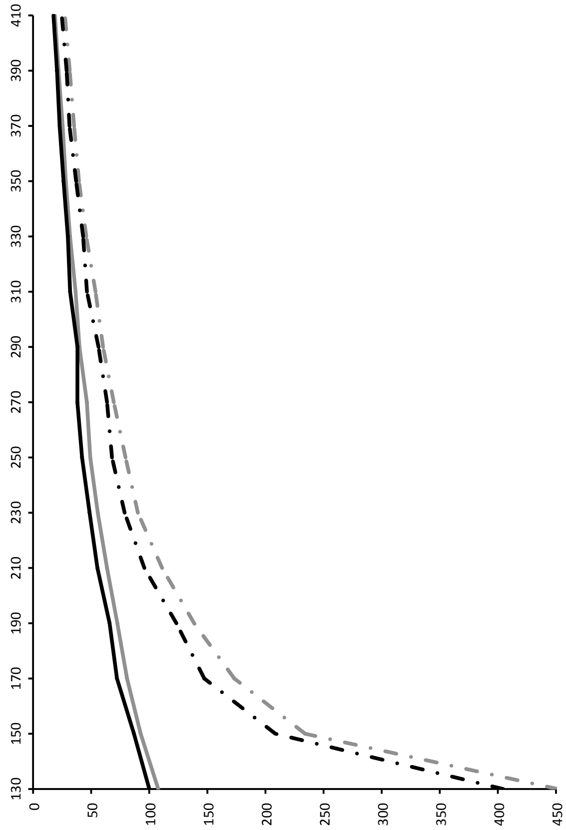

Figure 10: Demand curves in the *Bull* (gray) and *Bear* (black) Treatments. Solid lines are the results in the NL-economies; dotted lines in the L-economies.

	Average	S1	S2	S3	S4	S5
NL	188	182	187	203	195	175
L	230	228	236	230	230	227
Spread	42	46	49	27	35	52

Therefore, as in the Bullish Market, the relaxation of the collateral constraint from NL to L shifts demand upwards, and the price is higher in the L than in the NL-treatment. As Table 8 shows, the average equilibrium price is 188 in NL, and 230 in L. That is, the asset price increases when it can be used as collateral. The difference in prices between L and NL is statistically significant (p-value= 0.00)[29]

[29]See footnote 23 for a description of the test.

and robust to order effects.[30]

Nevertheless, in contrast to what theory predicts, in the L-treatment the price is lower than it was in the Bullish L-treatment– it decreases from 253 to 230. As a result, the spread between NL and L-treatment does not increase when we move from the Bullish to the Bearish treatment, i.e., when q goes from 0.6 to 0.4 (the spread moves from 38 to 42, a statistically insignificant difference).[31]

Why does the spread between NL and L not increase in the Bearish Market treatments? As we mentioned in the theory section, the spread between L and NL increases as we move from Bullish to Bearish because the price in the L-economy does not change with q. This occurs because the supply function is a step function, which crosses demand in its vertical segment; as the function shifts downward, equilibrium prices and quantities are unaffected. In the laboratory, however, the supply function is not a step function: as we commented before, supply increases smoothly as the price goes up. As a result, when we move from Bullish to Bearish, the equilibrium price decreases even in the L-treatment–and the equilibrium quantity increases. This decrease in the price for the L-treatment implies that the behavior of the $L - NL$ spread is not obvious. In fact, at the aggregate level in the laboratory, the spread is constant across Bullish and Bearish Market treatments. That is, we do not observe "*Flight to Collateral*" in the laboratory.

To summarize the previous discussion, the key driver of the indeterminacy of Flight to Collateral is, as we just mentioned, the behavior of the empirical supply. This behavior of the empirical supply curve is clearly not consistent with expected utility maximization by Pessimists. In fact, the observed supply suggests some sort of aversion to losses in the worst-case scenario. So for prices below 190 they want to avoid the worst case scenario in which they keep all the asset and the Low state realizes. On the contrary, for prices higher than 190 they want to avoid the worst case scenario which is selling all the asset and that the High state realizes.

3.3 Conclusion

We study the implication of leverage on asset price in a controlled laboratory environment. To this purpose, we develop a model of leverage that is amenable to

[30] The p-value is 0.000.

[31] When regressing the per-round spread on a constant, the p-value is 0.61 (correcting for by-session clustering).

laboratory implementation, and we gather experimental data. We show that, in the laboratory financial market, when an asset can be used as a collateral its price increase. Both the direction and the magnitude of the increase is in line with what theory suggests. However, important deviations from the theoretical model occur in the laboratory. First, the increase in price due to borrowing occurs even though agents do not use all their cash when borrowing is not allowed. Moreover, when bad news arrives, the spread between collateralizable and non-collateralizable assets does not increase.

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Appendix A: A Two-Asset Economy.

We consider a two-period financial economy, with time $t = 0, 1$. At time 1, there are two states of the nature, $s = High$ and $s = Low$, with probability q and $1 - q$.

There are three assets in economy, cash and two risky assets X and Y with payoffs in units of cash. Assets X and Y have the same payoff as in our benchmark model, and are independently distributed. All the other features of the model hold. In particular, agents payoff function is given by

$$u_s^i(\bullet) = w + D_{y,s}^i y + D_{x,s}^i x - \varphi \tag{12}$$

Agents cannot borrow using asset X as a collateral, whereas they can use asset Y as collateral with $\varphi \leq D_{y,Low}$. Taking as given the asset price, agents choose asset holdings y, x and cash holdings w in order to maximize the payoff function subject to their budget constraints :

$$w + px + py \leq m^i + pa_x^i + pa_y^i + \varphi \tag{13}$$

$$\varphi \leq D_{y,Low} y \tag{14}$$

We find the equilibrium for the same parameter values as in the Bullish market described in Table 1. The equilibrium is described in Table 9:

Table 9: The Equilibrium in the Two-Asset Economy

	Optimists	Pessimists
p_y	250	
p_x	190	
y	100	0
x	0	100
u_{High}	$75,000$	$40,000$
u_{Low}	$10,000$	25000

The equilibrium price for asset x (which cannot be used as collateral) is the same as the asset price in the NL-economy, whereas the equilibrium price of asset y (which can be used as collateral) is the same as the asset price in the L-economy. Note that exactly as in the L-economy, in equilibrium Optimists hold all the supply of the collateralizable asset.

Appendix B: Full Data Set.

The following tables incorporate data from all fifteen rounds of experimentation and can be compared with tables 4, 6, 7, and 9, respectively.

Table 10: Average Equilibrium Prices in the Bullish Market

	Average	S1	S2	S3	S4	S5
NL	216	223	205	215	208	230
L	251	244	254	260	242	256
Spread	33	21	49	45	34	26

Table 11: Per-Subject Average Transactions in the Bullish Market

	Average	S1	S2	S3	S4	S5
NL	55	54	45	62	66	49
L	70	73	61	70	78	69

Table 12: Optimists' Final Cash Holding and Borrowing in the Bullish Market

	Final Cash	Borrowing per Widget	Aggregate Loan to Value Ratio
NL	$3,156$	-	-
L	$1,535$	44	0.23

Table 13: Average Equilibrium Prices in the Bearish Market

	Average	S1	S2	S3	S4	S5
NL	190	185	186	207	191	181
L	235	232	234	233	238	237
Spread	45	47	48	26	47	56

Table 15: Per-Subject Average Transactions in the Bearish Market

	Average	S1	S2	S3	S4	S5
NL	59	53	54	61	69	59
L	71	77	60	75	76	70