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OANA PEIA, RADU VRANCEANU, WAEEL BOUSSELMI

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Strategic and insolvency risk in sovereign debt pricing: An experimental study *

Oana Peia[†], Radu Vranceanu[‡], and Wael Bousselmi[◇]

[†]University College Dublin, School of Economics. E-mail: oana.peia@ucd.ie

[‡]ESSEC Business School, CNRS, THEMA. E-mail: vranceanu@essec.edu

[◇]ESSCA School of Management. Email: wael.bousselmi@essca.fr

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Abstract

After the 2007 Global Financial Crisis, tensions in sovereign bond markets of advanced economies occurred quite frequently, driven by a combination of deteriorating fundamentals and self-fulfilling beliefs. However, it is difficult to disentangle empirically the contribution of these two factors in explaining government bond yields during episodes of sovereign debt distress. In this paper, we address this challenge through a controlled laboratory experiment. In the experiment, a government issues one-period bonds through a discriminatory price auction to finance a legacy of government debt. In a baseline treatment, sovereign default can result from investors' failure to coordinate in purchasing bonds (strategic risk) or the government debt reaching a solvency limit (fundamental risk). In a second treatment, a central bank intervenes as a bondholder-of-last-resort and eliminates roll-over defaults. We find that investors correctly price the probability of government default and demand higher interest rates as the risk of default increases. At the same time, the required risk premium is lower in the treatment with a central bank compared to the baseline treatment. The difference between interest rates across the two treatments can be viewed as the illiquidity component of sovereign debt risk.

JEL: C91; D84; E43; E58

Keywords: Experiments; Default premium; Sovereign bond pricing; Discriminatory price auction; Coordination game

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1 Introduction

After the Global Financial Crisis of 2007, the sustainability of sovereign debt became a matter of concern not only for emerging economies but also for many advanced economies. These tensions received additional momentum after the COVID-19 crisis when large fiscal stimulus packages led to significant increases in public debt levels across the world (Augustin et al., 2022). Global public debt rose to 93% of GDP in 2023 and 100% in advanced economies (IMF, 2024; Armendariz et al., 2024).

A prominent example of financial instability originating in the sovereign debt market is the 2010-12 Euro sovereign debt crisis when worried investors pushed the debt dynamics of countries like Italy, Spain, and Portugal into an unsustainable debt spiral.¹ In the same vein, in March 2020, a comment by the newly appointed President of the European Central Bank (ECB), Christine Lagarde, that “the bank is not here to close spreads” was followed by notable spikes in yields in Southern European countries.² In September 2022, Liz Truss, the UK Prime Minister, announced an ambitious fiscal program resulting in an additional deficit of 45 billion pounds. Bondholders perceived the initiative as leading to an unsustainable debt path, causing gilt yields to jump from 3.1% to 4.5% in just one month, and ultimately imposing the resignation of the PM after just 49 days in office (Ioanes, 2022).

A large theoretical literature has modeled the mechanism through which such episodes of self-fulfilling sovereign distress unfold: concerns about fundamental country risk cause investors to panic and demand higher yields on government bonds; these higher borrowing costs contribute to raising debt levels further, eventually driving countries into insolvency, thus justifying the high interest rates in the first place (Aguilar et al., 2016; Ayres et al., 2018; Lorenzoni and Werning, 2019). Furthermore, when public debt is very high, even if debt maturity is long-term, governments’ main

¹In December 2011, the interest rate on Italian 10-year bonds reached a worrisome peak of 7%, while the public debt of Italy was 2 trillion euros at the time. At the peak of the crisis, Greece, an advanced economy, entered a debt restructuring scheme with private investors akin to a partial debt default (Zettelmeyer et al., 2013). Sovereign bond spreads in these countries started falling only after Mario Draghi’s ‘Within our mandate...’ speech in July 2012, followed by the implementation of the *Outright Monetary Transaction* scheme in September 2022. It is worth mentioning that so far the scheme has not been activated.

²This alarming episode eventually only came to a close in July 2022 when the ECB implemented the *Transmission Protection Instrument*, which is essentially a tool to provide emergency liquidity to any financially distressed governments in the Eurozone.

challenge is to refinance this debt year on year, commonly referred to as *debt rollover problem*.³ If at least some major investors panic and shun public bonds, illiquidity (or rollover) default can occur even if country fundamentals are sound.

However, empirically it is quite challenging to disentangle the role of fundamental country risk from that of rollover risk in explaining bond yields, given the large number of factors simultaneously at work during episodes of distress in sovereign debt markets, and the endogenous nature of investors' beliefs. As such, a controlled laboratory experiment is a useful methodology as it allows us to disentangle the contribution of the two types of risks in the pricing of sovereign bonds. Over time, lab experiments become a stand-alone research method in finance, able to shed light on the essential questions of causality and omitted variables (Kirchler and Weitzel, 2023).

