

An Experimental Study of Bond Market Pricing*

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Abstract

An important feature of bond markets is the relationship between the IPO price and the probability that the issuer defaults. On the one hand, the default probability affects the IPO price. On the other hand, IPO prices affect the default probability. It is a priori unclear whether agents can competitively price such assets and our paper is the first to explore this question. We do so using laboratory experiments. We develop two flexible bond market models that are easily implemented in the laboratory. We find that subjects learn to price the bonds well after only a few repetitions.

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New assets are often brought to market using an initial public offering (IPO). While there is a variety of studies analyzing different IPO mechanisms, little is known about the impact of IPO prices on the subsequent financial health of the company issuing the new assets. The IPO price could, for example, affect the performance of an equity-issuing company as the funds that are available to the company for additional investments could vary with the IPO price. Similarly, with new debt issues, the IPO price determines the financing costs of the bond issuer and therewith the probability that the bond issuer is able (or willing) to meet those new or pre-existing debt obligations. Such feedback effects from IPO prices to the real side of the economy and to the value of the assets themselves are often overlooked in the literature on asset pricing and are fully absent in the experimental part of this literature. Our paper seeks to fill this void. In particular, we report on the first experimental study of assets with endogenous, price-dependent default probabilities.

We focus on the pricing of bonds with credit risk for two reasons. First, the feedback from IPO prices to the probability that the bond issuer defaults and therewith to the value of the bonds is particularly clear in this case. While there is evidence that default risk accounts for much of the yield spread between high risk corporate bonds and risk-free government bonds of comparable maturities (Longstaff, Mithal, and Neis (2005), Huang and Huang (2012)), the interdependency between the initial issue price of such bonds and default risk has not been clearly identified. Second, bond markets dwarf markets for other assets such as equities in terms of the value of outstanding issues (Roxburgh, Lund, and Piotrowski (2011)). Indeed, bond sales are often the cheapest means of financing as compared with alternatives like equity issues or bank loans, and bond issues comprise the primary means of financing for most large, mature firms and governments. This preference for bond financing, however, presumes that bond purchasers are able to correctly price new bond issues. If newly issued bonds are mispriced relative to fundamentals, the financing costs to the bond issuer may be increased, leading to an increase in the issuer's default risk.

Rather than use field data to address the pricing of high credit risk bonds, we pursue an experimental approach where subjects in a laboratory are asked to buy new risky bond issues and earn money proportionate to the payoffs possible in the bond market setting in which they operate. An important advantage of a laboratory evaluation of bond market pricing is that we have control over the information that is available to bond purchasers regarding features of the bond issuance and in particular the probability that the bond issuer defaults, and we can evaluate the extent to which providing them with this information allows them to correctly determine bond prices. Knowledge of such information and this same level of control are not generally available or feasible in the field. For this reason there is now a large literature using experimental methods to evaluate the pricing of many types of assets (see, for example, Bossaerts (2009) for a survey).

Specifically, we develop and evaluate the empirical relevance of two models of bond pricing that follow the approach of Merton (1974), in that IPO prices are related to features of the bond issue (e.g., face value, coupon payment, maturity date) and to the probability that the bond issuer defaults on its obligations to bond holders. In the first experiment, the relationship between prices in the IPO and default probabilities is made as salient as possible to participants. The model used in that experiment reduces the mechanisms behind the feedback from IPO prices to default probabilities to a single mapping (with default probabilities that are equal in all periods). The second experiment is based on a structural model that fully spells out the relationship between the revenue raised in the IPO and the ability of the bond issuer to meet its obligations. In this model, the default probabilities are not equal in different periods (and thus no mapping exists that is similar to the one in the model of the first experiment). As a consequence, participants in the second experiment need to derive all implications of the feedback from IPO prices to default probabilities themselves.

To preview our results, we find that subjects learn to price bonds subject to endogenous default risk rather well after only a few repetitions (both during the IPO and while trading

in the secondary market that follows). As in other asset pricing experiments, we find that bubbles in bond prices are only observed among inexperienced traders. This is a remarkable finding, given that the bonds in our experiments are relatively long lived, giving ample opportunity for bubbles to occur (e.g., Noussair and Tucker (2013)) and that the learning of the equilibrium IPO price is not an easy task – we had to compute the solution numerically. The fundamental value of the bond in the secondary market depends on the IPO price, so that learning in the secondary market is related to learning in the IPO. The overall high degree of market efficiency that we find occurs in a variety of environments. It occurs in environments with a straightforward relationship between IPO prices and default probabilities (Experiment I), independently of whether (equilibrium) fundamental values are increasing or decreasing over trading periods. It similarly occurs in environments where the relationship between IPO prices and default probabilities is more complex (Experiment II), independently of the structure of noise in the underlying cash flows.

There is now a large literature on experimental asset pricing,¹ but we are not aware of any prior experimental studies examining the pricing of bond-type assets with interdependencies between the IPO price and default risk. There have been some experimental asset markets with an explicit possibility of default (e.g., Ball and Holt (1998), Crockett, Duffy, and Izhakian (2017)), and in other asset market experiments a random cash-flow can be interpreted as a type of partial default (e.g., Plott and Sunder (1988)). However, in those studies, the pricing of the asset does not affect the probability of a default as it does in our framework. Finally, our models can easily be implemented in the laboratory, but this does

¹For some of the more recent studies, see Gneezy, Kapteyn, and Potters (2003), Dufwenberg, Lindqvist, and Moore (2005), Haruvy and Noussair (2006), Bossaerts, Plott, and Zame (2007), Haruvy, Lahav, and Noussair (2007), Bossaerts et al. (2010), Palan (2010), Cheung and Palan (2012), Kirchler, Huber, and Stöckl (2012), Sutter, Huber, and Kirchler (2012), Cheung, Hedegaard, and Palan (2014), Füllbrunn, Rau, and Weitzel (2014b), Bosch-Rosa, Meissner, and Bosch i Domènech (2015), and Crockett, Duffy, and Izhakian (2017).

not mean that the computation of equilibrium prices is easy (in fact, these computations are rather complex).

Recent surveys of the experimental asset pricing literature by Bossaerts (2009), Noursair and Tucker (2013), and Palan (2013) reveal just a few experiments that explicitly consider assets labeled separately as “bonds”; more generally assets are simply labeled as “assets”. In the studies that do refer to certain assets as bonds, the bonds are included primarily as a means of expanding the portfolio of assets available to traders. For instance, in a study of risk versus ambiguity aversion, Bossaerts et al. (2010) allow agents to trade in riskless bonds paying a known fixed return in contrast to other assets having either known probabilistic (risky) returns or ambiguous returns. Fischbacher, Hens, and Zeisberger (2013) allow agents to trade in a riskless, interest-bearing bond as well as a Smith, Suchanek, and Williams (1988)-type risky asset. The latter is known to exhibit price bubbles and crashes and so the authors’ aim is to explore the role of interest rate (monetary) policy (via the riskless bond) on the extent of mispricing of the risky asset. By contrast, our focus in this paper is on bond pricing alone, with a particular focus on the initial price of bonds. Further, we are not interested in risk-free bonds, but rather in bonds that are subject to default risk. Most corporate bonds and some government bonds are subject to this type of risk. While we focus on bond IPO price-dependent default probabilities, as noted above, such dependencies may also extend to other asset classes, like equities. Similarly, such a feedback effect between the amount raised and the probability to default is not restricted to IPOs but may also apply to private placement of debt and equity.

Based on the historical record, the frequency of real-world bond defaults tends to be *lower* than the probability implied by the initial prices of bonds subject to default risk (see, for example, Hull, Predescu, and White (2005)). Indeed, the credit spread between risk-free government securities and comparable corporate bonds subject to default risk is many times greater than can be explained by the risk of default alone, a phenomenon known in the literature as the “credit spread puzzle” (Huang and Huang (2012); Amato

and Remolona (2003)). The reasons for this are unclear. One possible explanation is mispricing of the bonds, but other explanations have been offered, including difficulties in estimating the bond issuer's default risk and systematic macroeconomic factors that can affect the default risk of all bond issuers simultaneously but which cannot be diversified away. An important advantage of our laboratory approach is that it allows us to abstract from potentially confounding factors and therefore provide a cleaner test of the theory of bond pricing subject to default risk. In our first experiment, we make clear to subjects the function mapping IPO prices into default probabilities. Aside from the possibility of a default, there are no other shocks to the environment in which subjects make decisions. In our second experiment, we add complexity to the process underlying the relationship between IPO pricing and default probabilities, but again no other shocks are added. Our main finding is that in both experiments, subjects eventually do learn the difficult task of pricing bonds subject to default risk. This suggests that the source of the credit spread puzzle may indeed lie in factors or assumptions that are not presently found in the theory of bond pricing subject to default risk.

There is a relevant theoretical and empirical finance literature on “feedback effects” between asset prices and various real fundamental economic factors; see Bond, Edmans, and Goldstein (2012) for a survey. For example, Subrahmanyam and Titman (2001) explore how small changes in a firm's stock price can affect its cash flow, which affects the *behavior* of the firm's stakeholders and thus has an amplifying positive or negative feedback effect on the firms' stock price which further affects the firm's cash flow, etc. Their focus is on the implications of such feedback effects for the firms' management of information about fundamental factors. While the feedback mechanism in our bond market has a similar flavor, we do not explore information management or stakeholder behavior. Instead, we are concerned with whether the interdependency between the price and fundamental factors (i.e., default risk) is correctly valued by the market, a maintained assumption in their theory. Similarly, Khanna and Sonti (2004) show how firms may react to increases

in their stock price by making greater acquisitions, thereby validating further increases in their stock prices and potentially leading to price bubbles. While we are also interested in potential mispricing of assets, we do not attribute this to the actions of firm decision makers but rather to asset trading decisions alone. Edmans, Goldstein, and Jiang (2012) and Edmans, Goldstein, and Jiang (2015) provide evidence that decreases in a firm's stock price leads firm managers to take corrective actions that attenuate or even completely reverse the initial decline in the firm's stock price. They note that these endogenous feedback effects make it difficult to find actual confirmatory evidence of these feedback mechanisms (though they do develop an empirical strategy). The latter observation provides a further rationale for the controlled laboratory approach that we adopt in this paper.

Davis, Korenok, and Prescott (2014) explore feedback effects on a firm's equity price from its issuance of contingent convertible bonds, which have been proposed as a means of preventing systematic financial risk, for example, in the banking system. These contingent capital bonds represent subordinated debt that automatically convert to equity shares once some pre-specified trigger event occurs, for example, a change in the stock price of the bond issuer. Feedback effects between stock prices and bond conversion expectations can lead to a multiplicity of equilibria or an absence of equilibria resulting in informational and allocative inefficiencies. Davis, Korenok, and Prescott (2014) find evidence for such inefficiencies in their experiment using three different market-price-based mechanisms for triggering bond conversions. While contingent capital bonds are a motivation for their study of the effect of trigger mechanisms on equity prices, their experiment does not actually involve any such contingent claim bonds. Instead, experimental traders are instructed that the fundamental value of their equity assets may change if the price of that asset increases or decreases beyond a certain level as determined by the trigger mechanism in place. Nevertheless, their paper does explore feedback effects between pricing decisions and fundamental factors (bond conversions) and, as in this paper, they also explore both asset-value decreasing and asset-value increasing effects from those factors.

Finally, our paper is also related to theoretical and experimental research on bond market IPOs. We use a multi-unit, uniform-price auction for this IPO. Friedman (1960) advocated such a mechanism as opposed to discriminatory price auctions where each bidder whose bid exceeds the stop-out price pays the amount of her bid. Friedman argued that discriminatory auction rules increased incentives for bid shading and collusion relative to the uniform price rule. Subsequently, many developed countries, including the U.S., the U.K. and several Eurozone countries have adopted uniform pricing rules for their treasury bond auctions. Nevertheless, as Wilson (1979), Back and Zender (1993), and Wang and Zender (2002) have pointed out, results for uniform price, single unit auctions may not carry over to share, or multi-unit auctions, where seller revenues can be lower than for comparable single unit auctions due to collusive underpricing by bidders. On the other hand, Kremer and Nyborg (2004) argue that these underpricing inefficiencies can be mitigated by having bidders submit multiple, discrete price-quantity pairs (as opposed to elicitation of their demand schedule), a practice that we adopt in our experimental design. Experimental evidence on multi-unit auctions suggests that seller revenue under uniform pricing can be reduced if bidders are allowed to communicate with one another (Goswami, Noe, and Rebello (1996)) or if there is asymmetric information about resale values (Morales-Camargo et al. (2013)). Seller revenues can be increased if the seller is permitted to reduce the supply of units conditional on amounts bid (Sade, Schnitzlein, and Zender (2006a)) or if there are asymmetric capacity constraints limiting how many units individual bidders can buy (Sade, Schnitzlein, and Zender (2006b)), as these innovations reduce collusive opportunities. However, in our setup, the supply of bonds is fixed, bidders are not allowed to communicate with one another and there are no asymmetries among bidders. Zhang (2009) experimentally compares uniform price auctions to fixed price offerings of initial equity shares and reports greater revenues under the uniform price auction mechanism, despite the possibility of collusion that this mechanism offers. Finally, Füllbrunn, Neugebauer, and Nicklisch (2014a) investigate three different IPO mechanisms

in the laboratory and observe under-pricing in all mechanisms. What this overview of previous studies shows, is that there are many reasons why we might not expect markets to price IPOs well. Together with the feedback loop that further complicates IPO pricing in our setting, we conclude that a priori, the case in favor of accurate pricing is weak at best.

The remainder of this paper is organized as follows. Section I describes the models of bond market pricing that will be used in our experiments. Section II presents the experimental designs. The results are discussed in Section III and Section IV concludes.

I. Bond Market Models

In this section, we introduce two models of bonds subject to default risk that capture the main features we are interested in and at the same time can be implemented in the laboratory. The first model can be thought of as a “reduced form” model since the process by which IPO prices map into default probabilities is treated as given. The second model, developed upon suggestion by the editors of this journal, can be regarded as a “structural form” model meaning that the (somewhat complex) structure by which IPO prices determine the probability of default is completely spelled out. We present these two models as distinct since, in general, they will not lead to exactly the same outcomes, but because of their similarities they can also be seen as two versions of the same model.

Both models exhibit some typical features of bond markets, such as the payment of a coupon and the payment of the face value of the bond at the maturity date. Aside from the feedback loop between IPO prices and default probabilities, the models are also similar to more general asset market models. For this reason, the relevance of experiments based on these models extends beyond bond markets alone.²

²With minor modifications, these models could for example be used to describe equity markets with endogenous default probabilities (the money raised in equity market IPOs could influence the probability of

A. *Reduced Form Model*

We begin with an overview of the reduced form model. Then we discuss the timing of moves and derive the fundamental value of the bond given a default probability. Finally, we discuss the relationship between the IPO price and the default probability.

A.1. *Brief Description*

The payments to a bond holder are as follows. If the bond issuer does not default prior to the bond's maturity date in period T , then the bond holder receives a payment of the bond's face value K . Prior to the maturity date, the bond holder also receives a coupon payment of iK in each period (i is thus the interest rate) so long as the bond issuer has not yet defaulted. If the bond issuer defaults in some period, the bond holder receives no more coupon payments from the period of default onward and also loses payment of the bond's face value.³

When the bond issuer issues new bonds, they are auctioned off in an IPO. The prices paid in the bond market IPO determine the costs to the bond issuer of its fixed maturity debt issue (the lower the IPO price, the higher are the costs of the debt). These costs have an influence on how likely it is that a bond issuer will default over the fixed term of the bond (the higher are the costs, the higher is the probability that the bond issuer defaults).

We use a uniform-price auction for the IPO, as it facilitates the specification of the probability that the bond issuer will default, and as noted earlier, it is a commonly used IPO

default (bankruptcy), for example, because the availability of additional funds allows the company to absorb greater negative shocks).

³More generally, one can specify a default amount, D , which the bond holder receives in the event that the bond issuer defaults. In our reduced form model, we always assume that there is no such payment (i.e., $D = 0$) for simplicity. Similarly, one could add an outside interest rate for holding money, r , which for simplicity we also assume to be zero in the remainder of the paper.

mechanism. In the auction, the face value and the coupon payments are fixed and known and the potential bond holders bid on the price they are willing to pay to receive a bond.⁴ Once all bonds have been auctioned off, they can be traded on a secondary market where prices are determined by supply and demand. Trade takes place over several periods, up to the maturity date period T , assuming of course that there is no default prior to that date.

A.2. *Timing and Fundamental Value with Known Default Probabilities*

The price in the IPO determines the default probability of the bond issuer. After the IPO, the default probability of the bond issuer remains constant until either a default occurs or period T is reached.⁵ Once the default probability is known, the fundamental value of the bonds in all subsequent periods can be calculated. The calculation of these fundamental values depends on the timing of the market, which we now discuss.

In the initial period 0, the IPO of bonds is held. The result is a market clearing price, which we refer to as the IPO price, p_{ipo} . Thereafter, in periods $t = 1, 2, \dots, T - 1$ bond market participants can buy and sell bonds provided that they have bonds to sell or funds to buy bonds. Specifically, the timing of moves in each of periods $0 < t < T$ is as follows:

⁴It is of course possible to use alternative auction mechanisms and indeed, different mechanisms are used in real-world bond IPOs. Instead of holding face value and coupon payments constant, one can also hold face value and initial price constant and allocate the bonds in an auction where bids are made on the coupon payments. We choose to use the version where coupon payments are fixed, because this leads to a large similarity between the initial auction and trading in the secondary market in the experiment.

⁵We assume for simplicity that the default probability is identical in all periods, but one could relax this assumption (in the structural model described in Section I.B the default probability differs across periods). We also assume that a subsequent IPO can only take place after the bonds from the previous IPO have been redeemed. One could also model overlapping “generations” of bonds; however, this would make modeling the default probability more complex, because it would then depend on a combination of IPO prices of all bonds in the market.

1. It is determined whether or not the bond issuer defaults.
2. Conditional on no default having occurred in the current period or earlier, the coupon payment is made.
3. The bond market opens and trade in bonds can take place.

Finally, if the final period T is reached (i.e., no default has occurred in period T or earlier), then (i) no more trading occurs and (ii) the face value of the bond is paid out together with the final coupon payment.

The default probability depends on the IPO price; the precise way in which IPO prices map into default probabilities is described below in Section I.A.3. Once the default probability, P_d , is known (the probability of not defaulting is $P_n := 1 - P_d$), the fundamental value of a bond in period t can be calculated. Note that the fundamental value, V_t , of the bond in period t is conditional on the bond holder not having previously defaulted. The fundamental value (when the trading occurs) is then the face value times the probability of receiving this final payment plus the expected value of the remaining coupon payments:

$$V_t = KP_n^{T-t} + \sum_{m=t+1}^T iKP_n^{(m-t)} = KP_n^{T-t} + \sum_{m=1}^{T-t} iKP_n^m \quad (1)$$

$$\stackrel{\text{for } P_d > 0}{=} KP_n^{T-t} + iK \left(\frac{1 - P_n^{T-t+1}}{1 - P_n} - 1 \right).$$

A.3. Default Probability and Equilibrium Fundamental Value

The default probability of a bond depends on the bond's IPO price and is thus endogenously determined.⁶ As a higher IPO price leads to lower financing costs for the bond issuer and therefore a lower probability of default, the function mapping IPO prices into default probabilities is assumed to be monotonically decreasing. We model the default probability

⁶A possible channel through which IPO prices determine default probabilities is the following: a lower IPO price leads to a lower investment by the bond issuer and thus generates lower cash flows; lower cash flows lead to a higher probability of the firm not being able to pay the coupon (which is fixed).

using an exponential function, which we use as a reduced form function relating IPO prices to default risk and thus bond payoffs:

$$P_d(p_{ipo}) = m \exp(-c p_{ipo}) + b. \quad (2)$$

The parameter b (with $0 < b < 1$) represents a base risk (the default probability can never be lower than b). The parameter m (with $0 < m < 1 - b$) represents the maximal bond-price-dependent default probability. Thus, this is the maximal possible probability of default due to low bond prices. The highest possible default probability is then $m + b$ (which may be smaller than 1 even if a bond issuer receives a price close to zero for its bonds; this is because the bond issuer might have other means of debt financing – such as equity issue or taxes – and may choose not to default in order to reestablish credibility). The parameter c (with $c > 0$) determines the sensitivity of the default probability to variations in the IPO price (the greater is c , the faster the probability of default approaches the base risk when the IPO revenue increases).

As the probability of default is now endogenous, one cannot simply calculate the fundamental value of the bond in the IPO. However, it is possible to calculate competitive equilibrium prices for the IPO and use these to determine the equilibrium fundamental values with Equation (1). Of course, the actual fundamental value after period 0 depends on the realized IPO price. Depending on the model specification, more than one equilibrium price can arise. There can, for example, be a high-price equilibrium with a low probability of default and a low-price equilibrium with a high probability of default. As this is the first experimental paper exploring the pricing of bonds subject to default risk, our focus is on the extent to which equilibrium is reached and not on equilibrium selection. We therefore leave this possibility unexplored by choosing a specification that yields a unique equilibrium.

While the equilibrium IPO prices do not have a simple closed-form solution, the solu-

tion is easily computed numerically. The procedure is as follows. For any IPO price, the expected profit per bond can straightforwardly be calculated; it is the expected return on this bond minus the IPO price paid for it (the expected return of the bond can be calculated with Equation (1), plugging in the default probability that is determined by the IPO price, which is now given). With risk-neutral investors, equilibrium prices must yield zero expected profits. Negative expected profits cannot be an equilibrium outcome as otherwise agents would be better off not buying bonds. Positive expected profits also cannot be an equilibrium outcome, since investors would have an incentive to bid even more for the bonds, driving up prices until expected profits were zero.⁷

We now describe how the equilibrium price in the IPO depends on each of the model parameters. In this description, we assume that everything except the respective parameter, remains unchanged (again focusing only on cases with a unique equilibrium). A higher interest rate, i , leads to a higher equilibrium price. This is intuitive as a higher i leads to greater returns from holding the bond. A higher face value, K , leads to a higher equilibrium price for the same reason. Turning next to the parameters of the default probability function, a higher base risk, b , leads to a lower equilibrium price. This is again intuitive, because the probability of default is higher with a greater b (for any IPO price, the default probability function is shifted upward). Therefore each bond yields lower expected returns (all else equal), so that the price for it in equilibrium is lower. Similarly, a higher maximal bond-price dependent default probability m leads to a lower equilibrium IPO price. A greater m does not shift the default probability function up, but it still leads to

⁷Thus, equilibria are the IPO-prices at which the expected profit curve (a function of IPO-prices) equals zero. In cases where multiple equilibria exist, one can add the following stability criterion: a price is a stable equilibrium price if the expected profit curve changes sign from plus to minus. Only for such equilibrium prices will small deviations from the equilibrium lead to a return to the same equilibrium (if the price is lower than the equilibrium price, positive expected profits will drive prices up; if the price is higher, negative expected profits will drive prices down). As noted earlier, for simplicity we focus on parameterizations for which there is a unique equilibrium IPO price. In that case this stability requirement is generally satisfied.

a higher default probability for each IPO price (with decreasing differences as IPO prices increase). Again, bonds yield a lower expected return, which leads to a lower equilibrium IPO price. A similar reasoning also holds for the sensitivity parameter c . A greater c leads to a lower default probability for each IPO price and therefore to higher expected returns from holding a bond. This results in a higher equilibrium IPO price.

B. Structural Form Model

We next discuss the structural model. This model presents a more challenging environment in which to price bonds subject to default risk. Rather than imposing a reduced form function mapping IPO prices into default probabilities, we now model precisely how default is endogenously determined. We provide a relatively simple model of this process, but the additional structure of this version of the model comes at the expense of losing the simplicity of having the *same* default probability in each trading period. As a consequence, we cannot construct a structural model that leads to exactly the same functional form for the mapping from IPO prices to default probabilities as in the reduced form model. Nevertheless, most parts of the model remain the same as before and wherever possible the notation is identical.