This paper introduces an original laboratory experiment to study government debt dynamics and the evolution of bond prices as debt approaches default. In the experiment, a government seeks to roll over its debt over ten periods, by issuing one-period bonds in the primary market. Participants in the experiment play the role of investors who purchase the one-period bonds through a discriminatory price auction. In the experiment, the government can default for two reasons: (i) coordination failures and (ii) insolvency. Coordination failures result from the inability of investors to coordinate in providing funds to the government. A government defaults if it cannot sell enough bonds to cover its maturing debt. Sovereign default can also occur due to the accumulation of debt over time to the point that all available funds cannot cover the government's debt.⁴ If investors bid too low prices for the bonds (i.e., demand too high yields), debt rises fast, and the government reaches the insolvency limit before the game ends. We calibrate the experiment such that debt accumulates slowly and the default limit cannot be reached in the ten periods of the experiment if all investors accept the lowest yield (5%). However, if investors ask for higher yields, debt moves to an unsustainable path and the insolvency limit can be reached within the ten rounds of the experiment.

A key feature of the experiment is the endogenous probability of default, which depends on the

³For instance, Chen et al. (2019) report a public debt maturity of advanced economies in the interval 1995-2014 of 8.1 years on average. Many large countries such as France, Spain or Italy, must raise annually around 300 bn. euros of new debt.

⁴This narrow definition of insolvency is meaningful in our finite-time, repeated decision framework of investors. In an infinite-time framework, insolvency should be defined as the discounted flow of investors' future income.

bond's initial public offering in each period. Higher yields demanded by investors mean debt accumulates faster, which increases the risk of default, thereby further increasing the risk premium in future periods. Importantly, default is costly for players who invest in the defaulting period, as we assume a haircut is applied to both government debt as well as future investor resources. This makes coordination failures likely, as it is optimal for players not to invest if they believe the government will default in the current period (players not investing in the defaulting period do not have their funds reduced in future periods).

We design two treatments that allow us to disentangle between the two types of default and their contribution to the overall risk premium. In a Baseline treatment, the two types of default are possible, while in a second treatment, a central bank, simulated by the computer, purchases any of the bonds unsold to investors at the highest price (lowest yield). This eliminates the possibility of default due to coordination failures. A comparison between yields and defaults between the two treatments will allow us to disentangle the strategic premium from the overall risk premium, and understand how different policies such as debt monetisation can slow down or precipitate a self-fulfilling debt crisis.

We find that, while strategic defaults are eliminated in the treatment with a Central Bank (CB treatment), default due to insolvency still occurs rather frequently in both treatments. This allows us to test players' understanding of the crucial interaction between bond prices (yields) and subsequent default.

The results show that players understand this link well and price bonds accordingly: risk premium increases as the government approaches default or as debt increases. Moreover, we find that the risk premium is significantly lower in the CB treatment where strategic risk is eliminated. While the average interest rate in the Baseline treatment is 9.7%, it is only 7.6% in the CB treatment. The difference is sizable, given the range of prices available in the auction which correspond to yields between 5-30%. This difference between interest rates across the two treatments can be viewed as the illiquidity component of sovereign debt risk.

Related literature

Our results provide experimental evidence on how sovereign debt crises unfold and contribute to understanding some key empirical puzzles observed during these episodes, such as the high volatility

of yields which is not always aligned with country fundamentals (Aguiar et al., 2016). They also allow us to provide empirical evidence for the large body of theoretical literature on sovereign debt crises. Many studies assign an important role to belief formation in a context prone to multiple equilibria due to the intertemporal dimension and the substantial uncertainty involved in bond trades. In pioneering models, such as Calvo (1988), the probability of future default has a bearing on the contemporary price of sovereign bonds. In Eaton and Gersovitz (1981) competitive investors interact with a strategic sovereign borrower, who must decide how much to borrow, whether to default and when. Many variants of such self-fulfilling crises were developed, allowing for various sources of uncertainty, such as the cost of default, the government's income, debt maturity, random shocks, etc (see, among others, Cole and Kehoe, 1996; Aguiar and Amador, 2014; Aguiar et al., 2016; Ayres et al., 2018). In many of these models, suddenly deteriorating beliefs can explain the debt crisis as a shift from a good to a bad equilibrium.

Our experimental design is closest to the model in Lorenzoni and Werning (2019). Inspired by the Euro-area sovereign debt crisis of 2010-12, they model a slow-moving debt crisis in which, fearing future default, investors demand higher yields on government bonds. The higher cost of borrowing contributes to raising debt levels, eventually driving countries into insolvency, thus justifying the high interest rates in the first place. In the model, this feedback loop between interest rates and debt accumulation opens the door to multiple equilibria. Our experiment provides empirical evidence for this mechanism, as the economy moves from a low-interest sustainable equilibrium to a high-interest rates one due to self-fulfilling investor beliefs.

Other papers extend the classical models of self-fulfilling sovereign default to study whether central bank support can eliminate such crises without challenging the goal of price stability (see, for example, Corsetti and Dedola, 2016; Roch and Uhlig, 2018; Bianchi and Mondragon, 2022; Fontanier, 2023). Largely inspired by the success of the conditional bail-out policy introduced by Mario Draghi in 2012, which brought to an end the sovereign debt crisis of 2010-12, these models generally show that central banks can largely eliminate rollover crises by means of debt monetization, be it effective or just an announcement. Our experiment represents in a stylized manner this key role of central banks and allows us to disentangle the coordination risk premium from the overall default risk.

Several papers employing a global games methodology are also concerned with characterizing these

two components of credit risk and how fundamental factors or policies can influence them.⁵ For example, [Morris and Shin \(2004\)](#) study the price of coordination failure in a model where creditors of a distressed borrower face a coordination problem in renewing their loan. In the global games framework, default is pinned down by fundamentals, but is the outcome of the investor coordination problem (see also [Morris and Shin, 1998, 2004](#)). Similarly, [Morris and Shin \(2016\)](#) provide a theoretical decomposition of bank credit risk into insolvency risk and illiquidity risk as a result of a run. Our experiment also emphasizes the interaction between “fundamental” risk related to the sustainability of government debt, and “strategic” risk which results from investors’ coordination failure. As such, it is also related to a large experimental literature on coordination games in the lab in a global games framework (see, among others, [Heinemann et al., 2004a](#); [Schotter and Yorulmazer, 2009](#); [Cornand and Heinemann, 2014](#)). This literature has mainly focused on bank runs (see [Peia and Vranceanu, 2019](#); [Kiss et al., 2022a,b](#); [Trautmann and Vlahu, 2013](#)). [Bayona et al. \(2023\)](#) study the effects of credit rating in corporate bond markets. None of these papers, however, focuses on how strategic versus fundamental defaults determine bond prices.

Finally, our work is also related to an extensive literature in experimental economics and finance that studies the determination of asset prices under various institutional contexts, building on the pioneering work by [Smith et al. \(1988\)](#) (see survey by [Bossaerts et al., 2009](#); [Noussair and Tucker, 2013](#); [Palan, 2013](#); [Nuzzo and Morone, 2017](#)). While many papers model stock market bubbles and price formation, experimental analyses of bond markets and bond pricing are scarcer. Closest to our work is [Weber et al. \(2018\)](#) who analyze the feedback effect between IPO prices and the probability of issuer default in the corporate bond market. In their paper, bonds are sold to investors through an IPO via a uniform price auction, who then trade these bonds in a ten-period secondary market. The prices investors pay in the IPO determine the costs to the bond issuer. In one treatment, the probability of default is exogenously determined, while in another treatment, the probability of default is related to the initial price. They find that subjects learn to price bonds rather well, with the empirical price converging toward the theoretical price.⁶ Contrary to our study, there is no

⁵Global games refers to an equilibrium refinement as applied to standard coordination games ([Carlsson and Van Damme, 1993](#); [Morris and Shin, 1998](#)). If players obtain only noisy signals about the fundamentals of the system, then the multiplicity of equilibria disappears, and the model is characterized by a *threshold equilibrium*, where all players coordinate on either the high or the low action, depending on whether fundamentals cross this threshold.

⁶[Weber et al. \(2024\)](#) extend to model in [Duffy and Ochs \(2012\)](#) to analyze CDS pricing in an experimental bond market subject to default risk.

roll-over risk of default in their analysis, since after the IPO the bonds are traded on a secondary market. At the same time, in our paper, the focus is on public debt refinancing and the illiquidity risk associated with debt rollover.

The paper is organized as follows. The next Section introduces our experimental design. Section 3 presents the results, first focusing on a group-level analysis, followed by an analysis of individual decisions. Section 4 is our conclusion.