B.1. Description

Suppose that the bond issuer, which we will refer to as the “company” in this description, has previously issued some number, n_o , of bonds. These bonds have a face value of K and pay a coupon of iK in each period. The face value has to be redeemed in period T . Suppose further that the company issues n_n new bonds with the same seniority as the pre-existing bonds. These new bonds are also redeemed in period T and pay a coupon of iK each period. At the moment of the IPO of the new bonds, we assume that the company has no savings (of course, this assumption can easily be modified). We again label the period

of the IPO period 0 (we assume that in this period only the IPO takes place, no coupon payments are made on the old bonds; in a sense, period 0 is an interim period preceding period 1). The company receives cash flows from two sources. The first is independent of the price achieved in the IPO for the new bonds, p_{ipo} . This cash flow, X_t , is a random variable taking on different values over time. In particular, if the company has a promising project that can result in a large profit in period T , this can be reflected in the cash flow (if the project is successful the realization of X_T is large). The second source of cash is a return on investment from the amount of money raised in the IPO of the new bonds. This amount is invested so that it yields, in each period $1, \dots, T$, a random return of $R_t * n_n * p_{ipo}$. We assume that the probability distributions of X_t and R_t are known by all traders for all t . While many specifications for these two random cash flows are possible, we only consider, for simplicity, cash flows where the random outcome is independent of all other draws of X_t and R_t . We furthermore assume, again for simplicity, that the expectation of R_t is constant, that is, $E(R_t) = R$ for all t .

So long as the company has enough money to meet its obligations there will be no default. If its cash flow in any period $1, \dots, t-1$ is higher than the coupon payments it needs to make ($i * K * (n_o + n_n)$), then the company can save at a zero interest rate. Thus, the savings of the company at the end of a period $1, \dots, T-1$ evolve as follows:

$$S_t = X_t + R_t * n_n * p_{ipo} + S_{t-1} - i * K * (n_o + n_n). \quad (3)$$

If the company does not have enough money to meet its obligations in a period, that is if $X_t + R_t * n_n * p_{ipo} + S_{t-1} < i * K * (n_o + n_n)$ in periods $1, \dots, T-1$, then the company defaults. In period T the face value of the bonds is due in addition to the coupon payments. Then the company defaults if

$$X_T + R_T * n_n * p_{ipo} + S_{T-1} < (1 + i) * K * (n_o + n_n). \quad (4)$$

We assume that the actual realizations of the cash flow variables are the private information of the company alone, that is, market participants only observe whether a default occurs or not.

In case of a default, the company goes bankrupt. Its bonds no longer yield coupon payments and the face value of the bonds is not repaid. However, the company's remaining funds are distributed, so that each bond holder receives the same share per bond. That is, if $X_t + R_t * n_n * p_{ipo} + S_{t-1}$ is so low that the company cannot meet its obligations, each bond holder receives $(X_t + R_t * n_n * p_{ipo} + S_{t-1}) / (n_n + n_o)$ per bond and no other payments. For simplicity, we abstain from considering the company's liquidation value from the sale of its physical assets, real estate, etc., which could be added to the compensation that bondholders receive in the event of a bond default.⁸

B.2. Timing

The timing is largely the same as for the reduced form model. In the initial period 0, the IPO of new bonds is held (no coupon payments for old or new bonds are made). In subsequent periods, random draws for the realizations for the two cash flow variables are made, and the company is found to be solvent or in default. In periods $t = 1, \dots, T - 1$, market participants can buy and sell bonds provided that they have bonds to sell or funds to buy bonds. The timing of moves in each of the periods $t = 1, \dots, T - 1$ is as follows:

1. The random draws of the cash flow variables X_t and R_t are realized and the company receives these funds.

⁸Note that it is also possible to develop a version of the model without previously issued bonds. However, the model with outstanding bonds possesses some intuitive features. These outstanding bonds motivate obligations the company has (coupon payments and repayment of the face value) that are independent of the new issue of bonds. Without such obligations, there would be a less clear-cut motivation for the company to issue the new bonds in the first place. Finally, if there are outstanding bonds it is natural to assume that the newly issued bonds have the same characteristics as the bonds already in place.

2. A determination is made as to whether the company has enough funds to meet its obligations.

- If the firm does not have enough funds, a default is declared. In this case, bonds become worthless in all future periods. Bondholders receive a share of the company's remaining funds per bond held. No further realizations of cash flows, payments, or trading occurs in periods following a default.
- If the company has enough money to meet its obligations a coupon payment is made; then the bond market opens and trade in bonds can take place.

In period T , the company's obligations include the repayment of the face value of the bond. No more trading takes place in this period.

B.3. Default Probabilities and Fundamental Values

After the IPO, the probability that the company defaults can be calculated for every period. Again, these probabilities are conditional on no prior default having occurred. In contrast to the reduced form model, the probability of default is now in general different across periods. Conditional on knowing the savings that the company has, the default probabilities are as follows (the savings are known by the company but not by the agents trading bonds; an exception is a common knowledge of $S_0 = 0$). In any period $t = 1, \dots, T - 1$, the default probability is

$$P_{d,t,S_{t-1}}(p_{ipo}) = P(X_t + R_t * n_n * p_{ipo} + S_{t-1} < i * K * (n_o + n_n)). \quad (5)$$

In the last period, due to the repayment of the face value, the default probability becomes

$$P_{d,T,S_{T-1}}(p_{ipo}) = P(X_T + R_T * n_n * p_{ipo} + S_{T-1} < (1 + i) * K * (n_o + n_n)). \quad (6)$$

In the calculation of $P_{d,t}$, the savings of the company at the end of the previous period, S_{t-1} , are unknown to market participants. However, as the evolution of S_t depends on X_t and R_t of which the distributions *are* known, the market participants know the distribution of S_t . The default probabilities $P_{d,t}$ can thus be determined immediately after the IPO as in the reduced form model.⁹ In contrast to the reduced form model, there is no mapping from the IPO price to a default probability that is identical across periods. But, of course, the feature that higher IPO prices lead to fewer defaults also holds in the structural model.

After determination of the IPO price, the fundamental value can be calculated for each period. Eq. (7) is a straightforward extension of Eq. (1) for the reduced form model, now allowing the default probabilities to vary across periods. Again using $P_{n,t} := 1 - P_{d,t}$, the fundamental value of the bond is given by:

$$V_t = K \prod_{m=t+1}^T P_{n,m} + \sum_{m=t+1}^T \left(iK \prod_{j=t+1}^m P_{n,j} \right). \quad (7)$$

Again, one cannot determine the fundamental value path before the IPO price is known, because the probability of default is endogenous. However, it is again possible to determine the equilibrium IPO price and with it the equilibrium fundamental value path. This can be done in a manner that is similar to the determination of the equilibrium IPO price in the reduced form model.¹⁰ In general, the structural model, like the reduced form model, can

⁹If the cash flow of the company were not its private information, the default probabilities relevant to market participants would not only depend on the IPO price but also on the realizations of the random variables determining the company's cash flow. We opt here for a version where the cash flows are private information so that IPO prices alone determine the default probabilities as in the reduced form model. We believe that there are reasons both for and against thinking that in the world outside of the laboratory such cash flows are private information.

¹⁰That is, an expected profit curve conditional on IPO prices can be obtained (e.g., with Monte Carlo simulations). Equilibrium prices must have the property that expected profits are zero. In case of multiple equilibria, the same stability criterion as described in Footnote 7 can be added, if so desired.

have multiple equilibria, but we will again only study cases for which there exists a unique competitive equilibrium.

II. Experimental Design and Procedures

For this study we designed two experiments. The second was designed after the data from the first had been studied and is based on suggestions by the editors of this journal. Experiment I involves the reduced form model. Experiment II uses the structural form model. The treatment variation in Experiment I concerns the slope of the equilibrium fundamental value path, which is decreasing in one treatment and increasing in the other treatment. The choice of these two treatments is motivated by the experimental asset market literature, which suggests that the slope of an asset's fundamental value over time can play a role in the incidence of price bubbles and crashes.¹¹ Our findings for the first experiment (as described in Section III) suggest that whether the fundamental value path is increasing or decreasing does not affect how well subjects price bonds subject to default risk. Therefore, in Experiment II, we consider a different treatment variation. In that experiment, we focus on the noise in the two sources of cash flow that the bond issuer receives: in one treatment, only the current income variable X_t is random, while in the other treatment both sources of cash flow, X_t and R_t , are random variables; in all treatments for Experiment II, the fundamental value of the bond is decreasing over time. Experiment II was designed to make the interaction between IPO price and default probability less direct, thereby making it more difficult for market participants to discover the equilibrium price.

Both experiments were programmed in PHP/MySQL and conducted in English at the

¹¹See Noussair, Robin, and Ruffieux (2001), Kirchler (2009), Noussair and Powell (2010), Huber and Kirchler (2012), Kirchler, Huber, and Stöckl (2012), Breaban and Noussair (2014), Giusti, Jiang, and Xu (2014), and Stöckl, Huber, and Kirchler (2014).

CREED laboratory of the University of Amsterdam. Each experiment involved 96 subjects recruited from the CREED subject pool. No subject in Experiment I participated in Experiment II, thus we report results from a total of 192 subjects. Each experiment consisted of two treatments – as explained below – with eight groups of six subjects (48 subjects) for each treatment. Subjects were primarily undergraduate students with an average age of about 22 years. A little less than half of the participants were female, about two thirds were majoring in economics or business, and more than 50% were Dutch. During the experiment, “points” were used as currency and final point balances were exchanged into euros at the end of each session at a known exchange rate of 1 euro per 1000 points. The experiment lasted between two-and-a-half and three hours. Participants earned on average 27.65 euros (including a show-up fee of 7 euros). The experimental instructions are reproduced in Internet Appendix A for Experiment I and in Internet Appendix B for Experiment II. After reading the instructions and prior to the start of the experiment, subjects had to correctly answer a set of comprehension test questions. These test questions are also reproduced in Internet Appendices A and B, respectively. We now first describe the design of Experiment I and then Experiment II.

A. Experiment I: Reduced Form Model

A.1. Treatments

As noted above, Experiment I consists of two treatments. In one, which we call *DEC*, the equilibrium fundamental value of a bond is decreasing over time while in the other, *INC*, the equilibrium fundamental value of a bond is increasing over time. The difference in the equilibrium paths is realized by using distinct parameterizations of the default probability function. Our choice of parameters was guided by the following considera-

tions.¹² Most importantly, a parameterization was chosen that equalizes the equilibrium fundamental value at the IPO in both treatments. Because subjects also received the same endowment in both treatments, both treatments have the same cash to asset ratio in the IPO and also the same ratio of cash to the value of assets priced at the equilibrium price. In equilibrium, subjects receive zero expected earnings. A monetary incentive for subjects to buy and trade only exists when prices are below the fundamental price. One can determine the IPO price for which the expected earnings (and, therefore, the incentive to participate in the market) are maximized. Note that this ‘maximal-earnings’ price may be non-zero because a zero price will lead to a high probability of default. In the experiment, we ensure that the maximal possible expected earnings in the two treatments are of equal magnitude.¹³ Obviously, if equilibrium prices in the IPO are equal between treatments while (equilibrium) fundamental values are increasing in one case and decreasing in the other, then face values must be different. The requirements to keep equilibrium IPO prices and maximal expected earnings equal across treatments, together with the wish to avoid parameterizations that yield multiple equilibria, make it necessary to introduce several differences in the parameters.

Specifically, the parameterizations chosen in the two treatments are as follows. In *DEC*, the parameters of the probability default function are $b = 0.02$, $m = 0.6$, and $c = 0.003$. In *INC*, these are $b = 0.14$, $m = 0.25$, and $c = 0.00175$. The interest rate is the same in both treatments, $i = 0.12$. The face value of bonds is $K = 1000$ points in *DEC* and $K = 2500$ points in *INC*. Graphs of the two probability default functions used in the experiment are shown in Figure 1. The treatment variation generating decreasing or increasing equilibrium fundamental values is realized via these probability default functions (and the bond’s

¹²There are some minor differences between the two treatments due to our preference for round numbers. It is not reasonable to expect that these minor differences would have a noticeable impact on the outcomes.

¹³This does not mean that the IPO price at which the maximum is achieved is the same in both treatments, because the probability default functions are different.

face value).

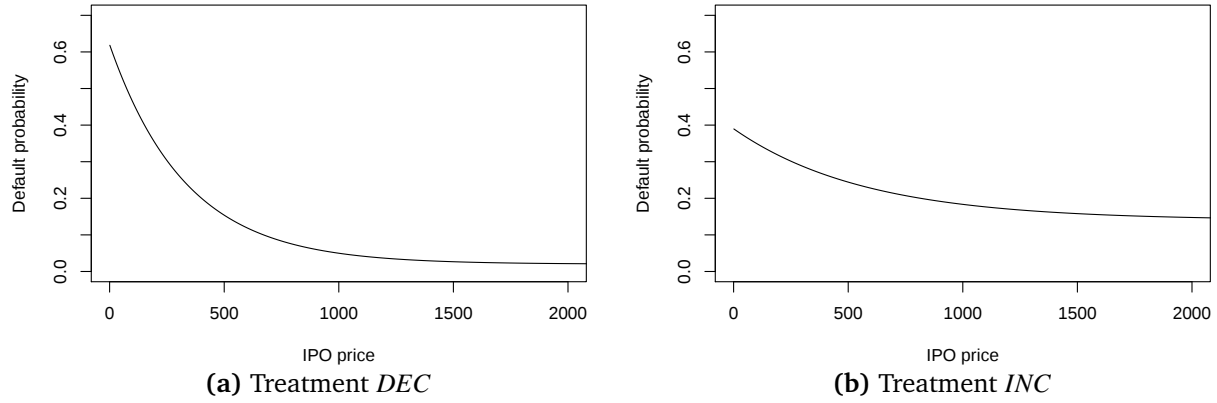


Figure 1. Default Probability Functions. The graph shows the default probability as a function of IPO prices in both treatments.

Using different default probability functions to achieve different treatments reflects the intricacies of such bond markets. Treatment *DEC* uses a default probability function that is decreasing fast in the IPO price from a very high level to a very low level. Treatment *INC* uses a default probability function with a lower maximal default probability than in *DEC*, but the function decreases more slowly in the IPO price. In equilibrium, the IPO price is approximately 1860 points in both treatments (1861 in *DEC* and 1862 in *INC*, rounded to integer numbers).¹⁴

The equilibrium default probability is higher in *INC* than in *DEC*. The bonds in *DEC*

¹⁴When talking about the equilibrium price in the IPO we usually talk about the competitive equilibrium price. The number of subjects per group (six) is large enough to justify this (see, for example, Huck, Normann, and Oechssler (2004)). Note, however, that in our experiment, a game theoretical analysis yields the same equilibrium price. While there are infinitely many Nash equilibrium strategies, all of them lead to the competitive equilibrium price. This can be seen as follows. Obviously, any price p_H above the competitive equilibrium price cannot be the price of a Nash equilibrium, because it leads to negative expected profits. On the other hand, any price p_L below the competitive equilibrium price also cannot be the price of a Nash equilibrium; if a combination of strategies leads to p_L then there is always at least one subject with an incentive to enter an additional bid at price $p_L + \varepsilon$ (or to increase a bid to this level) with a very small ε . This reasoning can be applied if the quantity is only available in whole units while bids can be made on a

can be thought of as bonds from an issuer who is economically strong and relies to a great extent on bond financing. In equilibrium, the probability of default is quite low; however, if the financing costs were to increase sharply, a default would become much more likely. The bonds in *INC* can be thought of as bonds from an issuer facing economic troubles (which could be an economy in a severe recession or a company with an uncertain future) only making limited use of bond financing. The probability of default is high, but the low reliance on bond financing mitigates the negative reaction to increases in the costs of such financing.

The different default probability functions lead to distinct (equilibrium) paths for the fundamental value. These paths are shown in Figure 2 for both treatments with solid lines. The equilibrium IPO price is shown as the period 0 value in the graph.

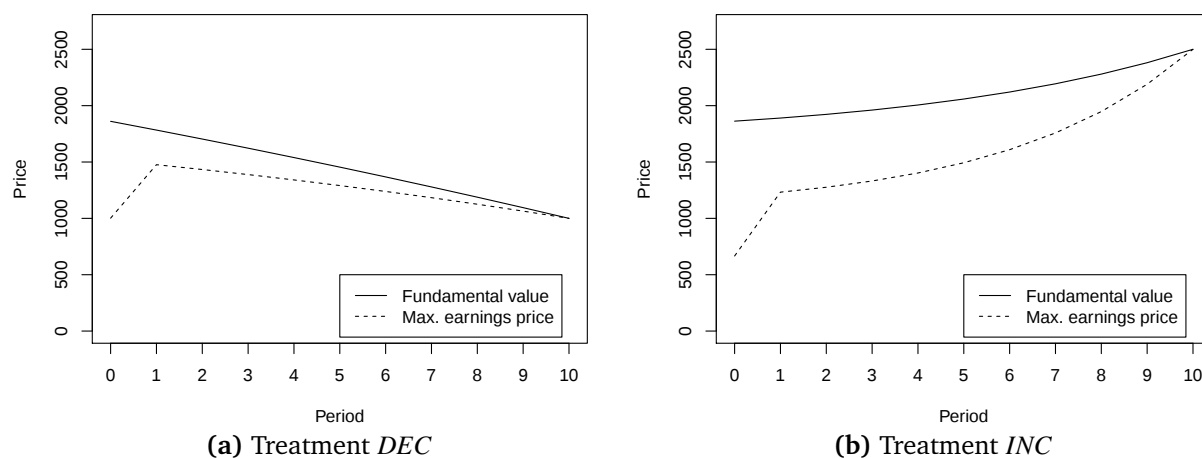


Figure 2. Fundamental Values. The graph shows the equilibrium fundamental values in both treatments (solid lines). It also shows the price that yields the highest expected joint earnings for the subjects (dotted line).

Aside from the (equilibrium) fundamental values, the graphs in Figure 2 show a second price. This is the price that maximizes (expected) joint earnings across subjects. Because

continuous scale (this is a rather accurate description of the experiment where bonds are sold in whole units while subjects can enter their bids with a decimal separator). For a careful theoretical analysis of pricing in uniform-price auctions, see Kremer and Nyborg (2004).

bonds are only allocated once (at the IPO), the joint earnings themselves do not change after the IPO. In traditional experimental asset markets, joint earnings are maximized by initially buying the assets from the experimenter at the lowest allowable price (if subjects are not already endowed with the assets). In a bond market, such minimal prices do not necessarily maximize joint earnings because of the effect that the IPO price has on the probability of default. The joint earnings maximizing price in the IPO is shown by the value of the dashed line at period 0. If bidders could collude against the issuer (i.e., the experimenter) they would in theory coordinate on this IPO price. This price is always below the equilibrium price and does not depend on the number of subjects per group. After the initial allocation in the IPO, the aggregate number of bonds in the market remains constant and collusion can no longer affect joint earnings. Subsequently, the dashed line from periods 1 to 10 represents the fundamental value of the bond conditional on the joint earnings maximizing IPO price having been realized. This explains the kink in the curve after moving from the IPO in period 0 to the first regular trading period 1. As the default probability depends on the IPO price, the continuation of this line after period 1 is not identical to the equilibrium fundamental value line (the solid line), though by the final period T , the two values become equal.

A.2. *Experimental Timing*

At the beginning of the experiment, subjects are randomized into groups (i.e., markets) of size six. Group membership remains constant over the course of the experiment so subjects only interact with the five other members of their own group when buying bonds in the IPO and when trading in the market in subsequent trading periods. The IPO auction and the trading mechanism are as described in Section II.A.3.

In the experiment there are four identical rounds. Each round consists of 11 periods, numbered from 0 (the IPO period) to 10. At the end of the experiment, for each subject

one of the rounds is randomly selected for payment. Subjects start each round with an endowment of 20000 points. The initial endowment is booked on a “cash account” which is used for all transactions subjects make when buying or selling bonds. The number of bonds allocated in the IPO is 25 per group. After the initial auction in period 0, subjects can trade the bonds with one another in periods 1 to 9 (henceforth, the “trading periods”; in period 10 no more trade takes place). The proceeds subjects receive from the coupon payments are deposited into an account called the “interest account”. The money on this interest account cannot be used to buy bonds; this is to ensure that the stock of cash in the economy remains constant in the trading periods.

In order to collect data on all periods, even after a default has occurred, we use a block design (see, for example, Fréchette and Yuksel (2017)). In this design, subjects are not told immediately whether a default has occurred. Instead, all markets continue for 9 trading periods as if no default has occurred. Only at the end of the round (i.e., following period 10) are subjects told whether a default had occurred and, if so, in which period. In case a default had occurred, subjects’ final earnings for a round are determined according to their cash and interest account balances at the time of default. This means that any action a subject takes is only payoff relevant conditional on no default having yet occurred in the round. This procedure is described carefully in the experimental instructions (see Internet Appendix A). Figure 3 shows a schematic overview of the timeline of the experiment.

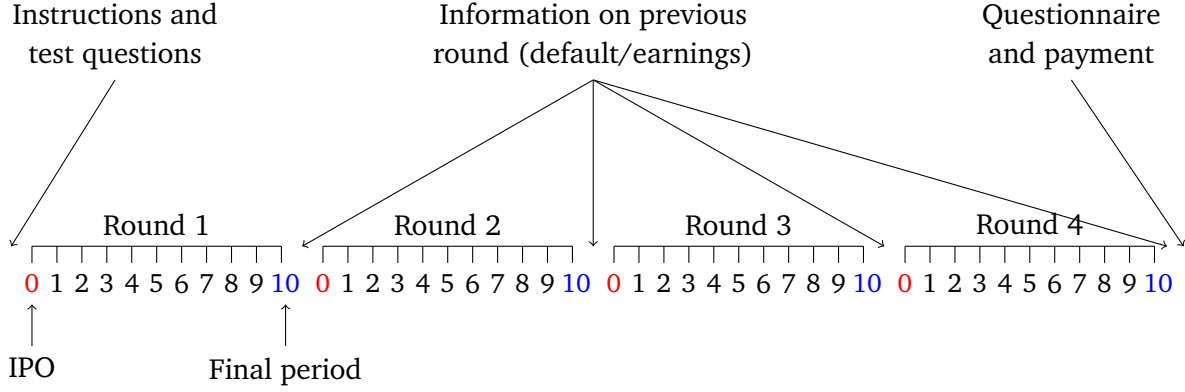


Figure 3. Timeline of the Experiment. The four rounds are identical. For each participant the earnings of one of the rounds are randomly selected for payment. Period 0 is the IPO, period 10 is the final period of a round in which no more trading takes place.

A.3. *Trading Mechanisms*

The one-sided call market auction mechanism used for the IPO in period 0 is implemented as follows. Each subject submits a demand schedule, that is, specifies for self-chosen prices how many bonds they would like to buy at each of those prices. Then, the computer program constructs an aggregate demand schedule by sorting bids from highest to lowest. The intersection of this demand schedule with the fixed supply of 25 bonds determines the uniform IPO price at which the bonds are sold. This amounts to the highest price for which all 25 bonds can be sold. If there are more units demanded at the market clearing price than 25, then all bids above the market clearing price are successful, while it is randomly determined which units demanded at exactly the market clearing price are traded (that is, some buyers are rationed). This uniform price auction mechanism is used in many actual bond IPOs (see, for example, Monostori (2014)).

The trading mechanism used in periods 1 to 9 is also a call market, but now a double-sided one. Subjects submit individual supply and demand curves. The computer program returns a warning if bids are invalid (for example if a subject tries to bid for a combination of bonds that she cannot afford with the points she has available in her account). Then

the program constructs aggregate demand and supply curves by sorting bids from highest to lowest and asks from lowest to highest. The market-clearing price is determined by the intersection of these aggregate supply and demand curves, and all trade is carried out using this uniform market price. If there is excess demand or excess supply at the market price, then successful bids or offers (of the ones exactly at the market price) are randomly determined.