2 Experimental design, testable hypotheses and implementation

2.1 Implementation

Experimental sessions were performed at the ESSCA Behavioral and Experimental Lab in Lyon, France. All subjects were recruited from the subject pool of the lab including students in engineering and management in close locations. The experimental sessions were organized in November 2023 and February-March 2024. A total of 110 students participated in the two treatments (55 in each); for each treatment, we ran three sessions with 20 participants and one with 15 participants.⁷ Participants played the game on a computer screen and could not interact with each other. Before moving to the active task, participants were given 20 minutes to read the (printed) instructions on their own, after which the administrator read the instructions aloud and addressed any questions from the participants. Instructions and data are provided in the online Appendix [A.1](#)). The game was programmed using O-Tree ([Chen et al., 2016](#)).

At the end of the experimental sessions, subjects received compensation in cash according to the rules specified in the instructions. On average, participants earned 16.11 Euro for 105 minutes spent in the Lab (this amount includes a 12 Euro show-up fee).

2.2 Experimental design

In the experiment, a government must finance its public debt by selling bonds in a primary market through a standard trading mechanism (discriminatory price auction). The debt must be rolled over during ten periods.

⁷This corresponds to 11 independent groups of 5 investors by treatment; there were 8 independent groups by treatment in the experiment by [Weber et al. \(2018\)](#).

The experiment has three distinct rounds. The first is a practice round, which is unpaid and includes only five decision periods. Rounds 2 and 3 are identical; they include 10 decision periods each. At the end of the experiment, the computer selected at random one of the 20 active periods and subjects received the payoff for that period in cash.⁸ The conversion rate was 10 ECU = 1 Euro.

At the beginning of each round, subjects were randomly assigned to groups of five. Groups did not change during one round, whereas groups were rematched from one round to another.

Let us first describe our Baseline treatment (detailed instructions are available in the Appendix A.1), then we introduce the Central Bank treatment. Subjects participating in one treatment could not participate in the other treatment, in a standard between-subjects design.

Baseline Treatment

In every period of each round, an investor can borrow up to 1,000 ECU (at no interest) and can use them to purchase government bonds. Players bid a combination of quantities and prices as shown in Figure 1. Bonds purchased have a maturity of 1 ECU so the prices listed correspond to bond yields ranging from approximately 5% (corresponding to a price of 0.95 ECU) to 42% (price of 0.70 ECU). The interest rate on bonds purchased represents the potential gain of the investor in the experiment. We assume that players cannot carry their gains across periods. At the end of the experiment, one period out of the 20 active periods is chosen at random and the gain, converted into euros, will be paid in cash. If players do not invest and default occurs in the period selected, the gain of the investor is zero.

The initial debt level at the beginning of each round is $D_0 = 2,500ECU$. In each period t , the government seeks to roll over the pending public debt D_t by issuing as many bonds as needed. All bonds have a one-period maturity and a face value of $1ECU$, with a zero coupon. For a bond sold at price $b_t < 1$, the associated interest (or yield) i solves $b_t(1 + i) = 1$.

Governments generally sell bonds in primary markets through either uniform or discriminatory price auctions or both to a relatively small number of institutional investors (primary dealers). In a discriminatory price auction, the government sells at the highest price offered (lowest interest

⁸Experiments in coordination games have found that random payments give the highest possible impact of risk aversion and induce players to avoid hedging (Heinemann et al., 2004b).

rate) first and if the bids at this price are not enough to cover the debt, it moves on to the second highest price and so on until the debt is covered. In a uniform-price auction, bidders pay the same price (of the marginal offer).⁹

In our experiment, the government sells bonds through a discriminatory price auction.¹⁰ Among the large EU countries, in the 2020s, [France](#), [Germany](#) and [Sweden](#) use discriminatory auctions and so does the EU to sell sovereign bonds related to [the NextGenerationEU](#) initiative.

More specifically, at the outset of a period, the screen will display a tender schedule for each of the five investors (Figure 1), where the investor fills in how many bonds they are willing to purchase at a given price. The listed bond prices vary from $b = 0.95\text{ECU}$ (5.2% interest) to $b = 0.70\text{ECU}$ (42.8% interest rate) with a step of 0.05ECU.

Once bids are submitted, the computer will adjudicate bonds in order, from the highest to the lowest price offered by the five investors in the group, until it finances the total debt. This process is explained in detail in the instructions and examples are given. More precisely, the computer first checks whether the pending debt can be financed at the price of 0.95. If the sum of the bid values for this price is lower than the debt, the algorithm moves down to the next price (0.90) and so on. The process stops at the price at which the total value of the bids is equal to the value of the pending debt. If at this last the demand for bonds is higher than the residual debt to be covered, each investor receives a share of bonds proportional to their bidding quantity.