Figure 4 shows the interface where subjects enter their demand function for the IPO of period 0. To start, one empty row is available to enter a quantity and a price, but subjects can add as many rows as needed by clicking on the button labeled “show more fields”. In the trading periods that follow the IPO, subjects see similar input fields on the same screen where they can also enter their supply schedule. These input fields for supply choices are placed to the right of the input fields for demand choices. An important advantage of the two mechanisms used for the IPO and trading periods lies in their similarity. De facto, subjects only need to become familiar with one mechanism and interface. In addition to the input fields, subjects see one button on the screen to submit bids in the IPO or to simultaneously submit bids and offers in the trading periods. Subjects also see past market prices in the round concerned. If no trade occurred in a previous period, this fact is indicated instead of the market price.

I would like to buy this quantity	if the price (per asset) is at most
12	356
7	688
2	911.5

Figure 4. Input Fields of the Computer Interface to Submit a Demand Function.

B. Experiment II: Structural Form Model

Experiment II is similar to Experiment I in many ways. We use again a one-sided call market in the IPO and a double-sided call market for the trading in the regular periods. Furthermore, we use the same block design and the experimental timing is identical; of course, within each period the timing of the structural model is used, as outlined in Section I.B.2, which corresponds to the timing in the reduced form model in a natural way. The main differences (except for using the structural model instead of the reduced form model) concern the treatment variations.

B.1. Treatments

We expect that the structural model makes it more difficult for subjects to price the bonds. This is because – in addition to the endogeneity of the default probability – participants now have to draw inferences about this default probability themselves rather than being given explicit information about how IPO prices map into default probabilities. The treatment variation in Experiment II varies how difficult it is for subjects to make these inferences. The equilibrium fundamental value paths are always decreasing in this experiment.

In one treatment, which we call treatment X , only the X_t part of the company's cash flow is random; there is no randomness in R_t , which is set to a fixed and known value. In the other treatment, which we call treatment XR , R_t is also random. Except for this difference, all other parameters of the experimental environment are held fixed across these two treatments. As in treatment DEC of Experiment I, $i = 0.12$, $K = 1000$, and the number of bonds auctioned off in the IPO is 25. The number of old bonds that the company has previously issued (n_o) is also set to 25.

In both treatments, X_t is a binary random variable with the following properties. The random draw can be favorable in which case $X_t = X_{G,t}$, which happens with probability

0.96. Otherwise, the random draw is unfavorable and the realization is $X_t = X_{B,t} = 0$. In periods $t = 1, \dots, 9$ $X_{G,t} = 6000$ and in period 10, $X_{G,10} = 56000$. These numbers were chosen so that if the good state is realized in a period, the bond issuer can meet its obligations that period from the cash flow from X_t alone. In particular, for the parameterization of the model studied in the experiment, $i * K * (n_o + n_n) = 6000$ and $(1 + i) * K * (n_o + n_n) = 56000$. Of course, the bond issuer can also meet its obligations via other means such as savings or its return on the funds raised in the IPO.

In treatment X , there is no random component in R_t , which is equal to 0.03 for all t . In treatment XR , R_t is a binary random variable with mean 0.03. The random draw of R_t can be favorable, so that $R_t = R_G = 0.06$, or it can be unfavorable, so that $R_t = R_B = 0$. The probability that the random draw of R_t is favorable is 0.5 for all t .

These specifications for X_t and R_t were explained to subjects in the written instructions. We use them to determine the equilibrium IPO prices and the corresponding equilibrium default probabilities and the equilibrium fundamental value paths.¹⁵ Equilibrium IPO prices are 1868 in treatment X and 1837 in treatment XR . The equilibrium fundamental paths in the new treatments are shown by circles in Figure 5. For comparison, the equilibrium fundamental value path of the *DEC* treatment of Experiment I is shown as a solid line. The equilibrium fundamental value paths are very similar in the two treatments in Experiment II and they are also similar to that in the *DEC* treatment of Experiment I. Finally, in Experiment II, the joint expected earnings by all participants in a group are always decreasing in the IPO price (i.e., for the joint earnings of a group, it is best if the group buys all the bonds in the IPO as cheaply as possible).

¹⁵We present simulation results. For each treatment, the equilibrium IPO price stems from simulations of the profit curve around the equilibrium, each point on the curve representing 100000 simulations. The equilibrium default probabilities and fundamental values are the corresponding values at the equilibrium.

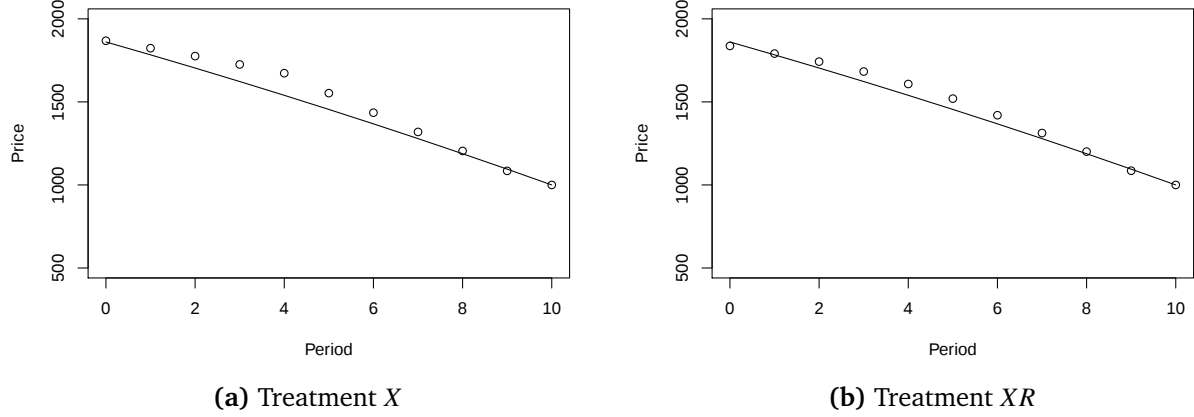


Figure 5. Equilibrium Fundamental Values. The graph shows the equilibrium fundamental values in both treatments (circles) as determined in numerical simulations. The equilibrium fundamental value in treatment *DEC* (Experiment I) is indicated by a solid line.

The equilibrium default probabilities vary across periods in Experiment II. There are also differences between the two treatments, *X* and *XR*, reflecting the treatment differences in the random nature of the cash flows. Figure 6 shows equilibrium default probabilities over time (for comparison, the solid line indicates the equilibrium default probability in treatment *DEC* of Experiment I). In treatment *X*, the returns from the second source of cash flow are not random and are perfectly known. In the first four periods, the non-random component of the cash flow is not sufficient to compensate for a bad draw in the remaining random component of the cash flow, X_t . Hence, the default probability is equal to the probability that $X_t = X_{B,t}$, which is 0.04. However, by the fifth period, the non-random cash flow is sufficient to compensate for a bad draw in X_t , so that the probability of default drops to zero. Afterward, the probability of default is non-zero but very low (in period 6, for example, a default occurs if no default has occurred in periods 1 to 5 while the random draws X_5 and X_6 are both unfavorable). In period 10 the default probability is again high, because the savings of the company cannot be enough to cover both the coupon payments and the redemption value of the bonds. The default probabilities for treatment *XR* follow a similar pattern, but because of the stochastic component of R_t , the

default probability changes more gradually over periods 1 to 9.

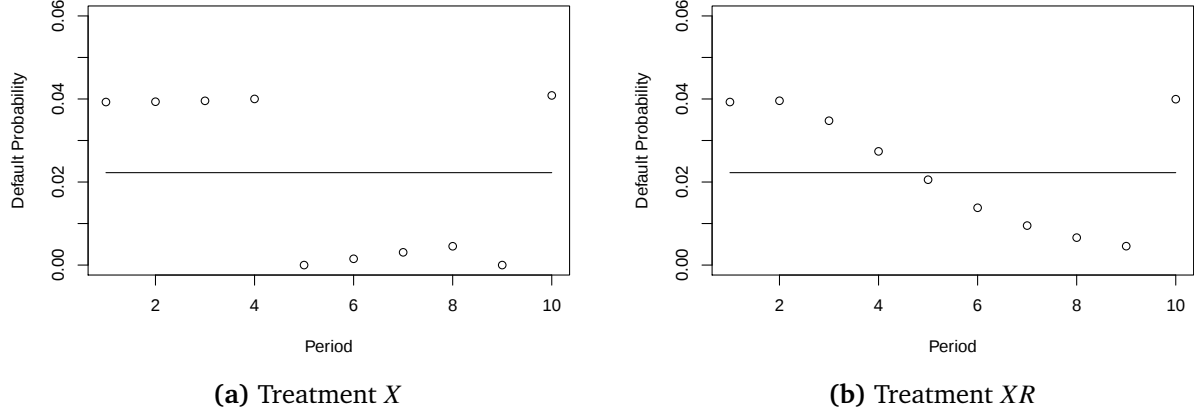


Figure 6. Equilibrium Default Probabilities. The graph shows the equilibrium default probabilities in all periods in both treatments as determined in numerical simulations. The equilibrium default probability of treatment *DEC* (Experiment I) is indicated by a solid line.

III. Results

For each of the two experiments, we have data from 16 independent groups of six subjects, split equally across each of the two treatments, or 8 independent groups per treatment. Each group participates in four markets, for a total of 32 markets per treatment. As noted earlier, the different groups do not interact with one another in any way, so that the observations at the group level are treated as being statistically independent.

We report results for both experiments jointly, usually starting with the results in Experiment I and then continuing with the corresponding results in Experiment II. As the two experiments are based on different (albeit very similar) models, we abstain from testing for differences between treatments of the two different experiments. All tests are between treatments of a *single* experiment and are two-sided.

A. *Aggregate Observations*

We begin with a brief overview of the aggregate findings before focusing more closely on IPO prices and prices in later trading periods. The graphs of all market prices in all rounds and periods for all groups separately can be found in Internet Appendix C for Experiment I and in Internet Appendix D for Experiment II. The graphs showing the traded quantities can similarly be found in Internet Appendices C and D.

Our main interest lies in the pricing of the bonds in the IPO, where the feedback loop between price and default probability makes the task arguably more difficult than in subsequent trading periods. The results are striking; in all treatments of both experiments, subjects learn, over time, to price the bonds well. This is shown in more detail in the next section. Overall, the differences in IPO prices between both treatments of Experiment I are rather small. Similarly, the differences in the IPO prices between both treatments of Experiment II are small. Furthermore, the outcomes of IPO pricing in Experiment II look very much like the results for the simpler environment of Experiment I. Learning to price in the IPO seems to take place similarly, independent of whether the mapping of IPO prices to default probabilities is explicitly given to subjects (Experiment I) or whether it has to be inferred from the structural equations of the model (Experiment II). Similarly, learning seems to take place independent of whether the fundamental value is decreasing or increasing (Experiment I) and independent of whether there is more or less randomness in cash flows (Experiment II). To give an idea of the magnitudes, IPO prices in the first round start out on average between 40% and 50% below the risk-neutral equilibrium and increase continuously over the rounds to, on average, just 0%-20% below equilibrium.

We next turn to a brief overview of prices across periods in the different rounds. Figure 7 shows a few examples of paths for observed bond prices in Experiment I. Market prices are shown as (red) circles. When there is no trade, but when both bids and offers are present, we indicate the midpoint between highest bid and lowest offer price with a

(red) cross. The equilibrium fundamental value is shown as a solid line and the maximum joint earnings line is shown as a dashed line (cf. Figure 2).¹⁶ Actual fundamental values in the trading periods depend on the price realized in the IPO (i.e., the price in period 0) and are shown as a (blue) dotted line. The figure shows two markets starting out a bit below the equilibrium fundamental value where bonds were priced close to fundamentals in all subsequent periods, one in *DEC* and one in *INC* (Figures 7a and 7c). The figure also shows two markets with pronounced bubbles, one in *DEC* and one in *INC*. In one case, the bubble is deflated slowly (Figure 7b) while in the other case the bubble bursts with hardly any subsequent trade (Figure 7d). Also in Experiment II, both bubbles and prices close to fundamental values are observed. Due to space constraints, we do not show examples of price paths observed in Experiment II here (for all of these paths, see Internet Appendix D).

¹⁶The equilibrium fundamental values may seem quite flat in this graph. That is because the scale of the y-axis was chosen to show the highest observed prices. Equilibrium fundamental values decrease from about 1860 in the first period to 1000 (the face value) in the tenth period of *DEC* and increase from about 1860 in the first period to 2500 (the face value) in the tenth period of *INC*.

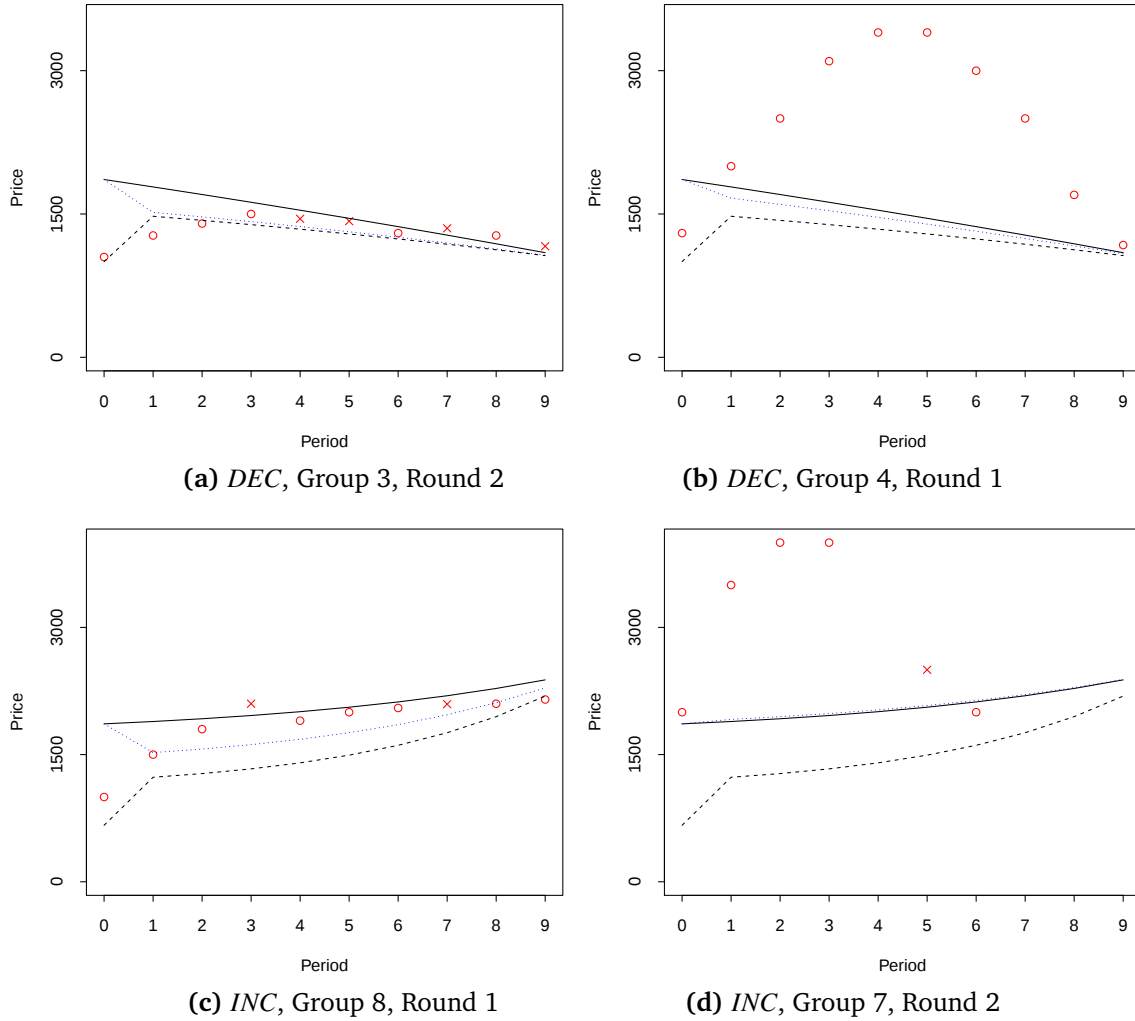


Figure 7. Examples of Market Prices in Experiment I. Market prices are shown as red circles. Red crosses show means of highest bid and lowest offer price when no trade is realized. The solid black line shows the equilibrium fundamental value and the dashed black line shows the price that maximizes expected joint earnings. The actual fundamental value within a round (which depends on the IPO price) is drawn with a dotted blue line.

Before discussing the occurrence of bubbles, we need to define what constitutes a bubble. While there is no generally accepted definition, we define it as follows: a market exhibits a bubble if the relative absolute deviation (see Stöckl, Huber, and Kirchler (2010)) is greater than 0.5. This measure of mispricing is described in more detail in Section III.C.

Bubbles in bond prices are relatively rare in Experiment I. Most groups learn to price bonds relatively well after the IPO. More specifically, we observe bubbles in four out of the 32 markets in *DEC* and in five out of the 32 markets in *INC*. The four bubbles in *DEC* arise

in the first round of one group and in the first three rounds of another group (groups 4 and 7, respectively, in Figures IA.9 and IA.10 in Internet Appendix C). The bubbles in *INC* arise in the first two rounds of two groups and in the second round of one group (two bubbles in groups 5 and 7 and one bubble in group 6 in Figure IA.12 in Internet Appendix C). We never observe any bubbles in the last (fourth) round.

Similar observations hold for Experiment II. Here, somewhat surprisingly, we observe more bubbles in treatment *X*, with noise only in cash flow X_t , than in treatment *XR* with noise in both cash flows (12 of the 32 markets in *X* as compared to 3 of the 32 markets in *XR*). In *X*, there are bubbles in the first three rounds for groups 2 to 4, in the second and third rounds for group 8 and in the first round for group 1 (see Figures IA.16 and IA.17 in Internet Appendix D). In treatment *XR* there are only bubbles in the first round for groups 4 and 5 and in the third round for group 3 (see Figures IA.18 and IA.19 in Internet Appendix D). Notice that in Experiment II, just as in Experiment I, no bubbles appear in the last round; that is, experienced traders are not susceptible to this mispricing.

Concerning traded quantities, in the IPO, all 25 bonds are always sold in both experiments. In the trading periods that follow, we observe some continued trade in bonds among most groups, with an average number of around two trades per period in Experiment I and two-and-a-half trades per period in Experiment II (for details on traded quantities, see Internet Appendix C for Experiment I and Internet Appendix D for Experiment II).

We next discuss the main experimental findings in more detail. We start with prices in the IPO, which are the main results of interest, and then consider prices over all periods in a round.

B. Prices in the IPO

The IPO (and its importance for the probability that the bond issuer defaults) is the most important feature of our experimental bond markets. Of particular interest is whether subjects can price bonds correctly in the IPO and how experience with the IPO influences this initial pricing. Figure 8 shows the IPO prices in all treatments of both experiments over the four rounds. Table I shows the mean prices across groups (represented by the (red) bold line in the graph) and the median prices.

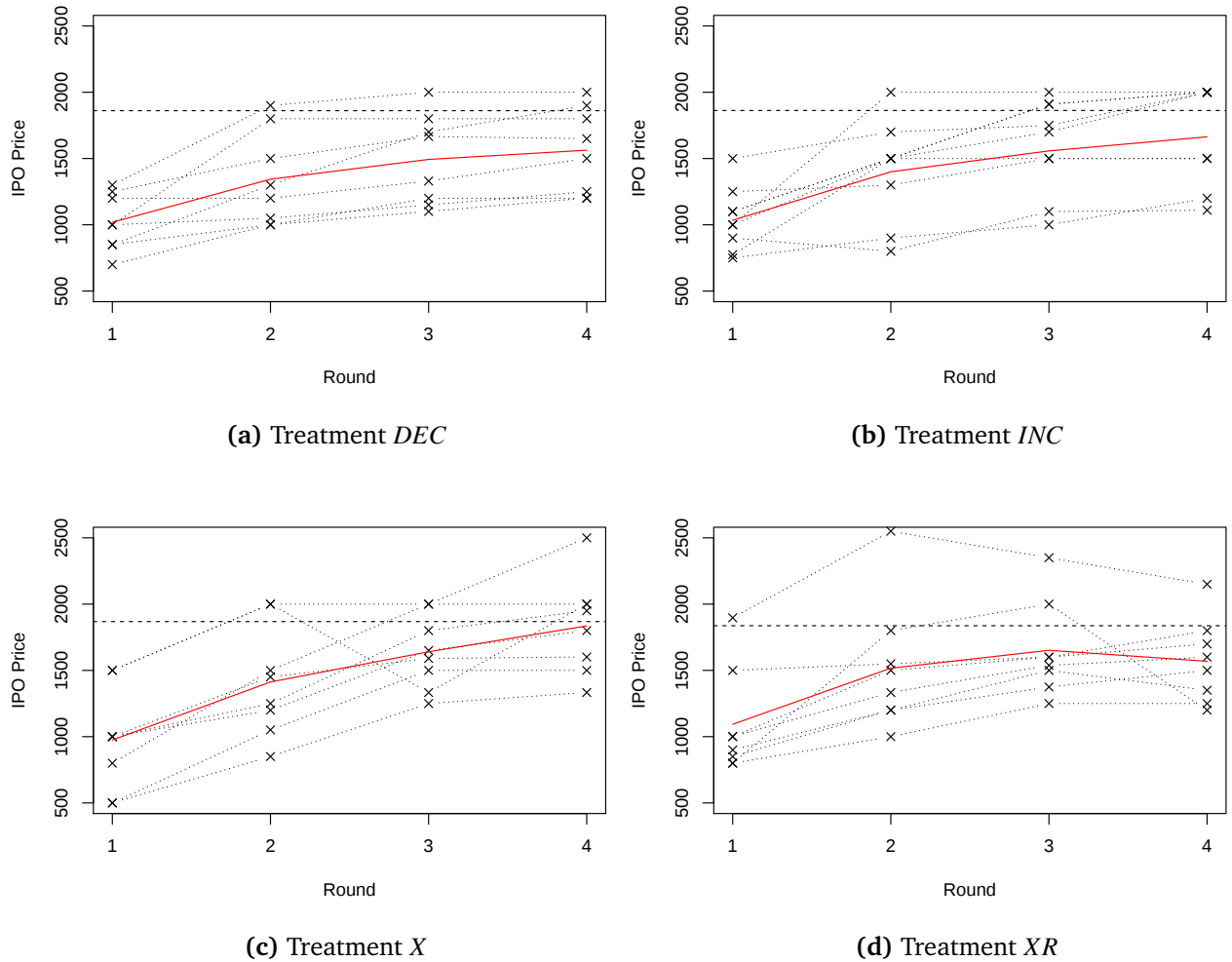


Figure 8. IPO Prices in all Rounds in Experiment I (Top) and Experiment II (Bottom). Each cross represents the IPO price of one group in one round. The prices of each group across rounds are connected by a dotted line. The dashed horizontal line is the equilibrium fundamental value in the IPO. The solid red line depicts the average of the eight IPO prices per round (cf. Table I).

Table I
Mean and Median IPO Prices

This table shows for each round the mean and median prices in the IPO (rounded to full points). The last column shows the equilibrium value.

	Treatment	Round 1	Round 2	Round 3	Round 4	Equilibrium
Exp. I (mean)	<i>DEC</i>	1019	1344	1493	1563	1861
	<i>INC</i>	1034	1400	1558	1664	1862
Exp. II (mean)	<i>X</i>	975	1413	1640	1836	1868
	<i>XR</i>	1094	1517	1652	1569	1837
Exp. I (median)	<i>DEC</i>	1000	1250	1498	1575	1861
	<i>INC</i>	1000	1500	1600	1750	1862
Exp. II (median)	<i>X</i>	1000	1351	1620	1875	1868
	<i>XR</i>	950	1417	1569	1550	1837

Figure 8 shows learning across rounds. Subjects clearly price the bonds better in the final IPO of the fourth round as compared to the first round. This effect is statistically significant. The absolute difference between actual IPO prices and their equilibrium value is smaller in the fourth round than in the first round for all treatments in both experiments. For Experiment I, the p -values from a Wilcoxon signed-rank test are less than 0.01 in both treatments, while in Experiment II, the p -values using the same test are 0.014 in treatment *X* and 0.023 in treatment *XR*. When pooling the data of both treatments in each experiment, the p -values are < 0.01 in both experiments.

Pricing the bonds in the IPO is a complicated task because of the endogeneity of default probabilities. Nevertheless, subjects price bonds so well in both experiments that by the fourth round, market prices are distributed around the equilibrium fundamental value, with mean prices somewhat below this value. We check whether the deviation from the equilibrium IPO value is significant. In the first round, there is a significant difference in both treatments of Experiment I with p -values from a Wilcoxon signed-rank tests of 0.014 in both cases (the p -value of the pooled data is < 0.01). In the fourth round, IPO prices are still marginally significantly different from the equilibrium IPO value in *DEC* (p -value

0.055) but not so in *INC* (p -value 0.287; the p -value from the pooled data is 0.149). It seems that whether the fundamental value in the trading periods is decreasing or increasing plays no particularly important role for how well subjects can price the bonds in the IPO; in line with this observation, IPO prices are not significantly different between treatments for any round. The findings between treatments are similar for Experiment II. In the first round, prices are significantly different from the equilibrium IPO in both treatments (p -values from a Wilcoxon signed-rank tests are 0.014 in *X* and 0.021 in *XR*; the p -value from the data of both treatments pooled is < 0.01). In the fourth round, IPO prices are still marginally significantly different from the equilibrium value in *XR* ($p = 0.055$) but not so in *X* ($p = 0.944$; pooled data: $p = 0.103$). Figure 8 suggests that IPO prices are similar between the treatments in Experiment II, independent of whether one or both sources of cash flow are noisy; unsurprisingly, IPO prices are not significantly different between the two treatments for any round. The p -values of the statistical tests are summarized in Table II.

Table II
Statistical Test Results IPO Prices

This table shows p -values of two-sided Wilcoxon signed-rank tests. The first column (learning R1-R4) tests whether the absolute distance to the equilibrium in round 4 is different from that in round 1 (null-hypothesis: no difference). The second column (R1-Eq.) tests whether prices in round 1 are different from the equilibrium value (null-hypothesis: no difference). The third column (R4-Eq.) reports the same results for round 4. Differences in IPO-prices between treatments (not shown in the table) are not significant in both experiments in any round (tested with Wilcoxon rank-sum tests).

	Treatment	Learning R1-R4	R1-Eq.	R4-Eq.
Experiment I	<i>DEC</i>	< 0.01	0.014	0.055
	<i>INC</i>	< 0.01	0.014	0.287
Experiment II	<i>X</i>	0.014	0.014	0.944
	<i>XR</i>	0.023	0.021	0.055

One can clearly observe that learning takes place in the IPO in all treatments of both experiments. Of course, we do not (and cannot) observe perfect convergence to the equi-

librium price. Nevertheless, Figure 8 and Table I give a very clear picture. Average prices in all treatments of both experiments start considerably below the equilibrium (about 40% to 50% below) and then increase continuously to less than 20% below the equilibrium. More precisely, the percentage deviations of average IPO prices from the equilibrium are in the first round 45 in *DEC*, 44 in *INC*, 48 in *X*, and 40 in *XR*. By the final fourth round, the percentage deviations are 16 in *DEC*, 11 in *INC*, 2 in *X*, and 15 in *XR*. Average IPO prices always stay below the equilibrium value and the slopes of the averages (the red lines in Figure 8) become flatter over time.¹⁷ Recall that the equilibrium is derived assuming risk-neutral investors and that the expected payoffs in equilibrium are zero. IPO pricing at the equilibrium would therefore mean that subjects take risks for zero expected profit. Prices below this value might therefore indicate risk aversion.¹⁸ Considering this possibility and keeping in mind that previous asset market experiments generate price deviations of often more than 50%, we judge our subjects' 20% or less mispricing of complex bonds to be remarkably accurate. Though we cannot claim full convergence to the equilibrium prices, our results do suggest a noteworthy extent of convergence of average IPO prices in the time-frame allowed by our experiment. Note that the convergence that we observe is convergence to the equilibrium prices and not convergence to the prices that maximize joint profits of a group's subjects which are always much lower (they are even zero in Experiment II). Observed prices move further away from those prices across the rounds; there is thus no sign of "collusion against the experimenter".

While pricing in the IPO is overwhelmingly similar across all treatments of both experiments, we do note that there are two groups that do not show any learning. Inspection of Figure 8 shows that in treatments *DEC* and *INC* all 16 groups learned to better price the IPO of bonds over time, but there are two groups in Experiment II for which such learning

¹⁷In treatment *XR* there is a minimal tick downward in the end, driven by one group for which no learning can be observed.

¹⁸For a careful discussion of risk attitudes and their modeling, see Friedman et al. (2014).

appears to be absent, one in each of the two treatments. These are the group in treatment X with IPO prices increasing in the four rounds from 800 over 1500 and 2000 to 2500 and the group in treatment XR with IPO prices of 800, 1800, 2000, and 1200 across the four rounds. We attribute these two non-convergent outcomes to the fact that IPO pricing in Experiment II is considerably more difficult for subjects. Nevertheless, despite this additional difficulty, for the vast majority of groups in both treatments (7 out of 8 groups each), there is strong evidence of learning of the IPO price.¹⁹

C. Market Prices across All Periods

We next consider the extent to which prices deviate from fundamentals across all periods of a round. Note that, even for a given IPO price (and, therefore, for a fixed default probability) our secondary market is different from previous experimental asset market studies based on Smith, Suchanek, and Williams (1988). Contrary to those previous markets, the situation in our markets typically changes from one round to the next, because the IPO price and, thus, the default probability can differ across rounds. In Experiment II this probability is even unknown to subjects (i.e., it has to be inferred from the structural equations). It is therefore interesting to consider whether this instability affects pricing in the secondary markets. Specifically, we consider two measures of the deviation of bond prices from fundamental values – the relative absolute deviation (RAD) and the relative deviation (RD). These are given by:

$$RAD = \frac{1}{T^*} \frac{\sum_{\{t|trade\ in\ t\}} |M_t - V_t|}{\bar{V}^*} \text{ and } RD = \frac{1}{T^*} \frac{\sum_{\{t|trade\ in\ t\}} M_t - V_t}{\bar{V}^*}, \quad (8)$$

¹⁹Actual defaults in the experiment are not of particular interest, because they are just a noisy consequence of IPO prices. More information on defaults can be found in Internet Appendix C for Experiment I and in Internet Appendix D for Experiment II.

where M_t stands for the market price in period t , V_t stand for the fundamental value in period t , T^* is the number of periods in which there is trade and thus a market price (in this experiment market prices can arise in periods 0 to $T - 1$; that is, the data we report in this section cover the IPO and all secondary market periods of a round jointly), and $\bar{V}^*$ is the average of the fundamental values in the periods in which there is trade.²⁰ RAD measures mispricing; both positive and negative deviations of the market price from the fundamental value V_t increase this measure. RD measures overvaluation; market prices above the fundamental lead to a higher measure, while market prices below the fundamental lead to a lower measure. Note that in our bond market setting, the fundamental value that is relevant to determine the accuracy of market prices in the secondary market is neither the fundamental value conditional on the competitive equilibrium IPO price nor the fundamental value conditional on the joint earnings maximizing price; instead, it is the fundamental value conditional on the IPO price actually realized in this market. Consequently, we use the actual fundamental values (i.e., the ones conditional on realized IPO prices) for periods 1,...,9 in these formulas.

The upper half of Table III shows the mean values of RAD across groups for each round. It is clear that mispricing decreases continuously over all rounds in all treatments. This downward trend suggests that, similar to the results regarding IPO prices, subjects also learn with experience to better price bonds in the secondary market.

²⁰These measures are straightforward adaptations of those introduced by Stöckl, Huber, and Kirchler (2010). The adaptations allow for periods without trade.

Table III
Means RAD and RD

This table shows the means of the relative absolute deviation (RAD) and of the relative deviation (RD) across groups for both experiments.

	Treatment	Round 1	Round 2	Round 3	Round 4	Mean R1-R4
Exp. I (RAD)	<i>DEC</i>	0.400	0.274	0.208	0.171	0.263
	<i>INC</i>	0.324	0.312	0.236	0.184	0.264
Exp. II (RAD)	<i>X</i>	0.603	0.491	0.408	0.202	0.426
	<i>XR</i>	0.347	0.266	0.223	0.151	0.247
Exp. I (RD)	<i>DEC</i>	0.158	0.124	0.054	-0.002	0.084
	<i>INC</i>	0.022	0.097	-0.102	-0.095	-0.019
Exp. II (RD)	<i>X</i>	0.341	0.361	0.320	0.131	0.288
	<i>XR</i>	0.116	0.141	0.093	0.022	0.093

Comparing the differences in RAD between the fourth and the first round for each group, Wilcoxon signed-rank tests reject the null-hypothesis of no learning in *DEC* with a p -value of 0.039, but this cannot be rejected for *INC* ($p = 0.461$). Pooling both treatments, the null is rejected with $p=0.044$ in favor of the alternative hypothesis that prices are closer to fundamentals in the last round. In Experiment II, the RAD also decreases continuously in both treatments; the patterns and magnitudes are very similar to Experiment I. The table suggests that pricing in treatment *X* is, on average, worse than in treatment *XR* (and also worse than in both treatments of Experiment I), in particular in the first rounds. This corresponds to the greater frequency of bubbles arising in treatment *X* as discussed in Section III.A. However, these differences in mispricing are eroded after the third round. Comparing the differences in RAD between the fourth and the first round for each group, Wilcoxon signed-rank tests reject the null-hypothesis of no difference in treatment *X* with a p -value of less than 0.01. The same holds for treatment *XR* ($p < 0.01$). In fact, in both treatments, all eight groups price bonds better in the last round than in the first round. Differences between treatments in Experiment I are not significant in any round. The same holds for differences between treatments in Experiment II despite poor pricing by

some groups in X . Table IV summarizes the p -values of the tests conducted in this section.

Table IV
Statistical Test Results RAD and RD

This table shows p -values of two-sided Wilcoxon signed-rank tests. The first column (RAD R1-R4) tests whether the relative absolute deviation (RAD) in round 4 is different from that in round 1 (null-hypothesis: no difference). The second column (RD R1-R4) shows results for the same test for the relative deviation (RD). Differences in RAD and RD between treatments (not shown in the table) are not significant in either experiment in any round (tested with Wilcoxon rank-sum tests).

	Treatment	RAD R1-R4	RD R1-R4
Experiment I	<i>DEC</i>	0.039	0.195
	<i>INC</i>	0.461	0.250
Experiment II	<i>X</i>	< 0.01	0.078
	<i>XR</i>	< 0.01	0.742

Table III also reports the extent of overvaluation as measured by the relative deviation, RD, for both experiments. The table reveals that overvaluation is more commonly observed than undervaluation and that there is a tendency to price bonds lower in later rounds in all treatments of both experiments. This tendency can be attributed to fewer bubbles appearing (as noted above we do not observe bubbles in the last round in any of the treatments of either experiment).

The data for Experiment I reveal that there is some overpricing in the first rounds of *DEC*, which then disappears with experience. In *INC*, there is a small amount of overpricing in the first two rounds which then turns to a small amount of underpricing in later rounds. The differences between the first and fourth round are statistically insignificant, however (Wilcoxon signed-rank tests, $p=0.195$ for *DEC* and $p=0.250$ for *INC*). The differences are marginally significant when the data of both treatments are pooled ($p=0.074$). For Experiment II, Table III shows consistent overpricing that diminishes over the rounds. Overpricing is highest in the first rounds of treatment *X*, while lower overpricing is observed in treatment *XR*. This is in line with the data on RAD and the discussion on

bubbles in Section III.A. The differences between rounds 1 and 4 are marginally significant for X ($p = 0.078$) but insignificant for XR ($p = 0.742$). This suggests a greater improvement in bond pricing in X as compared to XR (starting out from poorer pricing in X in early rounds). When the data of both treatments are pooled, the results are insignificant ($p = 0.117$). Differences between the two treatments in either experiment are statistically insignificant in any round.

D. Further Discussion of the Results

The described results show a considerable degree of learning as market prices approach equilibrium values. This holds for the pricing in the IPO, which is the main contribution of this paper, but also for the pricing across periods. It is beyond the scope of this paper to present a full-fledged analysis of the dynamics and mechanisms of this learning. However, here we want to discuss what factors may contribute to this learning (and subjects' market behavior in general) and which mechanisms are unlikely to play a major role.

First, we discuss the findings of the pricing in the IPO. Pricing the bonds correctly is a very difficult task due to the endogeneity of default probabilities. The fact that IPO prices in the first round are always considerably below the equilibrium value suggests that subjects react to this difficulty (which may be interpreted as uncertainty about the value underlying the bonds) with very cautious bidding behavior. Subjects thus seem to reduce the likelihood of losing a lot of money. If this uncertainty is interpreted as risk, this underpricing could be interpreted as a sort of risk aversion (although this uncertainty does not arise from a given probability distribution as the most common type of risk in economic models). Over the course of the rounds, subjects familiarize themselves with the workings of the model and the market, so that their uncertainty decreases. This reduced uncertainty (which is similarly a better understanding of the features of the model and therewith a better understanding of the correct – that is, equilibrium – price) leads to increasing prices

over the rounds. In other words, whenever prices are below the equilibrium price, subjects have a monetary incentive to buy more bonds; the better subjects understand the working of the bond market and therewith these incentives, the closer they drive the market price to the equilibrium. This may explain the convergence of IPO prices towards the equilibrium observed in the experiments.

One may also wonder whether rational speculation on capital gains by some subjects drives market prices. That is, some subjects may rationally anticipate mispricing of the bonds and therefore knowingly bid above or below the equilibrium. Anticipated overpricing would lead these subjects to place higher bids, as they would speculate on selling the bonds in the secondary market at a high price. Similarly, anticipated underpricing would lead such subjects to place lower bids, as they would speculate on being able to buy bonds cheaply in the secondary market. However, while we cannot exclude the possibility that such behavior plays some minor role in the pricing of the bonds, it is certainly not a main driver of the observed market prices or of the learning dynamics. This can be seen as follows. Overpricing is more common than underpricing in all treatments except for treatment *INC*, in which overpricing and underpricing are equally likely (see Table III). If some subjects of a group correctly anticipate the overpricing in the secondary market in these three treatments, they should bid above the equilibrium price in the IPO (because they expect capital gains). That is, the price that one could refer to as the “optimal IPO price given the average mispricing observed in subsequent secondary trading periods” is above the equilibrium IPO price in these treatments. However, observed market prices stay below the equilibrium price (see Figure 8). They are in particular lower than the equilibrium in the earlier rounds when the most overpricing in the secondary market is observed. It thus seems that rational speculation on capital gains on behalf of some subjects is not an important driver of market prices in the IPO. Furthermore, one can exploit the difference between treatment *INC* and the other treatments here. If this rational speculation were an important driver of IPO prices, we should observe lower IPO prices in *INC* than in the other

treatments. However, also this is not the case (see Figure 8). Similarly, if the mispricing in the secondary market were a crucial factor determining the learning dynamics in the IPO, we should observe slower convergence of IPO prices in treatment *INC* than in the other treatments. However, we do not observe this and again conclude that rational speculation on capital gains on behalf of some subjects is not a particularly important driver of the market prices or of the learning dynamics that we observe.

Now, we briefly turn to the pricing in the secondary market. In the early rounds, prices after the IPO are more often too high than too low (opposite to the prices in the IPO that are usually below the equilibrium value but similar to the findings of regular asset market experiments without IPO and endogenous default). Of course, also here, subjects understand the market mechanisms and the incentives behind them better over time. In addition to this, subjects who buy at too high prices (or sell at too low prices) are hurt by their decisions and lose money. This leads to their better pricing of the bonds in the later rounds of our experiments. The learning in the secondary market thus seems similar to the learning in regular asset market experiments.

IV. Conclusion

The two-way interaction between IPO prices and default probabilities is an important but under-studied topic in finance. As Bond, Edmans, and Goldstein (2012, p. 342), observe, “Unlike the traditional approach, where prices only reflect expected firm cash flows, in these models [with feedback effects], prices both affect and reflect firm cash flows. George Soros, a prominent trader, has termed this feature ‘reflexivity,’ and summarized it as follows: In certain circumstances, financial markets can affect the so-called fundamentals which they are supposed to reflect.”

While much of the research on feedback effects as surveyed by Bond, Edmans, and Goldstein (2012) focuses on the secondary market, for example, how changes in the

prices of existing stocks induce changes in firm behavior that in turn affect those same stock prices, we are interested in feedback effects in the primary (IPO) market for high credit risk bonds subject to default. Specifically, we have designed and reported on the first experiment to address the pricing of assets subject to default risk, where the default probabilities depend on the price that the assets raise in the IPO. That is, there is feedback from asset prices to default probabilities and vice versa. Such feedback effects can exist for a variety of asset classes, but it is particularly obvious for new issues of bonds.

The pricing of such bonds is more complicated than the pricing of other assets that experimentalists have studied in the laboratory. In this paper, we have developed two models of bond pricing in which bond purchasers must address these complications. We then incentivize human subjects in a laboratory experiment to test whether they behave according to the theory. We evaluate whether these subjects are able to correctly price the IPO of bonds and whether they trade these bonds in subsequent periods at prices that approximate the fundamental value given the default risk that was determined by the IPO price.

Our main finding is that with sufficient experience, subjects do learn to set an IPO price for bonds that is close to the equilibrium price. Importantly, this finding is obtained both when the relationship between IPO price and default risk is explicitly given and when this relationship has to be inferred from the structural equations of the economy. Further, we find that in subsequent trading periods, bubbles disappear with experience, that is, bond prices track fundamentals well after a few repetitions. These findings demonstrate that market forces are strong enough to provide efficient pricing of risky bonds in spite of the complexities of these assets in comparison to other types of assets that have dominated the experimental finance literature. Thus, experimentalists may also want to include bonds (or more generally assets with an endogenous default risk) among the assets that they explore in future experimental tests of asset pricing theory. Our research also reinforces the notion that, among experienced subjects, market equilibrium is a good predictor of

market behavior. This holds even in the case of complex feedback loops between market price and default probability as is present in many asset markets, most notably those for bonds.

If it were possible, it would, of course, be of great interest to examine how well real bond market traders price bonds subject to default risk in the field. However, the lack of control over important aspects of the theory inhibit such an analysis. These aspects include the relationship between default risk and IPO price, the details of the IPO auction rules, the set of traders and the information available to those traders. Laboratory control allows us to abstract from such confounding factors, providing a clean test of the theory. As the feedback effect does not prohibit rather accurate pricing of the bonds in the laboratory, it is likely that the feedback effect in itself does not lead to inaccurate pricing in the world outside of the laboratory.

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Internet Appendix for "An Experimental Study of Bond Market Pricing"*

MATTHIAS WEBER, JOHN DUFFY, and ARTHUR SCHRAM

A. Instructions and Test Questions for Experiment I

A.1. Instructions for Experiment I

In the following we reproduce the instructions of the treatment with decreasing fundamentals. The instructions of the treatment with increasing fundamentals are similar, only the numbers are correspondingly different (as described in Section II.A of the main text), of course also leading to a different graph of the default probability function. This graph, a table with values, and a short summary of the information (which is shown at the end of the instructions) for the treatment with increasing fundamentals are reproduced below the instructions of treatment *DEC*.

A.1.1. Instructions in the Decreasing Fundamentals Treatment

Instructions

Welcome to this experiment! Please read these instructions carefully as they explain how you earn money from the decisions that you make. You will be paid privately at the end,

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after all participants have finished the experiment. On your desk you will find a calculator and scratch paper, which you can use during the experiment.

During the experiment you are not allowed to use your mobile phone or other electronic devices. You are also not allowed to communicate with other participants. If you have a question at any time, please raise your hand and someone will come to your desk.

The experiment consists of four identical rounds. Each round consists of 11 periods, numbered from 0 to 10. Your earnings for each of the four rounds will be in points. **At the end, only your earnings from one randomly chosen round will be paid out to you!** **The points from the chosen round will be exchanged into euros at the exchange rate 1000 points = 1 euro.** In addition you will receive a show-up fee of 7 euros.

All participants will be randomly divided into groups of 6 people. The group composition will not change during the experiment. You will not know the identity of any group member nor will they know your identity even after the experiment is over. The following describes what you will be doing in each of the four rounds.

Market Setting

You will start the round with an endowment of 20000 points (your “cash”). During most of the experiment, you will be given an opportunity to trade an asset with the other participants in your group (called “asset A” – there are no other assets). In total there are 25 assets.

Holding assets can give you earnings in a way that will be explained below.

If you want to buy some of these assets you can enter the number of assets you want to buy (bid for) at a certain price using the computer interface. You can state as many different bid prices and quantities as you like.

Example (the numbers here provide no indication of what you should enter in the experiment):
Imagine that you would like to buy 12 assets if the price per asset is at most 356 points, 7 assets

if the price is larger than 356 but no more than 688 points, and only 2 assets if the price is larger than 688 points but no more than 911.5 points. To indicate this, you can enter numbers into the computer interface as follows (if you wanted to enter more numbers you could click on the “show more fields” button):

[Figure IA.1 appears here in the experimental instructions.]

I would like to buy this quantity	if the price (per asset) is at most
12	356
7	688
2	911.5

Figure IA.1. Input fields of the computer interface (not labeled in the instructions).

If the market price turns out to be 600 points, you will then receive 7 assets for 600 points each (thus NOT 2 plus 7, i.e. the quantities that you enter are for the total number you want to buy at a certain price).

If you want to sell assets you previously bought, you can do something similar. You can enter the number of assets that you want to sell (offer quantity) and the offer price that you would like to receive for those units (the interface will be almost identical to the buying example above). You can again enter multiple combinations of quantities and prices.

The bids and offers that you can enter into the computer interface are restricted as follows:

- You can only enter positive integer number as quantities.
- You can only enter positive numbers as prices (if you want to enter a decimal, use a point and not a comma).

- You cannot try to sell more assets than you have at that moment. Similarly, you cannot try to buy more assets than there are available (which is 25 minus the number of assets you have).
- You cannot enter bids that you would not be able to pay for (with the amount of cash you have).
- You cannot enter multiple bids to buy assets with the same quantity or the same price.
- Similarly you cannot enter multiple offers to sell assets with the same quantity or the same price.
- You cannot try to buy more assets for a higher price than you would want to buy for a lower price (i.e., if you enter for example the quantity 20 with the price 1850, you cannot enter the quantity 10 with the price 1480 in the fields for your bids to buy assets).
- Similarly you cannot try to sell more assets at a lower price than you would sell at a higher price.
- Finally, all of your selling offers must be at a higher price than your buying bids (i.e. you cannot sell to yourself).

Market Price and Actual Trades

The market price in each period is determined by supply and demand. This means that the price will be chosen that makes the most trades possible. All trades are then carried out at this single market price, which is centrally determined for your group in each period.