When filling their bid offers, investors know the amount of debt D_t to be financed (at the beginning of the period t). The computer will display not only the debt to be financed but also the past debt levels, using a line graph (see Figure 1). The graph also displays the total borrowing capacity of the five investors (red line), which is the “solvency threshold”. The solvency threshold represents the maximum amount of debt that investors can finance using all the funds they have available and financing the government at the lowest yield (price of 0.95 ECU). At the beginning of the game, this limit is $(4,750=0.95 \times 5,000)$. The graph in Figure 1 facilitates participants’ understanding of the debt trajectory in their environment.

⁹Scholars still debate on which of the two mechanisms allows the government to raise more funds ([Binmore and Swierzbinski, 2000](#); [Brenner et al., 2009](#); [Ausubel et al., 2014](#); [Hortaçsu et al., 2018](#); [Kagel and Levin, 2011](#)).

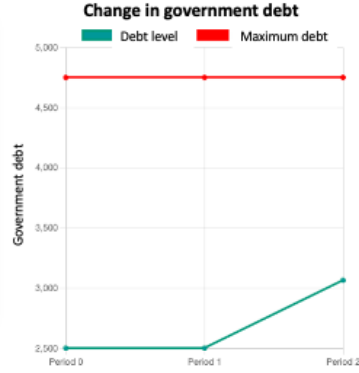
¹⁰In this respect, the trading mechanism in this paper differs from [Weber et al. \(2018\)](#) who used a uniform price auction mechanism. Because in a discriminatory price auction, participants pay what they bid, it might be easier for them to understand the underlying mechanism.

Figure 1: Decision screen

Period 2 / 5 – Round 1/3

Amount you can invest: 1000.0 EC
 Government debt for the previous period: 2896.0 EC
 Government income during this period: -168.0 EC
 Total debt to be financed: 3064.0 EC
 Please indicate the quantities you wish to buy in the table below, then press "Submit input" and wait. A lower price implies a higher interest (gain) for you; on the other hand, requests at higher prices will be served first.

Price	Quantity	Value	Gain
0.95	<input type="text" value="0"/>	0	0
0.9	<input type="text" value="0"/>	0	0
0.85	<input type="text" value="0"/>	0	0
0.8	<input type="text" value="0"/>	0	0
0.75	<input type="text" value="0"/>	0	0
0.7	<input type="text" value="0"/>	0	0
Total	0	0.00	0.00



The government seeks to finance its debt for ten periods in each round. In each period, debt accumulates depending on the prices at which the government sold bonds in the previous period as well as a random income. We assume that, at the end of the period, the government receives some revenue. This public revenue is a random draw from a uniform distribution with support $[0, 250]$. On average, this income can cover the lowest interest rate (5%) for the initial debt. The game is thus calibrated such that the initial solvency limit is not reached in the ten periods when debt is financed at the lowest cost (i.e., bonds were all sold at the price of 0.95 ECU).

As such, debt accumulation follows a simple rule:

$$\text{Debt}_t = \text{Total number of bonds sold}_{t-1} - \text{Revenue}_{t-1} \tag{1}$$

As the face value of a bond is 1ECU, the value of the debt at the beginning of period t is equal to the number of bonds sold at the beginning of period $t - 1$ minus the random income of the government (Revenue) recorded at the end of the period $t - 1$.¹¹

The government can fail to finance its debt and will default on its pending debt for two reasons:

1. Illiquidity (rollover) crisis: when not enough bonds are sold to cover current period debt;

¹¹The actual number of bonds sold will depend on the bids of the investors at the various prices.

2. Insolvency crisis: when the debt level reaches the solvency limit (defined as the sum of available funds of all investors). At the outset of the game, the threshold is 4,750ECU, which is the maximum amount of debt that investors can finance if they buy bonds at the highest price using all their available funds (5000×0.95).

If default occurs at the end of a period $t - 1$, the consequence is twofold. For the government, the debt that it must finance at time t is now $0.7 \times D_{t-1}$, implying a 30% haircut. Investors who purchased bonds at the beginning of a “default period” lose their investment and obtain no return. At the same time, from that period onwards, their available funds are also reduced to 70% of the before-default value. For example, in the periods after the first default, default-subjected investors can borrow no more than $0.7 \times 1000 = 700$ ECU. Those who did not invest in the default period keep on receiving the full amount. This payoff rule makes default costly for investors, similar to a real-life context. As such, the optimal action of an investor is not to make any bids in a period t if the individual expects default to occur in that period. If all investors have the same beliefs, this results in a rollover (or illiquidity) crisis. Anticipating a rollover crisis in period t , investors might find it optimal not to invest in period $t - 1$ and so on following a backward reasoning, causing the government to default due to illiquidity significantly before the insolvency limit is reached.