Explanation: Imagine you enter that you would like to buy 6 assets if the price is at most 1500 points and one other participant enters that she would like to buy 9 assets if the price is at most 1500. Imagine further that nobody else in the market enters a buying bid at 1500 points or a higher price. This means that all participants of the market together

would like to buy 15 assets if the price is at most 1500 points per asset. The aggregation of the buy orders can be done for all prices and yields the market demand schedule. This demand schedule contains the information of all buy orders for all participants of the market together and can be represented by a step function as below. On the horizontal axis you can see the total quantity demanded for each price on the vertical axis (this is a very simple example and the quantities and numbers provide no indication of what you should enter in the experiment). In the graph of this simple example you can see that all participants of the market together are willing to buy up to 75 assets at a price of 500 points per asset, only 50 assets at a price of 1000 points per asset, and only 15 assets at a price of 1500 points per asset.

[Figure IA.2 appears here in the experimental instructions.]

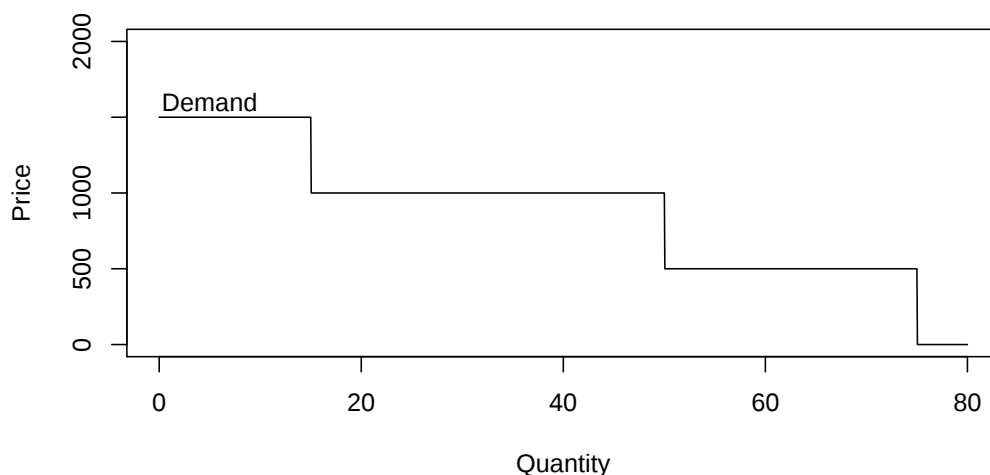


Figure IA.2. Demand schedule (not labeled in the instructions).

A similar schedule can be derived for the supply side of the market, aggregating all the sell offers. When drawn in the same graph, the supply schedule is an increasing step function.

[Figure IA.3 appears here in the experimental instructions.]

The market price is the price at which the two curves intersect (in this example 1000). Note that at this price, 10 more assets are demanded than supplied (50 assets are demanded

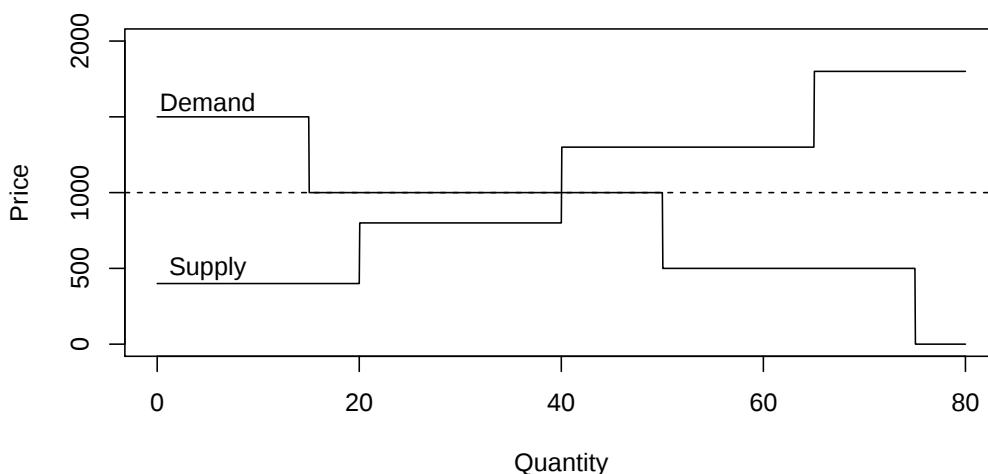


Figure IA.3. Demand and supply schedules (not labeled in the instructions).

while only 40 are supplied). In this case a random selection of 10 bids from all the bids at the market price would not be fulfilled (it is similarly possible that there is more supply at the market price than demand).

In some rare cases there can also be a whole interval of prices at which most trades can be carried out (then the demand and supply schedule overlap vertically). In such cases the middle of the interval will be the market price. If no bids or offers are made at all or if all bids to buy are at lower prices than all offers to sell there will be no trade and also no market price.

You will always be told the market price after the trading. You will not be told the total number of trades in the market (except if there are none).

Properties of the Asset

There will be no trading in period 10. If you hold assets in period 10, you will receive 1000 points for each asset, provided that the asset has not defaulted (more on this below).

In each of periods 1-10 you receive interest payments on your asset holdings (if they have not defaulted). The interest payment per asset is 12% of the final value (1000 points), which means that you will receive 120 points for each asset you hold in a period. These

earnings will be paid to a separate account – they are part of your earnings for the round, but you cannot use those points to buy more assets.

The asset you are trading has a special property. There is a constant possibility of “default”. At the beginning of each period (from period 1 on to period 10) it is determined whether a default occurs or not. How this probability of default is determined will be explained shortly. If a default occurs, the assets will become completely (!) worthless for all periods remaining in the round. This means that from the period of default onward there will be no interest payments and there will be no payoff of 1000 points per asset after period 10.

Period 0 Trading and Probability of Default

The first period of each round is a special period (period 0). In this period, none of the participants holds any of the 25 assets. You can try to buy them as in the regular periods 1, 2, ..., 9, but instead of buying them from other participants you will buy them directly from the experimenter. The computer interface is similar to the computer interface in the regular periods (i.e. you can enter the number of assets you want to buy at a certain price). The experimenter only sells assets in period 0 and does not interfere with the market thereafter. The experimenter will sell all assets in this period, for the highest unique price at which all of them can be sold (if there is not enough demand to sell all assets even at a minimal price, the experimenter will sell as many assets as are demanded).

The outcome of this period 0 is important not only because it distributes the assets amongst the participants in the group. It also determines the probability that the assets default in each of the other periods. The higher the market price is in period 0, the lower is the probability that there will be a default (this probability is determined in period 0 and stays constant once period 0 is over). The following graph shows you the exact relationship between period 0 price and default probability. On the horizontal axis you can see possible period 0 prices and on the vertical axis you can see the default

probability that would result from each price.

[Figure IA.4 appears here in the experimental instructions.]

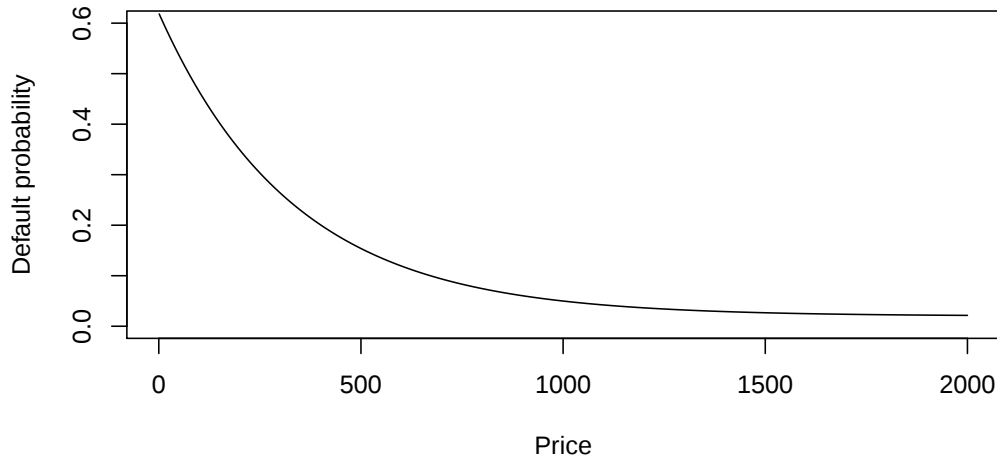


Figure IA.4. Default probability function, decreasing fundamentals (not labeled in the instructions).

The following short table gives you some period 0 prices and the corresponding default probabilities.

Price	1	100	200	400	600	800	1000	1500	2000	3000	5000
Prob.	0.618	0.464	0.349	0.201	0.119	0.074	0.050	0.027	0.021	0.020	0.020

At the beginning of each of the regular periods, the computer program determines whether or not there is a default *for the whole market* using the default probability determined by the price in period 0.

Information on Defaults

Although it will be determined at the beginning of each period whether there is a default in this period or not, we will not tell you whether or not a default has occurred! You will always continue the experiment as if no default has ever occurred – only after each 10 period round we will tell you if there was a default or not and if so, in which period the (earliest) default occurred. Your earnings for that round are then determined

as of the period the default occurred (your earnings are your cash holdings and the points earned in your interest account at the time of default – your assets at the time of default do not affect your earnings in any way). This means that any action you took after the default occurred does not affect your earnings (but when you take the decisions you don't know whether a default had previously occurred).

Summary of the Information

- 4 identical rounds
- 10 regular periods per round
- 20000 points cash to buy assets per round
- Period 0 is special and determines the default probability.
- If there is a default all assets become completely worthless. Earnings are based on interest paid before the default and cash holdings at the time of default.
- Each asset pays 120 points interest per period (if the asset is not in default).
- Points earned on assets in the interest account cannot be used to buy assets.
- If there is no default, then in period 10 each asset is exchanged for 1000 points.
- We don't tell you during a round if there is a default, you always continue as if there is none. However, the default is used to determine your round earnings.

A.1.2. Default Probability Function and Summary of the Information in the Increasing Fundamentals Treatment

In the instructions for the treatment with increasing fundamentals the numbers are different. Figure IA.5 shows the corresponding graph of the default probability function and Table IA.I shows the corresponding table. Furthermore, we reproduce here the short summary at the end of the instructions.

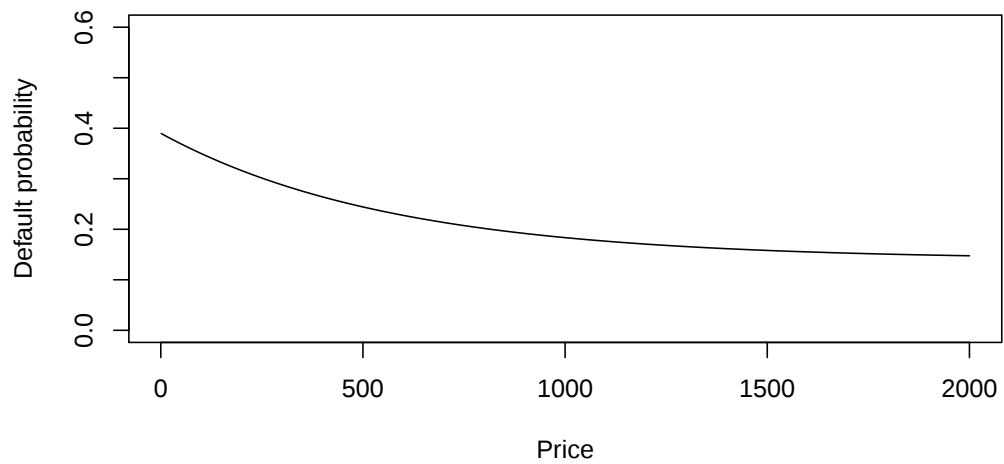


Figure IA.5. Default probability function, increasing fundamentals (instead of Figure IA.5 in the increasing fundamentals treatment).

Table IA.I
Table default probability function, increasing fundamentals

Price	1	200	400	600	800	1000	1500	2000	3000	5000	10000
Prob.	0.390	0.316	0.264	0.227	0.202	0.183	0.160	0.148	0.141	0.140	0.140

Summary of the Information

- 4 identical rounds
- 10 regular periods per round
- 20000 points cash to buy assets per round
- Period 0 is special and determines the default probability.
- If there is a default all assets become completely worthless. Earnings are based on interest paid before the default and cash holdings at the time of default.
- Each asset pays 300 points interest per period (if the asset is not in default).
- Points earned on assets in the interest account cannot be used to buy assets.
- If there is no default, then in period 10 each asset is exchanged for 2500 points.
- We don't tell you during a round if there is a default, you always continue as if there is none. However, the default is used to determine your round earnings.

A.2. Test Questions for Experiment I

The test questions that had to be answered by participants before they could start the experiment were the same in both treatments. They are reproduced here. We have added a checkmark behind the correct answers. Note that subjects had to answer all questions on one screen correctly in order to proceed to the next screen. If they did not answer all questions correctly and tried to proceed to the next screen they received the following error message: "You did not answer all questions correctly. Take another look at the instructions or raise your hand if you need help."

A.2.1. Screen 1

In period 0, the experimenter tries to sell all 25 assets. Imagine that all of the other 5 participants in your market enter only one bid each and that all of their bids are equal, specifying a quantity of 2 and a price of 1500. Imagine that you enter the following three bids:

Quantity 4 and Price 2000,

Quantity 8 and Price 900,

Quantity 25 and Price 50.

What will be outcomes of this?

- (a) All others receive 2 assets each and pay a price of 1500 points per asset. You receive 15 assets, some for a higher price than 1500 points, some for a lower price.
- (b) All others receive 2 assets each and you receive 15 assets. Everyone pays 50 points per asset. ✓
- (c) All others receive 2 assets each and you receive 4 assets. Everyone pays 1500 points per asset.
- (d) All others receive 2 assets each and you receive 25 assets. Everyone pays 50 points per asset.

In period 0, imagine that 4 of the other 5 participants in your market enter only one bid each and that all of their bids are equal, specifying a quantity of 5 and a price of 800. The fifth other participant and you both enter a quantity of 10 and a price of 600. What will be outcomes of this?

- (a) The market price will be 600. The 4 participants that entered the same bids receive 5 assets each, you and the person entering the same bid as you will receive 5 assets each.

- (b) The market price will be 800. The 4 participants that entered the same bids receive 5 assets each, you and the person entering the same bid as you will receive 5 assets each.
- (c) The market price will be 600. The 4 participants that entered the same bids receive 5 assets each, you and the person entering the same bid as you will receive 5 assets *together* (who receives how many exactly will be determined randomly). ✓
- (d) The market price will be 800. The 4 participants that entered the same bids receive 5 assets each, you and the person entering the same bid as you will receive 5 assets *together* (who receives how many exactly will be determined randomly).

Imagine that you want to buy 25 assets in total if the price is at most 204 points per asset. If the price is larger than 204 points but at most 788 points you want to buy 13 assets in total. If the price is larger than 788 points but at most 1800.5 points you want to buy 8 assets. What do you enter into the corresponding part of the computer interface?

- (a) Quantity: 25, Price 204, Quantity 13, Price 788, and Quantity 8, Price 1800.5. ✓
- (b) Quantity: 8, Price 1800.5, Quantity 5, Price 788, and Quantity 12, Price 204.

A.2.2. Screen 2

In periods 1 to 9 you can trade the asset with the other members of your group. You can enter bids to buy assets and offers to sell assets. Imagine that you consider both, buying and selling assets. Which of the following is correct?

- (a) You cannot try to buy assets at a higher price than the lowest price at which you are willing to sell assets. ✓
- (b) You can try to bid for as many assets as you like at any price. If the market price turns out to be high, your cash holdings may become negative.
- (c) You can make sell offers for the same quantity at different prices.

In the very beginning of each period from period 1 to 10 it will be determined whether there is a default. If there is a default, what happens to the assets?

- (a) The assets will not pay any interest anymore for the remaining periods of this round.
In the last period they will nevertheless be exchanged into 1000 points per asset.
- (b) The asset will not pay any interest anymore for the remaining periods of the round and participants will not receive any points for the assets in the last period. ✓

The default probability depends on the market price in period 0. Which of the following is NOT correct?

- (a) After period 0 has ended, the probability that there is a default is fixed for the rest of the round.
- (b) You can see in the corresponding graph in the instructions how the price in period 0 determines the probability of default.
- (c) When a new round starts, the default probability in the round before does not matter anymore for the new round.
- (d) The default probability for each period is determined in the period before. ✓

Imagine that in period 6 you hold 7 assets. Other members of your group each offer to sell 3 units at a price of 1100 and ask to buy 6 units at a price of 1000. You offer to sell 7 units at a price of 1151 and ask to buy 6 units at a price of 1149. What trades are you involved in, in period 6?

- (a) You sell 7 units at a price of 1151.
- (b) You sell 7 units at a price of 1149.
- (c) You sell 7 units at a price of 1100.
- (d) You sell 7 units at a price of 1000.
- (e) You buy 6 units at a price of 1000.

- (f) You buy 6 units at a price of 1100. ✓
- (g) You buy 6 units at a price of 1149.
- (h) You buy 6 units at a price of 1151.

A.2.3. Screen 3

If you hold assets at some point you may receive interest payments. Which of the following is correct?

- (a) You can use the money from your interest account to buy assets in later periods.
- (b) For each asset you are holding in a period you receive an interest payment of 120 points (if there has been no default before). ✓
- (c) An asset only pays interest in the period right after you bought it, even if you hold it for multiple periods.

There are rounds and periods in this experiment. Which of the following is correct?

- (a) There are 4 rounds in the experiment (each consisting of 10 regular periods and period 0). When you start a new round you have 20000 points in cash, 0 points in your interest account and no assets. ✓
- (b) In each of the regular periods you have 20000 points of cash to buy assets with.
- (c) Assets only last for one period, once the interest of an asset has been paid the asset always loses its value.

In each period there is the possibility of a default that makes all assets completely worthless. What happens when such a default occurs?

- (a) You will immediately be informed that the default occurs, your earnings are determined and your group will continue straight with the next round.

- (b) You will only be informed after the end of the round that this default occurred. Without you knowing it, the further actions you take during the rest of the round will no longer influence your earnings of the round. ✓

B. Instructions and Test Questions for Experiment II

B.1. Instructions for Experiment II

In the following, we reproduce the complete experimental instructions for the treatment with noise only in X_t . Up to the part “Underlying Model of the Assets and Defaults”, the instructions mirror the corresponding parts of the instructions of the reduced form model closely. Following the instructions for treatment X , we describe where and how the instructions of treatment XR differ.

B.1.1. Instructions in the Treatment with Noise only in X_t

Instructions

Welcome to this experiment! Please read these instructions carefully as they explain how you earn money from the decisions that you make. You will be paid privately at the end, after all participants have finished the experiment. On your desk you will find a calculator and scratch paper, which you can use during the experiment.

During the experiment you are not allowed to use your mobile phone or other electronic devices. You are also not allowed to communicate with other participants. If you have a question at any time, please raise your hand and someone will come to your desk.

The experiment consists of four identical rounds. Each round consists of 11 periods, numbered from 0 to 10. Your earnings for each of the four rounds will be in points. **At the end, only your earnings from one randomly chosen round will be paid out to you!** **The points from the chosen round will be exchanged into euros at the exchange rate 1000 points = 1 euro.** In addition you will receive a show-up fee of 7 euros.

All participants will be randomly divided into **groups of 6 people**. The group composition will not change during the experiment. You will not know the identity of any group

member nor will they know your identity even after the experiment is over. The following describes what you will be doing in **each** of the four rounds.

Market Setting

You will start each round with an endowment of 20 000 points (your “cash”). During most of the experiment, you will be given an opportunity to trade an asset with the other participants in your group (called “asset A”). In total there are 25 assets that you can trade.

Holding assets can give you earnings in a way that will be explained below.

If you want to buy some of these assets you can enter the number of assets you want to buy (bid for) at a certain price using the computer interface. You can state as many different bid prices and quantities as you like.

Example (the numbers here provide no indication of what you should enter in the experiment): Imagine that you would like to buy 12 assets if the price per asset is at most 356 points, 7 assets if the price is larger than 356 but no more than 688 points, and only 2 assets if the price is larger than 688 points but no more than 911.5 points. To indicate this, you can enter numbers into the computer interface as follows (if you wanted to enter more numbers you could click on the “show more fields” button):

[Figure IA.6 (identical to Figure IA.1) appears here in the experimental instructions.]

If the market price turns out to be 600 points, then you will then receive 7 assets for 600 points each (thus NOT 2 plus 7, the quantities that you enter are for the total number you want to buy at a certain price).

If you want to sell assets you previously bought, then you can do something similar. You can enter the number of assets that you want to sell (offer quantity) and the offer price that you would like to receive for those units (the interface will be almost identical to

I would like to buy this quantity	if the price (per asset) is at most
12	356
7	688
2	911.5
show more fields	

Figure IA.6. Input fields of the computer interface (not labeled in the instructions).

the buying example above). You can again enter multiple combinations of quantities and prices.

The bids and offers that you can enter into the computer interface are restricted as follows:

- You can only enter positive integer number as quantities.
- You can only enter positive numbers as prices (if you want to enter a decimal, use a point and not a comma).
- You cannot try to sell more assets than you have at that moment. Similarly, you cannot try to buy more assets than there are available (which is 25 minus the number of assets you have).
- You cannot enter bids that you would not be able to pay for with the amount of cash you have.
- You cannot enter multiple bids to buy assets with the same quantity or the same price.
- Similarly you cannot enter multiple offers to sell assets with the same quantity or the same price.
- You cannot try to buy more assets for a higher price than you would want to buy for a lower price (for example, if you enter the quantity 20 with the price 1850, then you cannot enter the quantity 10 with the price 1480 in the fields for your bids to

buy assets).

- Similarly you cannot try to sell more assets at a lower price than you would sell at a higher price.
- Finally, all of your selling offers must be at a higher price than your buying bids (i.e. you cannot sell to yourself).

Market Price and Actual Trades

The market price in each period is determined by supply and demand. This means that the price will be chosen that makes the most trades possible. All trades are then carried out at this single market price, which is centrally determined for your group in each period.

Explanation: Imagine you enter that you would like to buy 6 assets if the price is at most 1500 points and one other participant enters that she would like to buy 9 assets if the price is at most 1500. Imagine further that nobody else in the market enters a buying bid at 1500 points or at a higher price. This means that *all participants of the market together* would like to buy 15 assets if the price is at most 1500 points per asset. The aggregation of the buy orders can be done for all prices and yields the market demand schedule. This demand schedule contains the information of all buy orders for *all participants of the market together* and can be represented by a step function as below. On the horizontal axis you can see the total quantity demanded for each price on the vertical axis (this is a very simple example and the quantities and numbers provide no indication of what you should enter in the experiment). In the graph of this simple example you can see that all participants of the market together are willing to buy up to 75 assets at a price of 500 points per asset, only 50 assets at a price of 1000 points per asset, and only 15 assets at a price of 1500 points per asset.

[Figure IA.7 (identical to Figure IA.2) appears here in the experimental instructions.]

A similar schedule can be derived for the supply side of the market, aggregating all the sell offers. When drawn in the same graph, the supply schedule is an increasing step function.

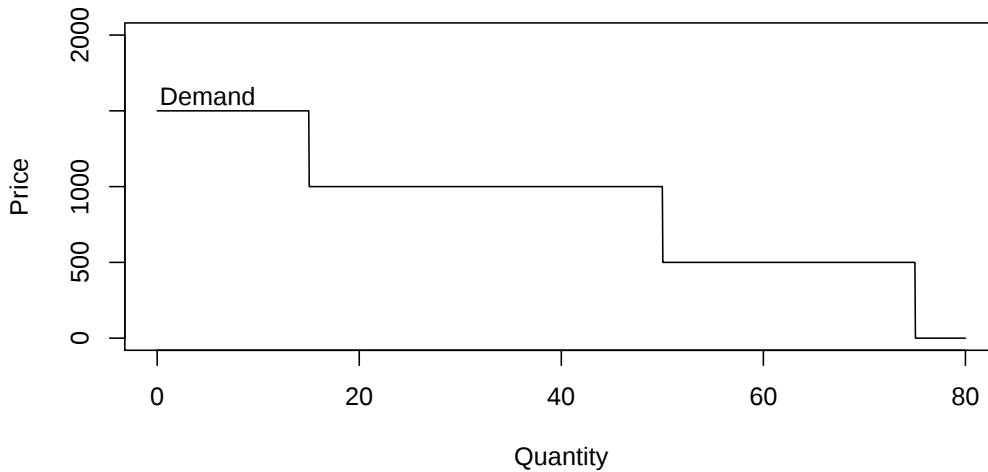


Figure IA.7. Demand schedule (not labeled in the instructions).