Once a default occurs and if some players see their borrowing limit reduced, the insolvency limit will also decrease to reflect the reduced available funds in the market. Furthermore, in all subsequent defaults government debt as well as the funds of defaulting investors are further cut by 30%. It should also be noted that even if players do not invest in the defaulting period and have their funds reduced, a default is still costly for them, as the government pays interest on a much lower debt level, which reduces their future interest income.

It is worth emphasizing that, in our experiment, the key event of interest is the first default; in line with real-life situations, the first default both alleviates the debt burden (a haircut applies) but also makes the funding of further debt more difficult. An alternative design would have allowed for the experiment to end immediately after the first default; however, this would make the time management of the experiment quite cumbersome, since different groups would default at different periods, if any. Observing how subjects play after the first default can bring additional insights into their decision-making process as well.

Figure 2: Feedback at the end of each period

Period 1 / 5 – Round 1/3

The government has managed to sell enough bonds to cover its debt.
 You have bought 668 bonds at the prices shown in the table below.
 Your total profit in this round is: 167.0 EC.
 The debt to be financed over the next period is: 2896.0 EC.

Your auctions and purchases:

You have successfully purchased the following bonds

Price	Purchase offer (number of bonds)	Actual purchase (number of bonds)	Gain
0.95	0	0	0.0
0.9	0	0	0.0
0.85	0	0	0.0
0.8	0	0	0.0
0.75	1333	668	167.0
0.7	0	0	0.0
Total	1333	668	167.0

Quantities of bonds allocated to the 5 investors:

The government sold the following quantities of bonds

Price	Total number of bonds (actual sales)	Value of debt hedged at each price
0.95	1052	999.4
0.9	0	0.0
0.85	1176	999.6
0.8	0	0.0
0.75	668	501.0
0.7	0	501.0
Total	2896	2500.0

At the end of each period, the computer displays (Figure 2) the bids and quantity obtained by the investor for each offered price, as well as the total amounts sold by the government (to the group of investors).

Central Bank Treatment

The second treatment (CB treatment) is similar to the first, with the only difference being the presence of an additional player, the “central bank” that is played by a computer. The central bank (CB) is a passive player that intervenes and eliminates illiquidity default. That is, whenever a solvent government cannot attract enough private investment (from the 5 investors) to finance its debt, the central bank will purchase any remaining bonds at the lowest rate of interest ($b = 0.95$ ECU).

Since the central bank is assumed to have unlimited funds, the only source of default is now insolvency, i.e., a situation where the total debt exceeds the solvency threshold (initially set at $S = 5000$ ECU).

Personal characteristics

In both treatments, after the end of the investment game, but before receiving the information about the final payoff from the experiment, subjects were asked for information on their gender,

age and major track of study.

To elicit their *risk tolerance* we use the self-reported measure introduced by [Dohmen et al. \(2011\)](#).¹²

Participants were asked:

- “How do you see yourself? Are you generally a person who is fully prepared to take risks, or do you try to avoid taking risks?”

The answers are on a scale from [Avoid taking risks=0] to [Fully prepared to take risks=10].

We adopt a similar method to elicit participants’ *financial literacy*. They were asked:

- “How would you rate your skill level in financial investment?”

For this question, the answer was also on a scale from [No knowledge =0] to [Extensive knowledge =10].

Finally, participants’ *practical experience in financial investing* was evaluated through another self-reported measure. We asked them to:

- Please assess your practical experience in financial investment and trading.

Answers were recorded on a scale from [No experience =0] to [Substantial experience =10].

Average measures by treatment are displayed in Appendix Table 6; there are no significant differences between groups with respect to personal characteristics, except a slightly higher frequency of women in the baseline treatment group (55% compared to 45%).

2.3 Testable hypotheses

The sovereign bond investment game presented in the previous section allows us to test several empirical hypotheses. In general, as debt increases, the default probability also increases from one period to another, so players must infer all implications of the feedback loop from bid prices to default probabilities themselves. Since default inevitably occurs at the insolvency threshold, if investors infer that this limit will be reached before the end of the game (period 10), they should

¹²Recently, this measure received a wide acceptance in experimental research, in particular since several studies pointed out the large noise intrinsic to standard incentive-based measures of risk aversion ([Gillen et al., 2019](#); [Perez et al., 2021](#)), and the lower noise of survey-based measures ([Mata et al., 2018](#)). Furthermore, [Dohmen et al. \(2011\)](#) reveal a strong correlation between the survey-based measure of risk tolerance and context-based choices.

demand a higher risk premium (interest rate) as debt levels approach the limit. This will maximize their gains before default occurs after which potential interest rate gains fall due to the debt haircut. As such, we can formulate our first testable hypothesis as follows:

H1: Investors require a higher risk premium (higher interest rates) as debt levels increase and the economy approaches insolvency default.