[Figure IA.8 (identical to Figure IA.3) appears here in the experimental instructions.]

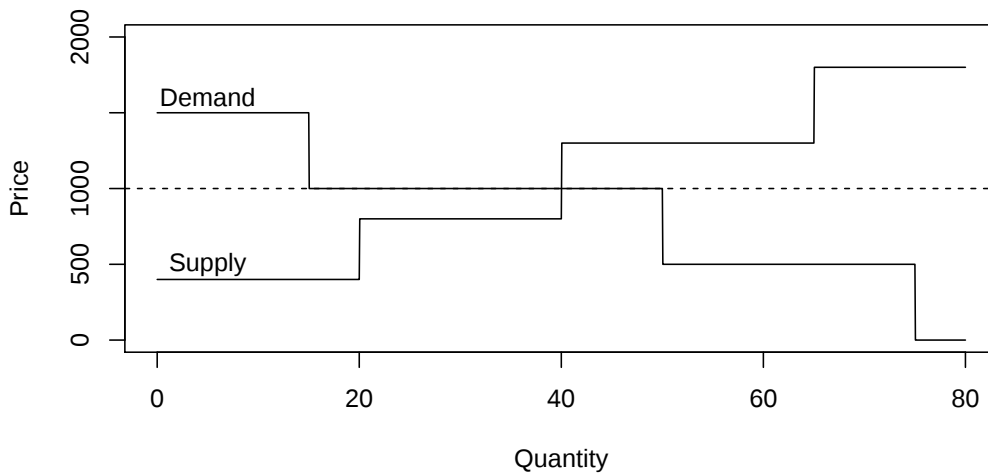


Figure IA.8. Demand and supply schedules (not labeled in the instructions).

The market price is the price at which the two curves intersect (in this example 1000). Note that at this price, 10 more assets are demanded than supplied (50 assets are demanded while only 40 are supplied). In this case a random selection of 10 bids *from all the bids at the market price* would not be fulfilled (it is similarly possible that there is more supply at the market price than demand).

In some rare cases there can also be a whole interval of prices at which the most trades can be carried out and the demand and supply schedules overlap vertically. In such cases

the middle of the interval will be the market price. If no bids or offers are made at all or if all bids to buy are at lower prices than all offers to sell there will be no trade and also no market price.

You will always be told the market price after the trading. You will not be told the total number of trades in the market (except if there are none).

Period 0

The first period of each round is a special period (period 0). In this period, none of the participants holds any of the 25 assets. You can try to buy them as in the regular periods 1,2,...,9, but instead of buying them from other participants you will buy them directly from the experimenter. The computer interface is similar to the computer interface in the regular periods (i.e., you can enter the number of assets you want to buy at a certain price). The experimenter only sells assets in period 0 and does not interfere with the market thereafter. The experimenter will sell all 25 assets in this period, for the highest unique price at which all of them can be sold (if there is not enough demand to sell all assets even at a minimal price, the experimenter will sell as many assets as are demanded).

General Properties of the Assets

There will be no trading in period 10. If you hold assets in period 10, you will receive 1000 points for each asset, provided that the asset has not defaulted (more on this below).

In each of periods 1-10 you receive interest payments on your asset holdings (if they have not defaulted). The interest payment per asset is 12% of the final value (1000 points), which means that you will receive 120 points for each asset you hold in a period. These earnings will be paid to a separate account – they are part of your earnings for the round, but you cannot use those points to buy more assets.

The asset you are trading has a special property. There is the possibility of a “default”. Each period (from period 1 on to period 10) it is determined whether a default occurs or not. If there is a default, *all assets in the market default*. How it is determined whether there is a default will be explained shortly. If a default occurs, the assets will become almost worthless for all periods remaining in the round. This means that from the period of default onward there will be no interest payments and there will be no payoff of 1000 points per asset after period 10. However, you will receive a small payment for each asset in case of default, which will also be explained shortly.

Underlying Model of the Assets and Defaults

The situation underlying these assets is as follows. There is a company which had already sold 25 assets similar to the ones that you can trade. These 25 “old assets” are not traded but receive the same interest payments as the new assets that you can buy and trade (120 points per asset per period) and also receive 1000 points per asset in period 10 if no default occurred before. Overall there are thus *25 old assets that are not traded and 25 new assets that you can buy and trade, so that the total number of assets is 50*. The company starts out without any cash, but it receives cash flows in each period. These cash flows come from two different sources.

The first source of cash flow is from income the company earns each period. In each of the periods 1 to 9, the company receives 6000 points with probability 96% and 0 points with probability 4%. In the final period, the company receives cash income of 56000 points with probability 96% (and otherwise 0 points). The numbers are such that with 96% chance the cash income is precisely enough to cover the coupon payments in any period 1 to 9 ($50 * 0.12 * 1000 = 6000$). In the final period cash income is enough to cover the last coupon payment and the repayment of the face value if the company receives this income ($6000 + 50 * 1000 = 56000$).

The second source of cash flow comes from the money the company received from selling the assets in period 0. The company invests this money and receives investment income in each period 1 to 10 that is equal to 0.03 times the amount raised in period 0. Assume that all 25 assets are sold in period 0 and that the price paid for each asset in period 0 is P_0 . Then the company receives in each period $0.03 * P_0 * 25$ points from this second source of cash flow (note that this money is only received for new assets, no money is received in period 0 for old assets). Notice that once P_0 is determined, the amount of this second source of cash flow is determined for the company and unlike the first source of cash flow there is no uncertainty as to whether the company receives this investment income in each period.

The company receives the two cash flows in the beginning of each period, that is, before it has to make the interest payments to asset holders. As long as the company has enough money to make the interest payments (or in the last period the interest payments plus the repayment of the 1000 points per asset) there is no default. If the company has more money than needed for the interest payment, the company saves the excess money at a zero interest rate and has this money available in future periods for the payments it has to make.

A default occurs if the company does not have enough money to make its promised interest payments in a period (or, in the last period, its interest payments plus the repayment of the 1000 points per asset). This occurs when the cash flows received in each period plus the money the company has saved from previous periods is lower than the total amount of payments it has to make. In this case, the company goes bankrupt. The assets are declared worthless, meaning that they will no longer pay any interest nor will they pay out 1000 points in the last period. However, in a default, any remaining money that the company has is distributed among all asset holders with the money received for each asset (old and new alike) being equal. If all 25 new assets are sold in period 0, then each asset holder will receive, per asset, one fiftieth of the remaining money the company has.

The timing in each period 1,...,10 is as follows. First, the company receives cash flows from the two sources. Then it makes its interest payments. If it cannot make these payments, a default occurs (in the last period, the company has to make payments of interest and the final value). If no default has occurred, then assets can be traded (in periods 1 to 9).

Information on Defaults

Although it will be determined each period whether there is a default in this period or not, we will not tell you whether or not a default has occurred! You will always continue the experiment as if no default has ever occurred – only after each 10-period round will we tell you if a default occurred or not and if so, in which period the default occurred. Your earnings for that round are then determined up through the period in which the default occurred. Your earnings in case of a default are your cash holdings and the points earned in your interest account at the time of default plus the part of the company's money that is distributed equally per unit of the asset held. This means that any action you took after the default occurred does not affect your earnings (but when you make your decisions you don't know whether or not a default has previously occurred). We will also not give you any additional information on the cash flows the company receives during a round.

Summary of the Information

- 4 identical rounds with fixed groups of 6
- 10 periods per round plus period 0
- 20 000 points cash to buy assets per round
- If there is a default then all assets become worthless in the remaining periods of the round. Earnings are then based on: 1) interest paid out to you before the default, 2) your cash holdings at the time of default and 3) the remaining cash holdings of the

company distributed equally per unit of the asset held.

- Each asset pays 120 points interest per period (if the asset is not in default).
- Points earned from asset interest in your interest account cannot be used to buy assets.
- In each period 1,...,9, the company has two sources of income. The first is a cash flow of 6000 (96% probability) or 0 (4% probability). The second is a return of 3% on the money raised in period 0.
- In period 10, the company has two sources of income. The first is a cash flow of 56000 (96% probability) or 0 (4% probability). The second is a return of 3% on the money raised in period 0.
- The company defaults in any period 1,...,9 if it has insufficient funds to pay interest (6000) in that period or in period 10 if its funds are insufficient to pay interest plus the final payment (56000).
- If there is no default, then in period 10 each asset is exchanged for 1000 points.
- We don't tell you during a round if there is a default, you always continue as if there is none. However, if there is a default, the timing of the default is used to determine your round earnings.

B.1.2. Differences in Instructions between the Treatments of the Structural Model

There are only two parts that are different in the instructions in treatment *XR*. First, the paragraph on the second source of cash flow (starting with “The second source of cash flow...”) is different. Second, two bullet points in the summary information are different (the bullet points starting with “In each period...” and “In period 10...”). These parts are reproduced here:

Different Paragraph

The second source of cash flow comes from the money the company received from selling the assets in period 0. The company invests this money and receives investment income in each period 1 to 10. In each period, with probability 50% this investment income is equal to 0.06 times the amount raised in period 0. With equal probability 50% this investment income is zero. Assume that all 25 assets are sold in period 0 and that the price paid for each asset in period 0 is P_0 . Then the company receives in each period either $0.06 * P_0 * 25$ points from this second source of cash flow or nothing (note that this money is only received for new assets, no money is received in period 0 for old assets). Whether the company receives positive investment income or nothing is determined anew each period (it is thus likely that the company will receive investment income in some periods but not in others). Notice that once P_0 is determined, the possible amounts that this second source of cash flow can yield are determined for the company.

Different Bullet Points

- In each period 1,...,9,, the company has two sources of income. The first is a cash flow of 6000 (96% probability) or 0 (4% probability). The second is a return of 6% on the money raised in period 0 (50% probability) or 0 (50% probability).
- In period 10, the company has two sources of income. The first is a cash flow of 56000 (96% probability) or 0 (4% probability). The second is a return of 6% on the money raised in period 0 (50% probability) or 0 (50% probability).

B.2. Test Questions for Experiment II

Except for a minimal change (“... tries to sell 25 assets” instead of “... tries to see all 25 assets”), the first screen of the test questions is identical to the first screen of test questions of Experiment I. Therefore, this screen is not reproduced again. Screens 2 and 3 are reproduced in the following. The test questions are identical in both treatments.

B.2.1. Screen 2

In periods 1 to 9 you can trade the asset with the other members of your group. You can enter bids to buy assets and offers to sell assets. Imagine that you consider both, buying and selling assets. Which of the following is correct?

- (a) You cannot try to buy assets at a higher price than the lowest price at which you are willing to sell assets. ✓
- (b) You can try to bid for as many assets as you like at any price. If the market price turns out to be high, your cash holdings may become negative.
- (c) You can make sell offers for the same quantity at different prices.

Which of the following is NOT correct?

- (a) The company has no savings before it sells the (new) assets in period 0.
- (b) The company receives cash flows from two different sources each period. The exact value of the cash received by the company each period can be different in different periods.
- (c) If the company's cash flows in one of the periods 1 to 9 are greater than the interest payment it has to make the excess money will be lost for the company and cannot be used for payments in the future. ✓

Which of the following is NOT correct?

- (a) A default occurs in periods 1 to 9 if the company does not have enough money to pay the interest payments for old and new assets.
- (b) A default occurs in period 10 if the company does not have enough money to pay the interest payments and the final values for old and new assets.
- (c) In case of a default, the money that the company has (from the same period's cash flows or due to savings that the company made in earlier periods) is distributed among all asset holders. The money received for each old and new asset is the same.

- (d) In case of default in periods 1 to 9, the payment per asset is always lower than the interest that the asset would yield in this period.
- (e) Before making your decisions on trading each period, you will receive information on the precise cash flows that the company receives. ✓

Imagine that in period 6 you hold 7 assets. The other 5 participants in your group each offer to sell 3 units at a price of 1100 and ask to buy 6 units at a price of 1000. You offer to sell 7 units at a price of 1151 and ask to buy 6 units at a price of 1149. What trades are you involved in, in period 6?

- (a) You sell 7 units at a price of 1151.
- (b) You sell 7 units at a price of 1100.
- (c) You buy 6 units at a price of 1100. ✓
- (d) You buy 6 units at a price of 1149.

B.2.2. Screen 3

If you hold assets at some point you may receive interest payments. Which of the following is correct?

- (a) You can use the money from your interest account to buy assets in later periods.
- (b) For each asset you are holding in a period you receive an interest payment of 120 points (if there has been no default in any prior period). ✓
- (c) An asset only pays interest in the period right after you bought it, even if you hold it for multiple periods.

There are rounds and periods in this experiment. Which of the following is correct?

- (a) There are 4 rounds in the experiment (each consisting of 10 regular periods and period 0). When you start a new round you have 20000 points in cash, 0 points in your interest account and no assets. ✓

- (b) In each of the regular periods you have 20000 points of cash to buy assets with.
- (c) Assets only last for one period. Once the interest of an asset has been paid out, the asset always loses its value.

In each period there is the possibility of a default. What happens when such a default occurs?

- (a) You will immediately be informed that the default has occurred, your earnings are determined and your group will continue straight on to the next round.
- (b) You will only be informed after the end of the round that the default has occurred. Without your knowing it, the further actions you take during the rest of the round will no longer influence your earnings for the round. ✓
- (c) You will only be informed after the end of the round that the default has occurred. Without your knowing it, the further actions you take during the rest of the round will continue to affect your earnings for the round.

The probability that the company has enough cash on hand to make its interest payments in any single period, 1-9, or to make its interest and final payment in the last period 10 and avoid default

- (a) is at least 96 percent.
- (b) depends on the IPO price.
- (c) depends on the company's savings from prior periods.
- (d) All of the above are correct. ✓

C. Additional Graphs and Data of Experiment I

C.1. Prices in all Markets

Figures IA.9 to IA.12 show the market prices in the experiment in all rounds and periods for all groups. Figures IA.9 and IA.10 show the prices for all eight groups in treatment *DEC*, Figures IA.11 and IA.12 show the prices for the eight groups in treatment *INC*. Each row corresponds to one group, starting with the first round on the left and ending with the fourth round on the right. Market prices are shown with red circles. Red crosses show the mean of the highest bid and the lowest offer price when no trade is carried out but when both bids and offers are present. Similarly to Figure 2, the equilibrium fundamental value is drawn with a solid black line and the price leading to the highest possible expected earnings for all subjects together is drawn with a dashed black line. Furthermore, the actual fundamental value within a round (which depends on the price in the IPO and is different across groups and rounds) is drawn with a dotted blue line. As there is no more trade in the tenth period, periods only reach from 0 (the IPO) to 9.

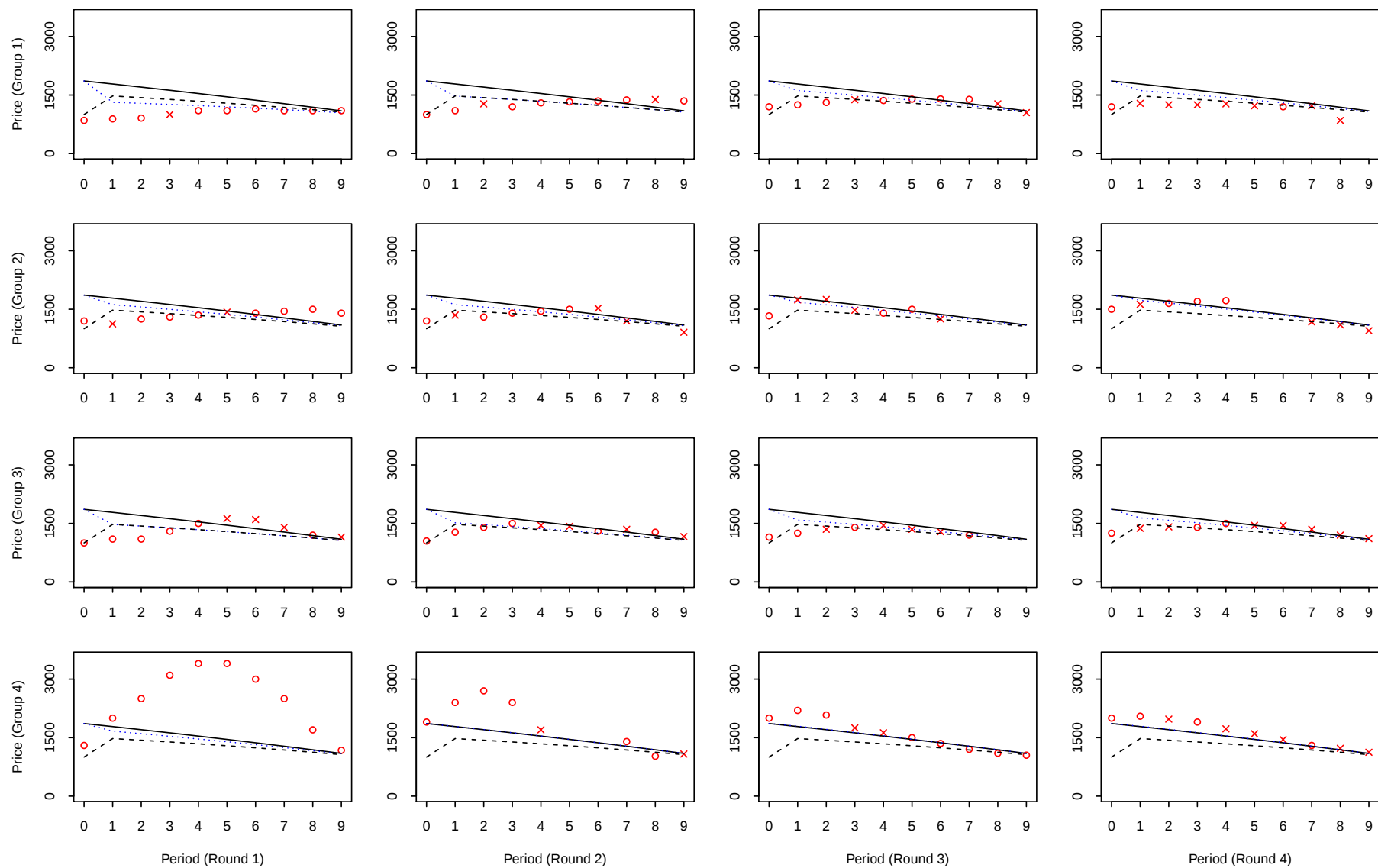


Figure IA.9. Prices in all Periods and Rounds, Groups 1 to 4, Treatment *DEC*.

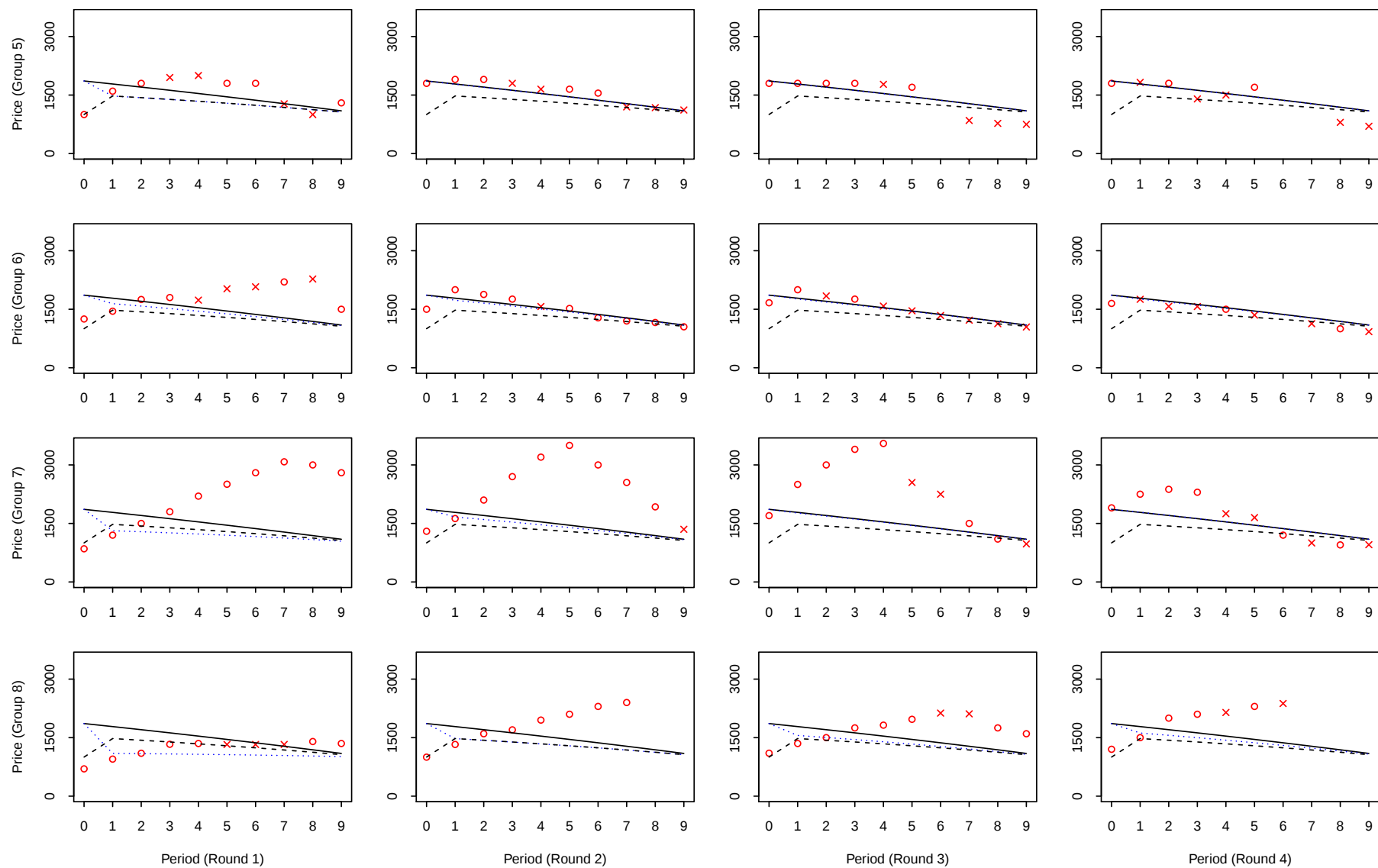


Figure IA.10. Prices in all Periods and Rounds, Groups 5 to 8, Treatment *DEC*.