The second key feature of our experiment is the ability to distinguish empirically between insolvency and illiquidity risk through the two treatments proposed. Specifically, in the Baseline treatment default can occur due to both coordination problems and insolvency, while strategic risk is eliminated in the CB treatment as the central bank intervenes whenever a shortage of liquidity occurs. Nonetheless, the intervention of the central bank as a lender of last resort might not necessarily eliminate fundamental defaults. For example, while a stable debt path is possible if investors coordinate on the low-yield equilibrium (all debt is financed at the price of 0.95), any deviation from the lowest yield implies debt will reach the insolvency threshold in the ten rounds of the game even when the central bank intervenes. Thus, a second testable hypothesis is:

H2: The overall number of government defaults is lower in the CB treatment as opposed to the Baseline treatment.

Furthermore, because strategic risk is eliminated by the presence of the central bank and defaults are less frequent, investors should price this in their bids and require a lower risk premium in the CB treatment, as compared to the Baseline one.

H3: The average interest rates are lower in the CB treatment as compared to the Baseline treatment.

Finally, in the Baseline treatment illiquidity and insolvency risk coexist. Illiquidity default will occur when the debt level reaches an illiquidity threshold, defined as the sum of all available investor resources in the economy. Therefore, as debt approaches this limit, investors are less likely to invest in a self-fulfilling anticipation of default. This relationship should be stronger in the Baseline, as in the CB treatment the central bank will eliminate insolvency defaults even prior to the limit being reached.

H4: The likelihood of participating in the auction and bidding for government bonds is decreasing in the debt level.

3 Results

Our main results are related to the aggregate investment behaviour at the group level. Later on, we analyse the predictors of individual investment behaviour.

3.1 Group level analysis

3.1.1 Frequency of defaults

We start by describing the outcomes of the bond investment game in terms of the evolution of government debt and sovereign defaults in each round.

Table 4 presents the number and type of defaults in each treatment. For the sake of transparency, we also include in this table the results from the practice round (Round 1), however, in the subsequent analysis we drop observations from this round.¹³ We find a total of 63 defaults in the Baseline Treatment which is around 23% of the total 275 group-period observations (11 unique groups per treatment playing for 25 periods, including the five practice rounds and ten periods for each of rounds 2 and 3). This number is almost halved in the Central Bank Treatment, where only 12% of periods resulted in a default and the difference is statistically significant (p-value < 0.001).¹⁴ This result corroborates **H2**, as most of the defaults in the Baseline Treatment are the result of coordination failures: around 71% of the periods with default was due to the fact that the government could not sell enough bonds to roll over the maturing debt, as opposed to the solvency limit being reached. In fact, a total of 17 defaults in the Central Bank (CB) treatment were avoided because the central bank intervened when participants did not coordinate on buying enough debt.

This evidence shows that coordination failure is an important reason for default in the model and validates our experimental design for the CB treatment where the central bank intervenes to eliminate this strategic/illiquidity risk in sovereign bond markets.

¹³The practice round included only five periods and was not incentivized.

¹⁴P-values reported throughout correspond to a t-test on equality of means performed at the unique group level.

Table 1: Sovereign debt defaults

	(1)	(2)	(3)	(4)
<i>Panel A: Baseline Treatment</i>				
	Overall defaults		Coordination Failure	
Total	63	23%	45	71%
Round 1 (practice)	10	4%	5	50%
Round 2	32	12%	22	69%
Round 3	21	8%	18	86%
<i>Panel B: Central Bank Treatment</i>				
	Overall defaults		Defaults avoided due to CB intervention	
Total	34	12%	17	50%
Round 1 (practice)	5	2%	0	0%
Round 2	16	6%	9	56%
Round 3	13	5%	8	62%

Column 1 presents the total number of defaults observed. Column (2) shows the proportion of periods with a default in each treatment out of the total number of 275 observations per treatment. Column (3) shows the number of defaults due to a coordination failure, while Column (4) shows the proportion of the coordination failure defaults of the total number of defaults that round.