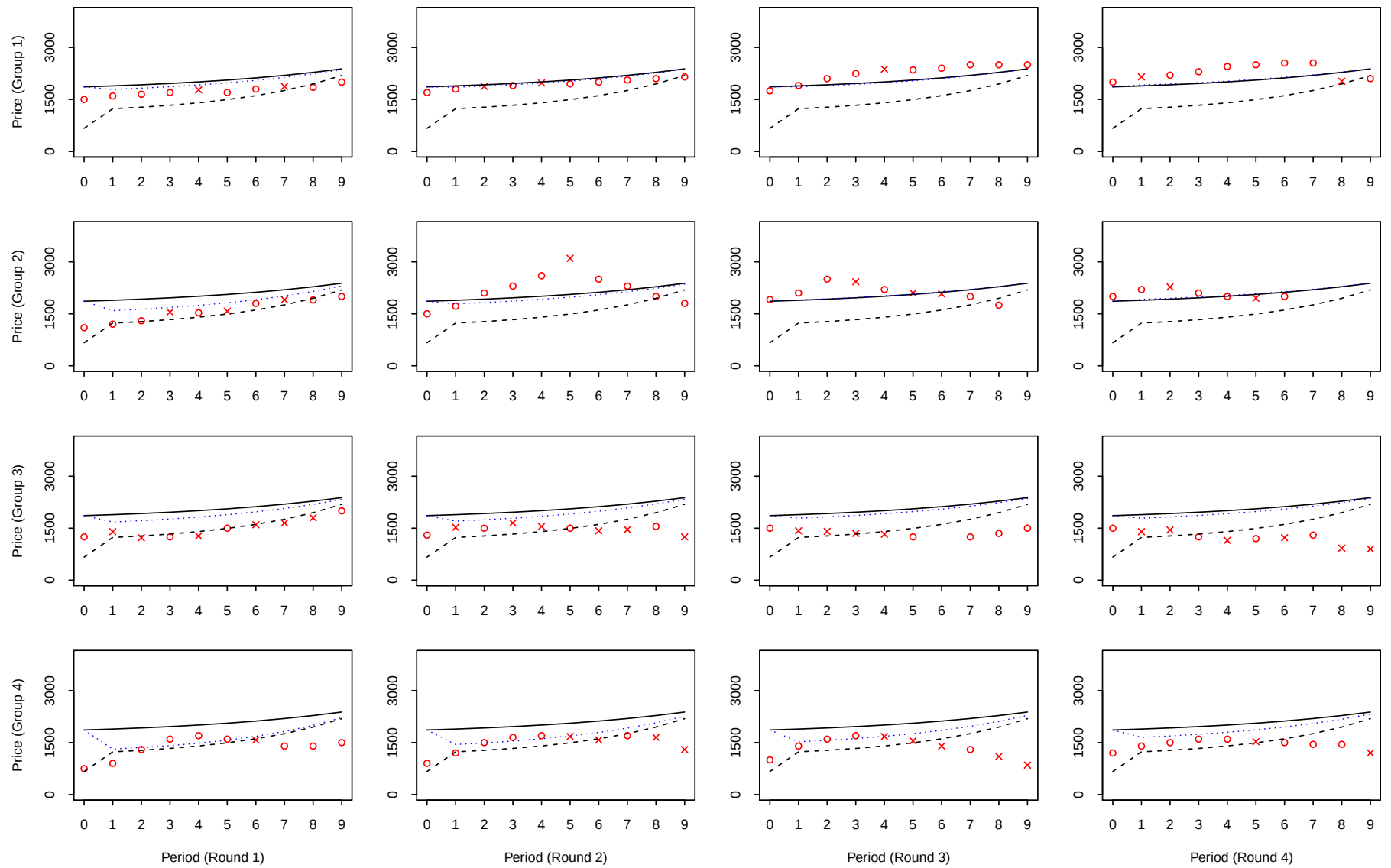


Figure IA.11. Prices in all Periods and Rounds, Groups 1 to 4, Treatment *INC*.

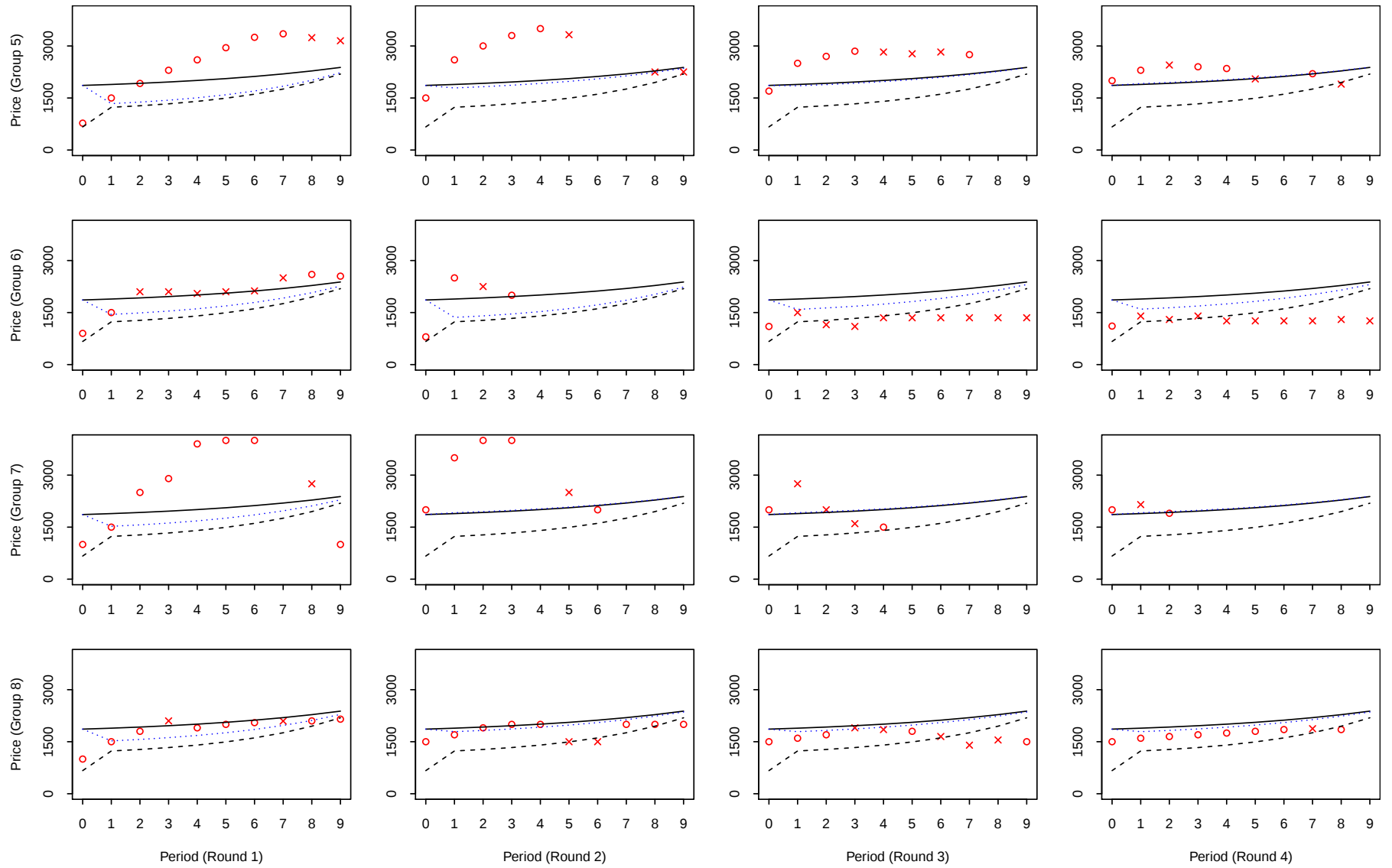


Figure IA.12. Prices in all Periods and Rounds, Groups 5 to 8, Treatment *INC*.

C.2. Traded Quantities

For all groups and all rounds, the IPO always resulted in all 25 bonds being sold. Following the IPO of each round, there is no longer an opportunity to ‘earn money from the experimenter’; that is the earnings any given subject makes (in expectation) from trading in periods 1-9 represent a loss (in expectation) for some other subject in the same group. Therefore, it is not surprising that the number of trades per period is much lower in these regular trading periods. Nevertheless, there is sustained trade in most groups with an average number of roughly two trades per period. There is no indication that the number of trades is different in the two treatments. Across rounds, the average number of trades per period decreases slightly but continuously, which can be interpreted as evidence for learning as subjects come to realize that trading in the regular periods does not lead to joint positive earnings. The average number of trades per period decreases in *DEC* from 2.60 in round 1 to 2.18, 1.64, and 0.76. The average number of trades in *INC* is 2.74 in round 1 and 2.10, 1.26, and 1.38 in rounds 2 to 4. Naturally, there are many more bids and offers in each period than there are trades.

Figures IA.13 and IA.14 show the quantities traded in the different groups in all rounds and all regular periods (in period 0, that is, in the IPO, always all 25 bonds are sold). Each line connects the quantity traded in the different periods of the same round. Figure IA.13 shows the data from the groups in treatment *DEC*, while Figure IA.14 shows the data from the groups in treatment *INC*.

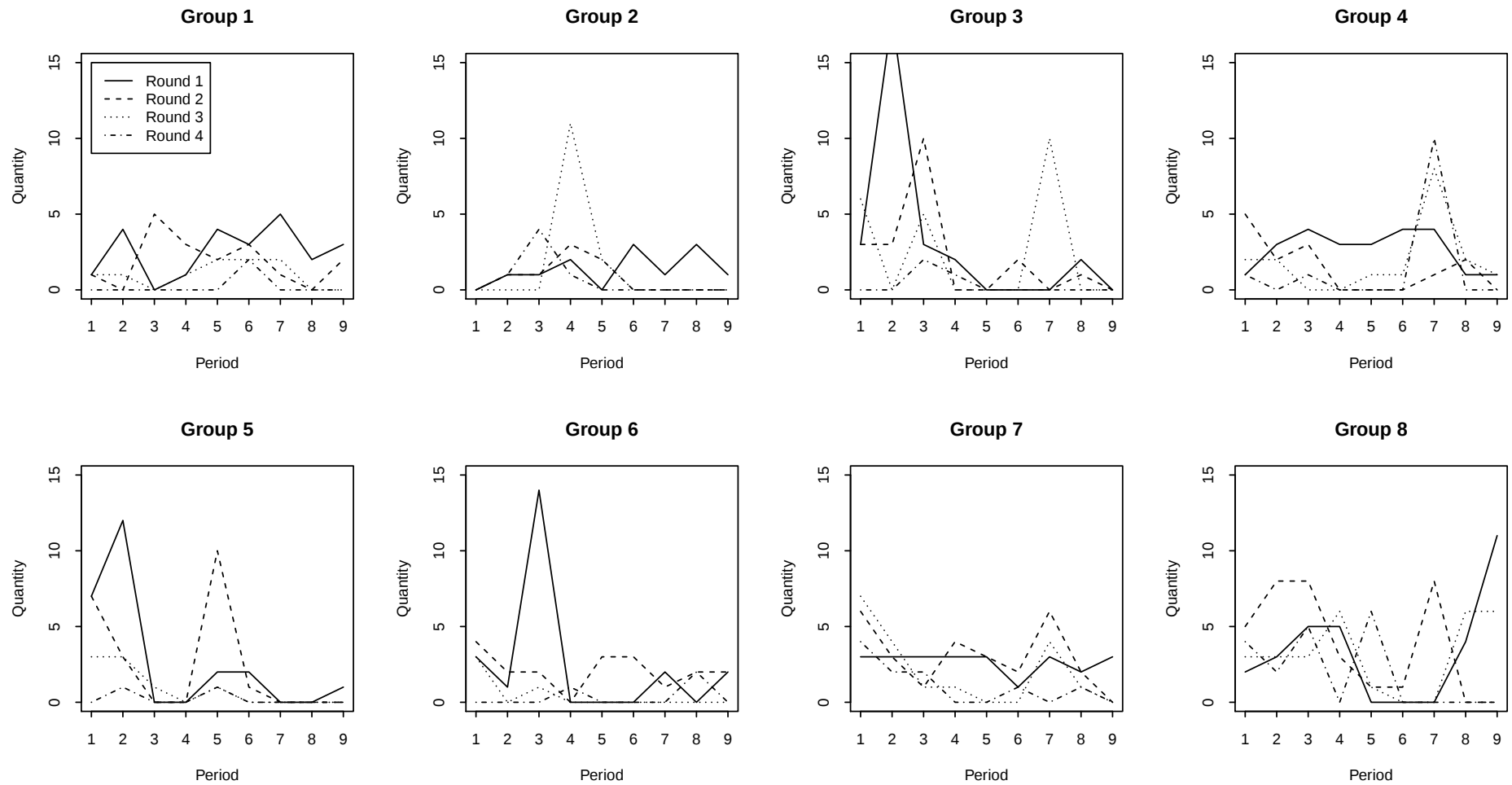


Figure IA.13. Quantities Traded in Treatment *DEC*.

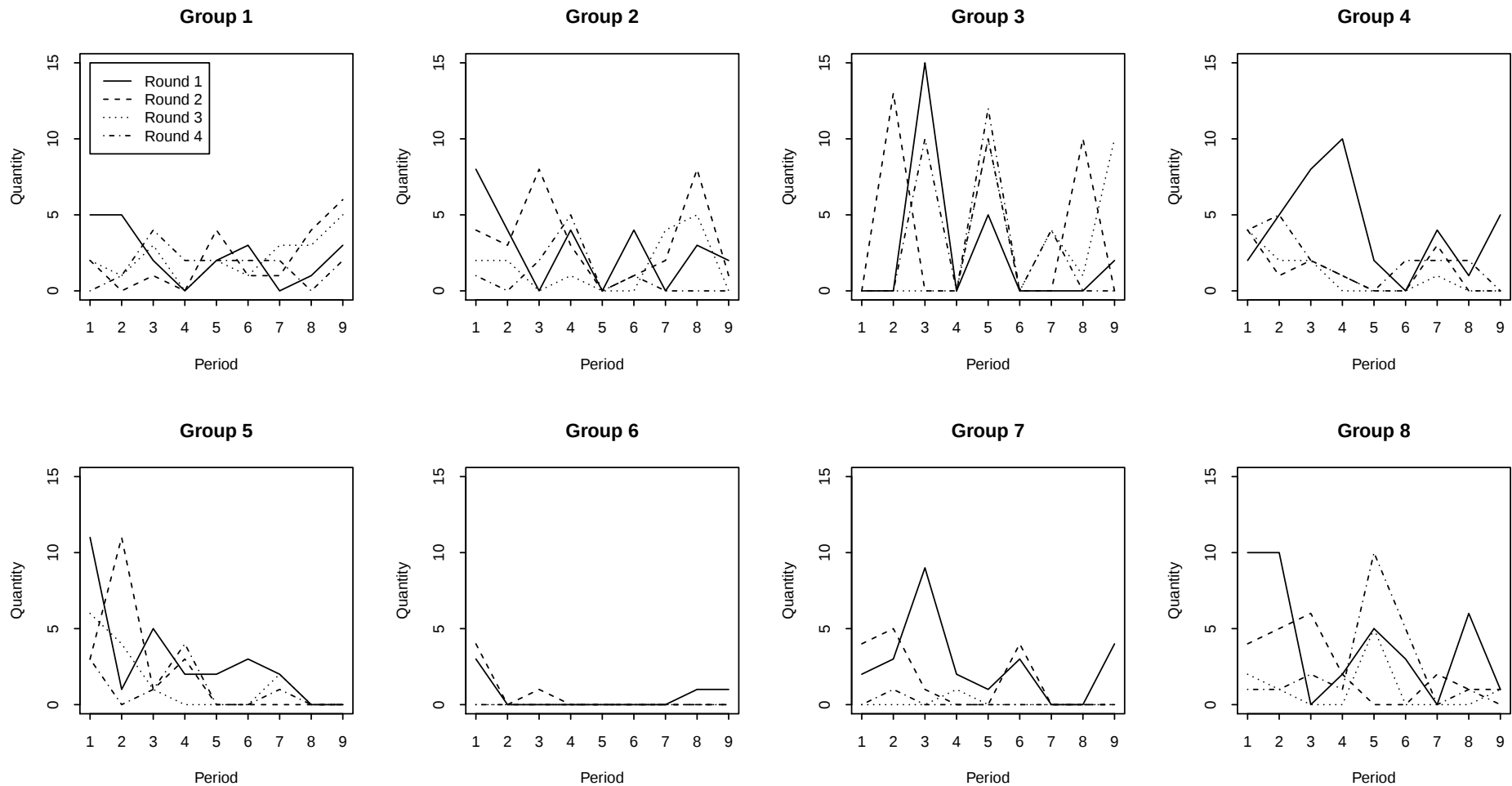


Figure IA.14. Quantities Traded in Treatment *INC*.

C.3. Defaults

In this experiment, default probabilities are determined by the IPO prices (the larger the IPO price the lower the default probability). Any order statistic of default probabilities is therefore the same as for IPO prices. Actual defaults are a noisy representation of default probabilities.

The numbers of defaults are very different between the two treatments as the treatment with increasing fundamental values features higher default probabilities by design. In *DEC* there are overall 10 defaults in 32 markets (i.e., in 4 rounds of 8 independent groups). This means that in 10 markets the bond issuer defaults in one of the periods 1-10. In *INC* there are 29 defaults in 32 markets. Recall that defaults have no influence on the data we collect because of the block design described in Section II.A of the main text.

Of course, defaults naturally have an influence on payoffs. Furthermore, while the timing of defaults in previous rounds should not matter in a rational world for subsequent rounds, the occurrence of a default, and the time period in which it occurred, could affect subjects' behavior and market outcomes in subsequent rounds. This reaction to defaults could occur, because subjects receive feedback on whether and when there was a default in a round after the round ends (see Figure 3 in the main text). Our data, however, show no evidence of such spillover effects. Figure IA.15 shows round-to-round changes in prices as a function of whether there was a default in period $k = 1, \dots, 10$ of the previous round. More precisely, the round to round change in the overvaluation of prices relative to fundamentals as measured by RD is shown on the vertical axis and the period of default in the earlier of the two compared rounds is shown on the horizontal axis. Crosses instead of circles are for the case where no default occurred in the previous round. Each circle or cross thus represents the price change of one group (there are three such observations per group). For example, one circle shows one group's change in RD from round 1 to round 2 on the vertical axis and the default period in round 1 on the horizontal axis. If prices were

to react negatively to an early-period default in the previous round, there would be a positive relationship between the prior round default period and the price change. As Figure IA.15 makes clear, there is no evidence for such behavior in either the *DEC* or the *INC* treatments.

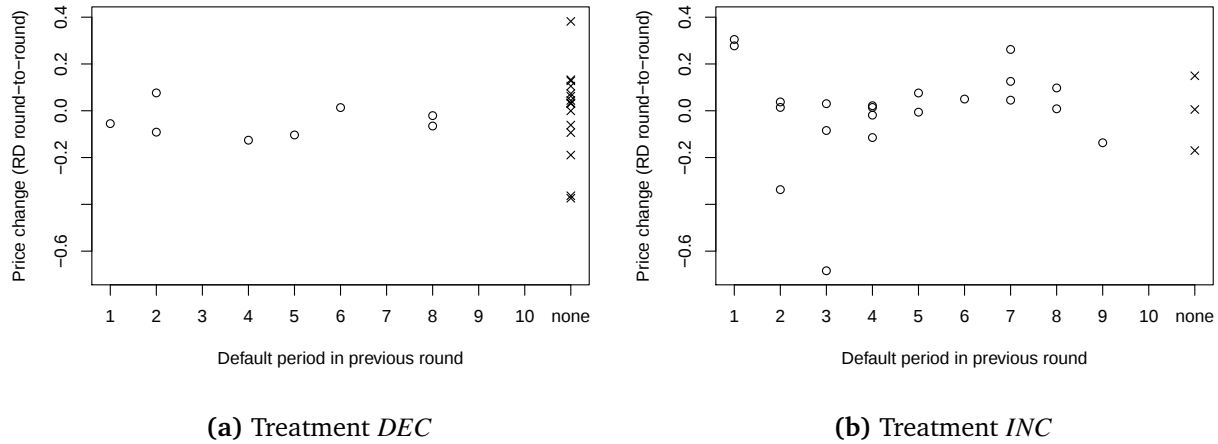


Figure IA.15. Defaults and Price Changes. Each circle or cross in the graph shows the change of prices from one round to the next on the y-axis for one group. On the x-axis is the period in which the bond issuer defaulted in the respective group's previous round (i.e., the round from which the price change is computed). For example, one circle shows one group's change in RD from round 2 to round 3 on the y-axis and the default period in round 2 on the x-axis.

D. Additional Graphs and Data of Experiment II

D.1. Prices in all Markets

Figures IA.16 to IA.19 show the market prices in the experiment in all rounds and periods for all groups. Figures IA.16 and IA.17 show the prices for all eight groups in treatment X, Figures IA.18 and IA.19 show the prices for the eight groups in treatment XR. Each row corresponds to one group, starting with the first round on the left and ending with the fourth round on the right. Market prices are shown with red circles. Red crosses show the mean of the highest bid and the lowest offer price when no trade is carried out but when both bids and offers are present. The equilibrium fundamental value is drawn with a solid black line and the actual fundamental value within a round (which depends on the price in the IPO and is different across groups and rounds) is drawn with a dotted blue line. As there is no more trade in the tenth period, periods only reach from 0 (the IPO) to 9. In this experiment, it is best for the joint earnings of a group if the group buys all bonds in the IPO as cheap as possible. Therefore we omit the line of the joint earnings maximizing price in the graphs.

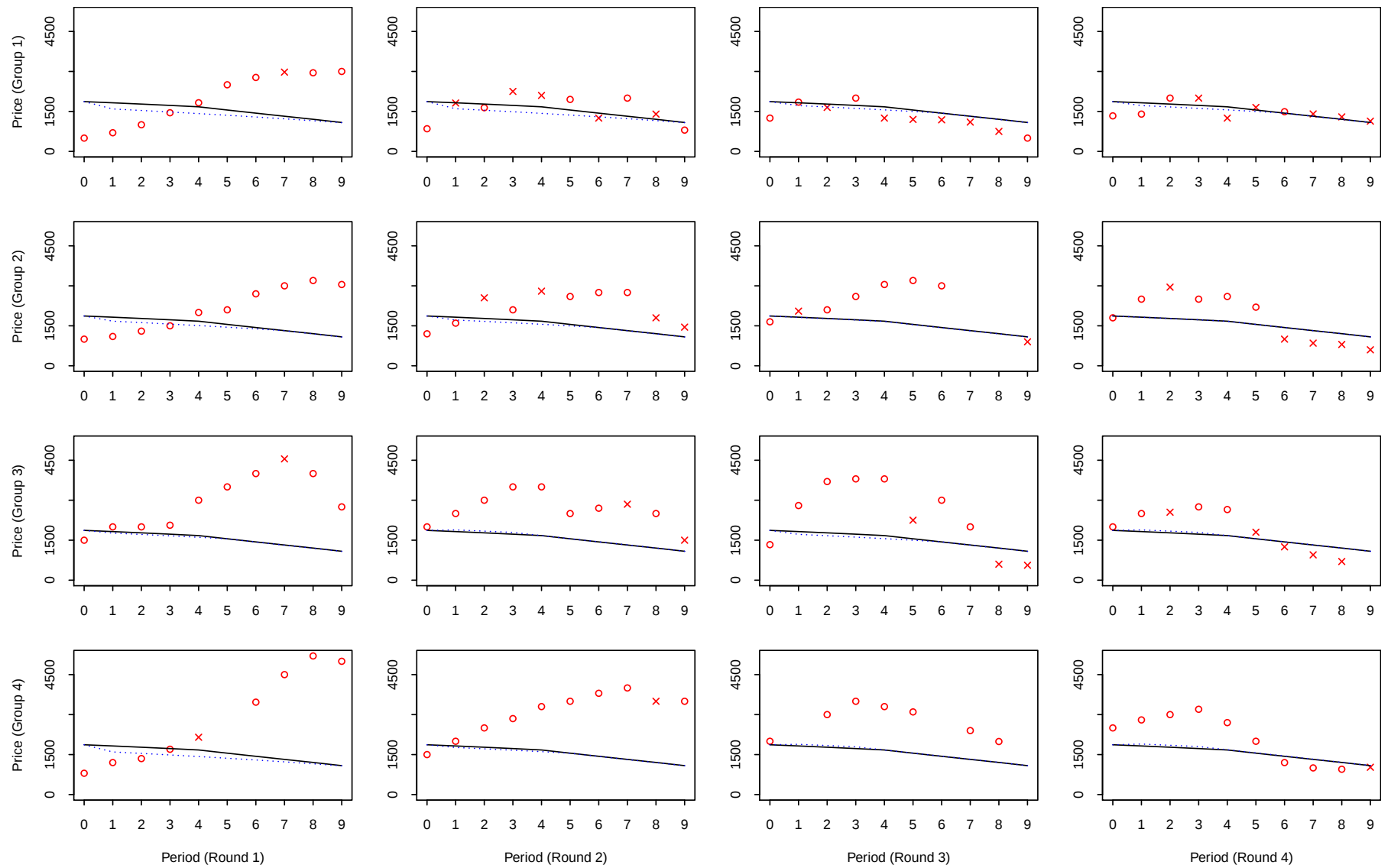


Figure IA.16. Prices in all Periods and Rounds, Groups 1 to 4, Treatment X.

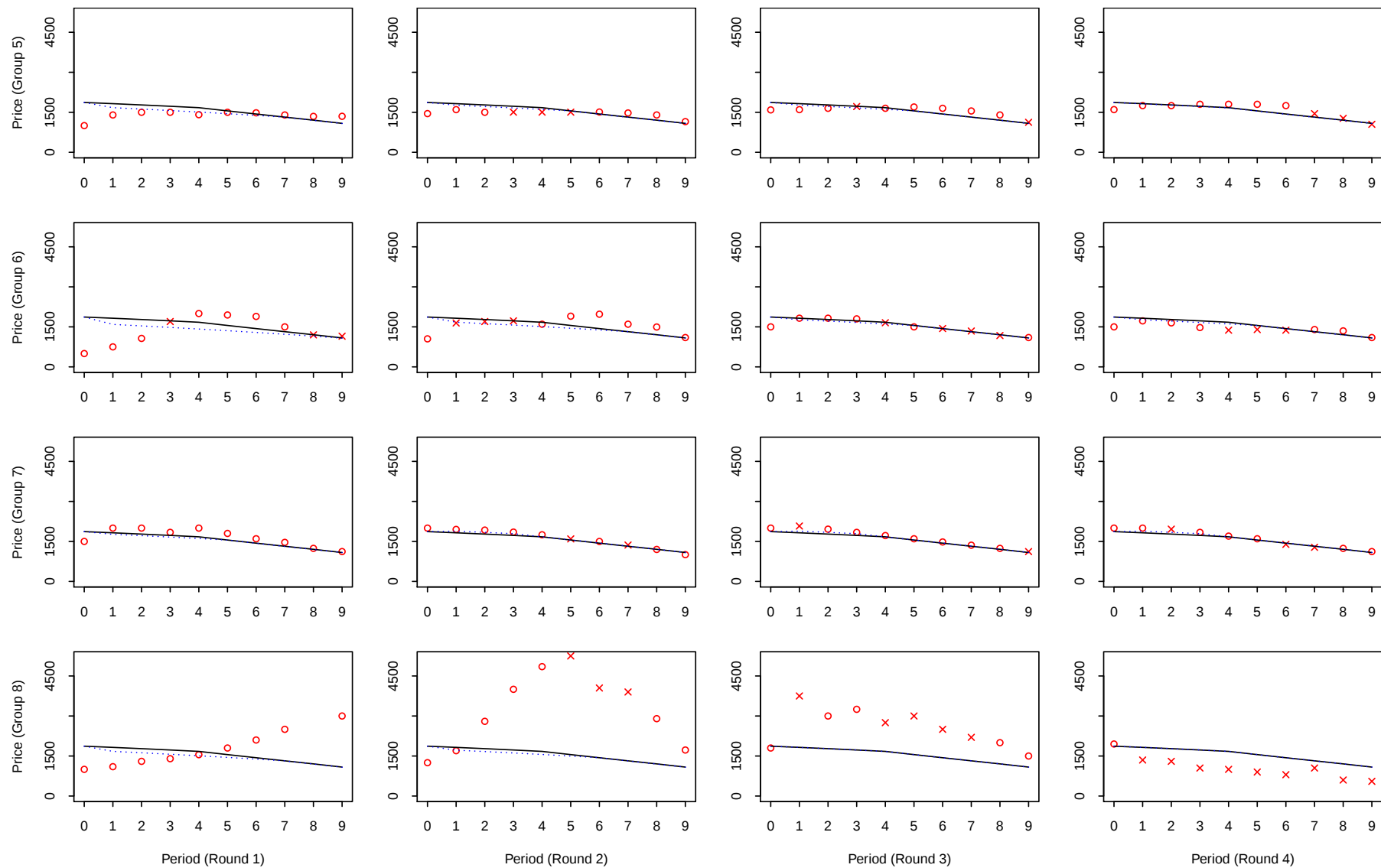


Figure IA.17. Prices in all Periods and Rounds, Groups 5 to 8, Treatment X.

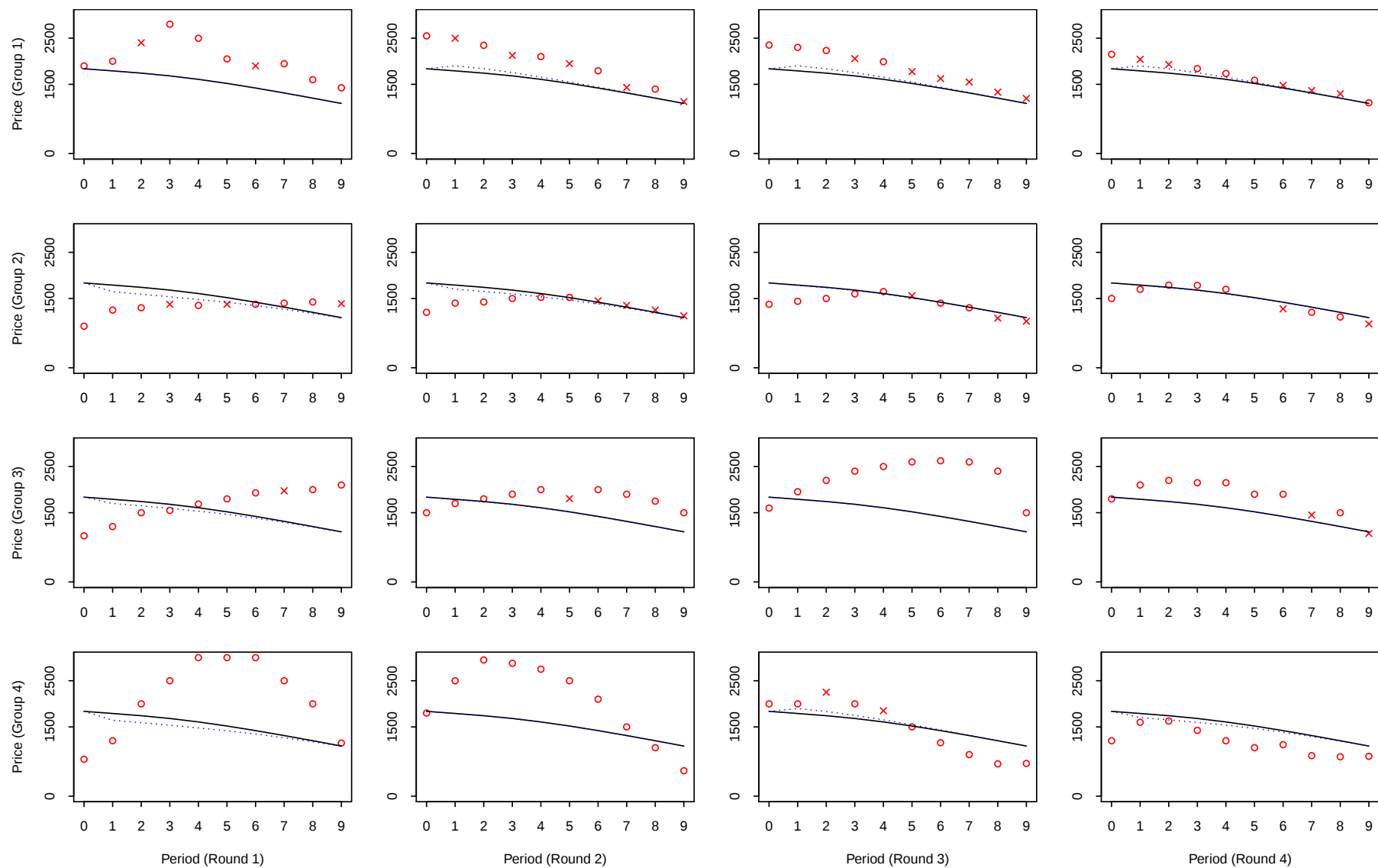


Figure IA.18. Prices in all Periods and Rounds, Groups 1 to 4, Treatment XR.

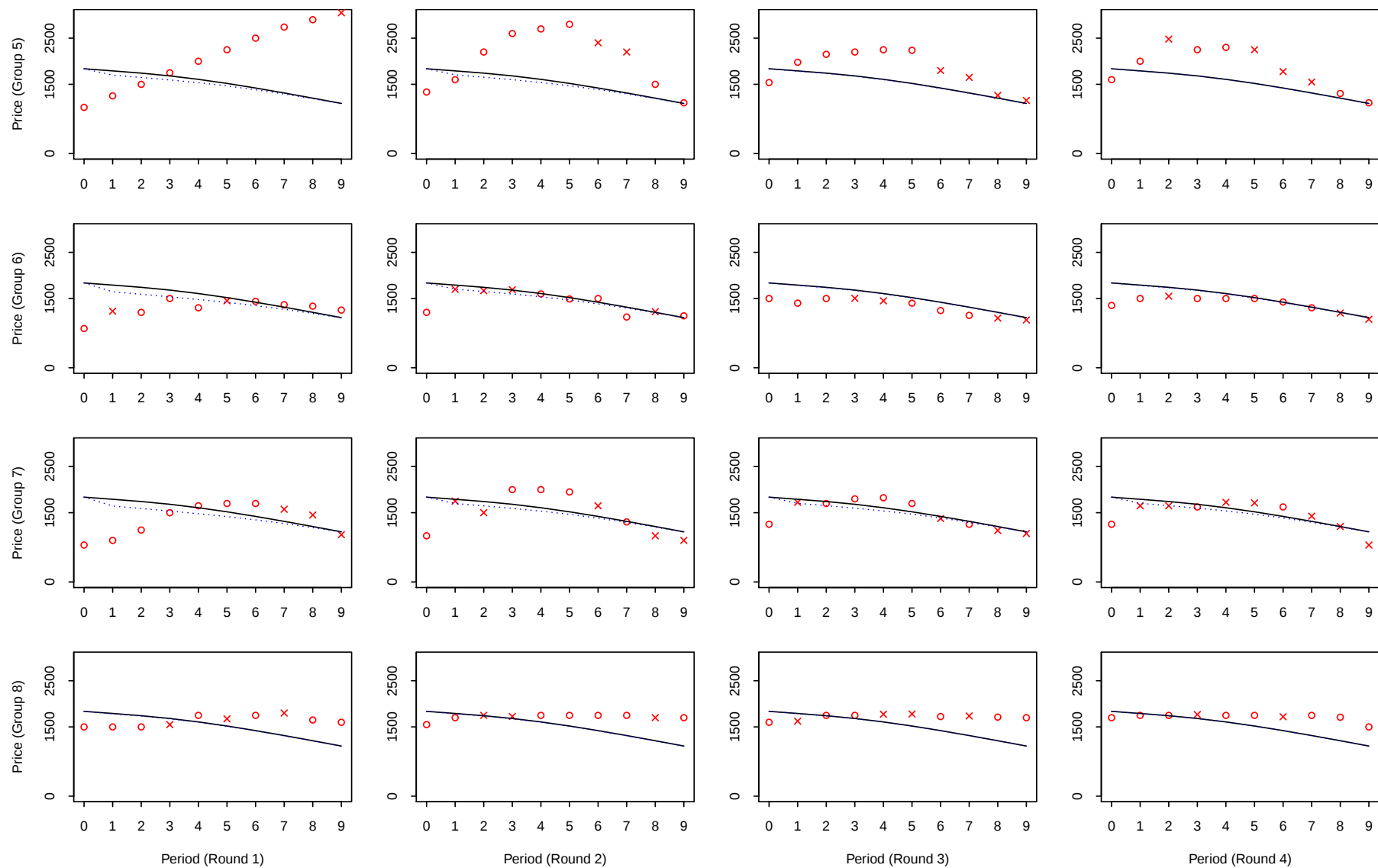


Figure IA.19. Prices in all Periods and Rounds, Groups 5 to 8, Treatment XR.

D.2. Traded Quantities

The IPO always resulted in all 25 bonds being sold. Similar to Experiment I, the number of trades per period is much lower in the regular trading periods. Nevertheless, there is sustained trade in most groups with an average number of a bit more than two trades per period. There is no indication that the number of trades is different in the two treatments. Across rounds, the average number of trades per period decreases also for Experiment II slightly. In treatment *X*, the numbers of average trades per period are 3.65 in round 1 and 2.15, 1.67, and 1.76 in rounds 2 to 4, respectively. In treatment *XR*, these numbers are 3.72, 2.14, 1.78, and 2.01, respectively. Naturally, there are many more bids and offers than there are trades.

Figures IA.20 and IA.21 show the quantities traded in the different groups in all rounds and all regular periods (in period 0, that is, in the IPO, always all 25 bonds are sold). Each line connects the quantity traded in the different periods of the same round. Figure IA.20 shows the data from the groups in treatment *X*, while Figure IA.21 shows the data from the groups in treatment *XR*.

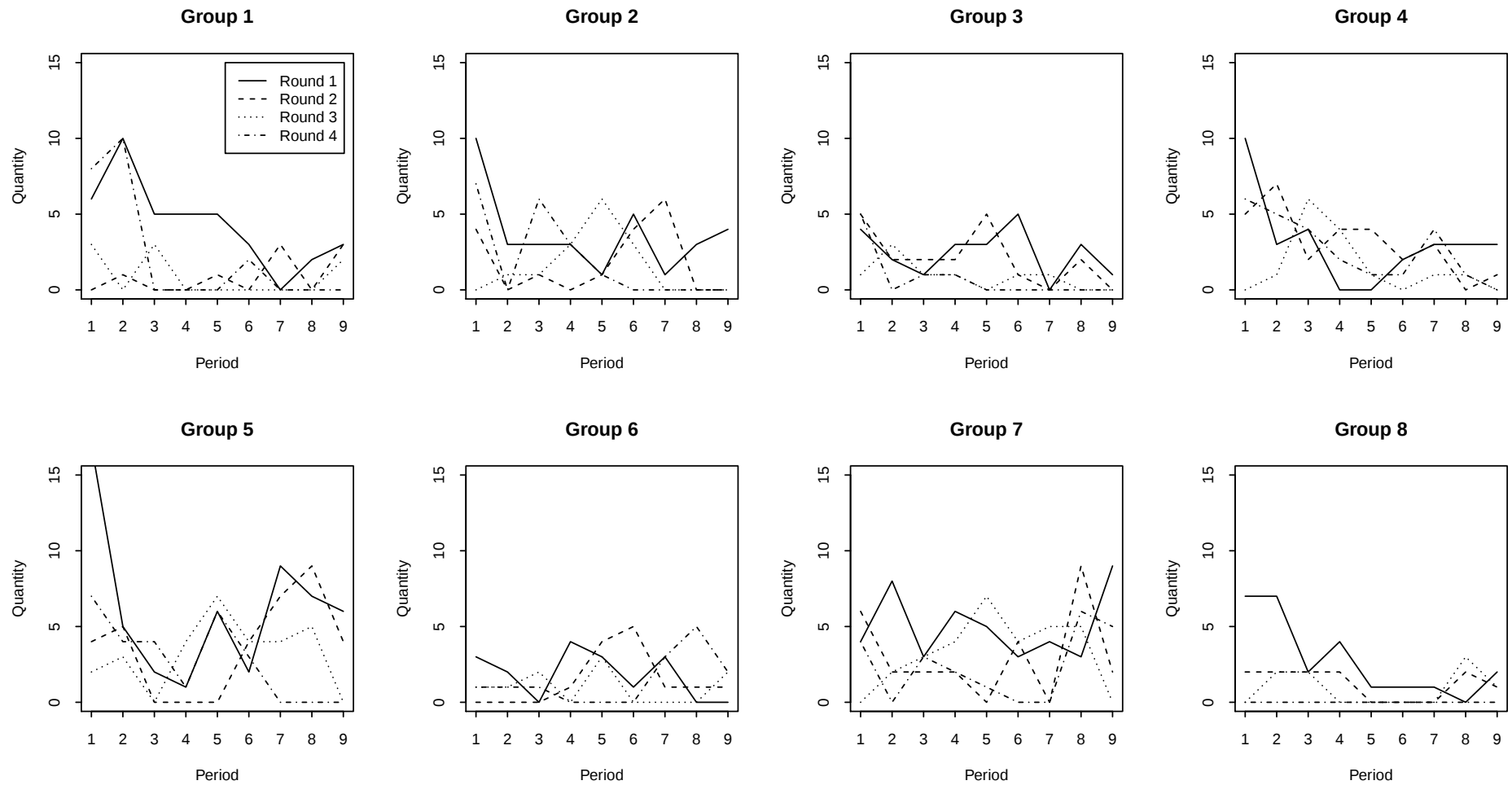


Figure IA.20. Quantities Traded in Treatment X.

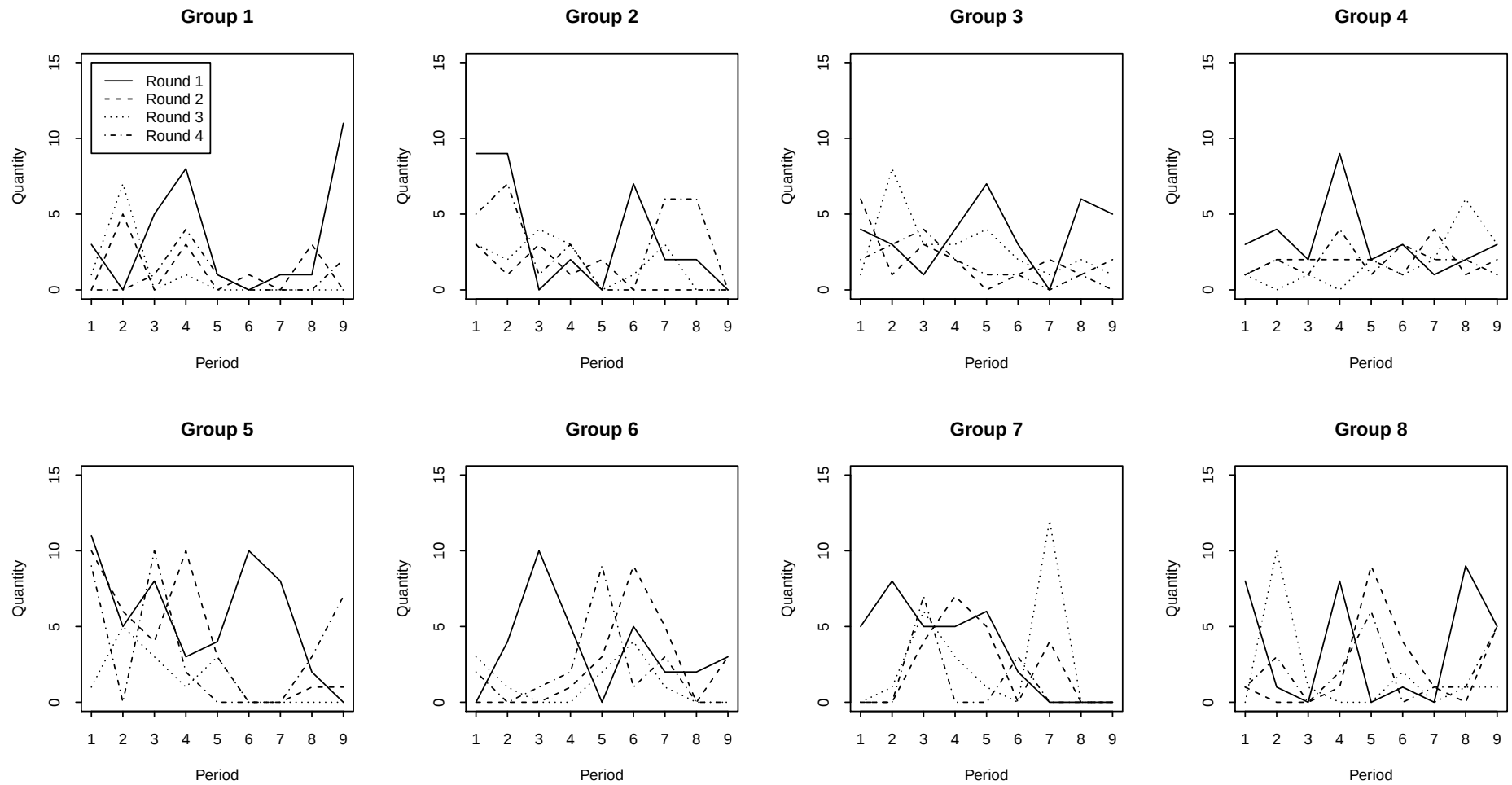
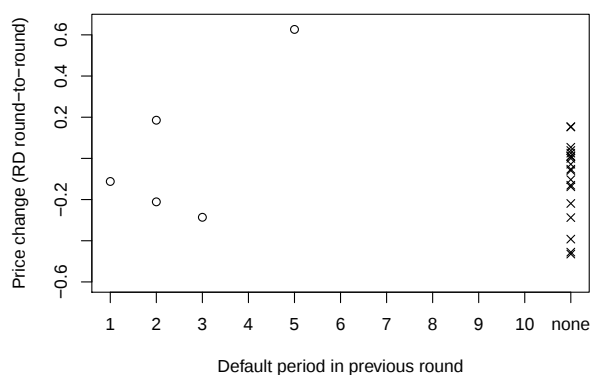


Figure IA.21. Quantities Traded in Treatment *XR*.

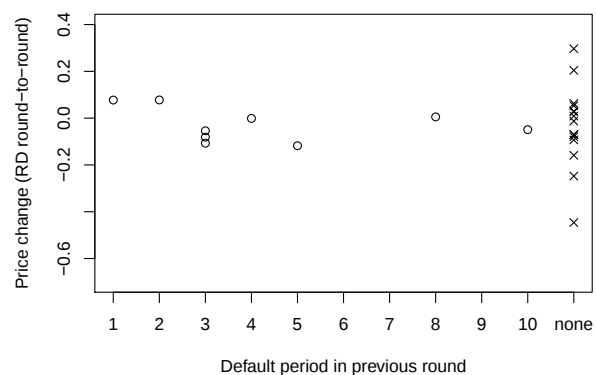
D.3. Defaults

Also in the structural model, actual defaults are not of particularly big interest when IPO prices are known, as actual defaults are just a noisy consequence of IPO prices. In treatment *X* overall 7 defaults occurred, in treatment *XR* 13 defaults occurred.

As in Experiment I, in a rational world the timing of defaults in previous rounds does not matter for subsequent rounds. However, the occurrence of a default and the time period in which it occurred could affect subjects' behavior and market outcomes in subsequent rounds. Again, our data show no evidence of such spillover effects. Figure IA.22 shows round-to-round changes in prices as a function of whether there was a default in period $k = 1, \dots, 10$ of the previous round (similar to Figure IA.15). Again, the round to round change in the overvaluation of prices relative to fundamentals as measured by RD is shown on the vertical axis and the period of default in the earlier of the two compared rounds is shown on the horizontal axis. If prices were to react negatively to an early-period default in the previous round, there would be a positive relationship between the prior round default period and the price change. As Figure IA.22 makes clear, there is no evidence for such behavior in either the *X* or the *XR* treatments.



(a) Treatment X



(b) Treatment XR

Figure IA.22. Defaults and Price Changes. Each circle or cross in the graph shows the change of prices from one round to the next on the y -axis for one group. On the x -axis is the period in which the bond issuer defaulted in the respective group's previous round (i.e., the round from which the price change is computed). For example, one circle shows one group's change in RD from round 2 to round 3 on the y -axis and the default period in round 2 on the x -axis.