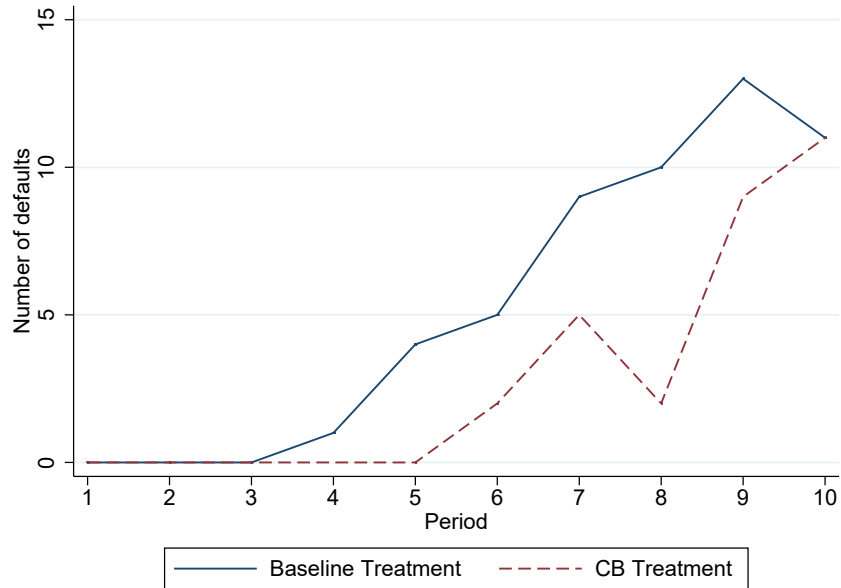
Next, Figure 3 documents the timing of defaults across the 10 periods in Rounds 2 and 3. As expected, defaults occur sooner in the Baseline Treatment, with the first default occurring in period 4 of the Baseline treatment, while in the CB treatment only in period 6. Defaults also gradually increase in the Baseline treatment after period 4, while in the CB treatment, later defaults seem to be avoided due to the intervention of the central bank. The maximum number of defaults was reached in period 9 when 13 out of the 22 groups in the Baseline Treatment defaulted.

Based on the evidence above, our first result can be summarized as:

Result 1: *Government default is significantly more common in the Baseline treatment, where a large share of defaults occur due to coordination failures.*

Figure 4 shows the evolution of the number of defaults in each treatment by the type of default (insolvency limit reached and coordination failure or illiquidity). Specifically, Figure 4(a)) presents the data for the Baseline treatment. We observe that defaults due to insolvency can be observed as early as period 4 and their number is constant in the remaining periods. Defaults due to

Figure 3: Number of defaults over time



The Figure shows the total number of defaults in each period in each treatment.

coordination, on the other hand, are increasing in number until period 9. For the CB treatment (Figure 4(b)), coordination failures are not possible as the Central Bank always buys all residual debt, so all defaults are due to the insolvency limit being reached. However, for this treatment, we can identify how many defaults were avoided due to the intervention of the CB (depicted by the dashed line in 4(b)). CB starts intervening in period 5, with an average of around 4 interventions per period across the 22 unique groups in this treatment.

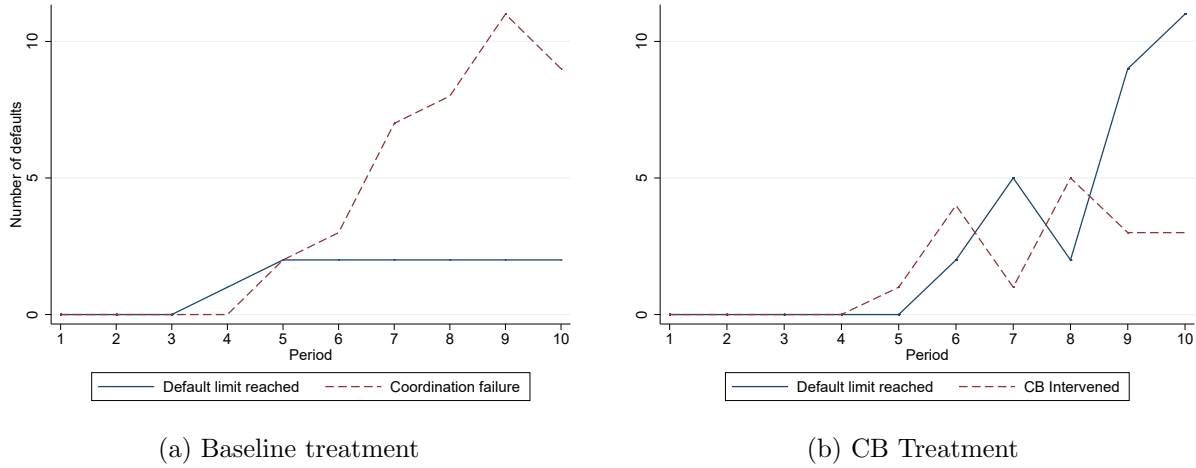
3.1.2 Evolution of government debt

Given our design, the debt trajectory can follow one of four specific patterns:

- All investors lend at the lowest interest rate (5%) and the debt moves randomly around the initial value.¹⁵
- The debt rises slowly but does not cross the insolvency threshold before the end of the experiment; furthermore, no coordination default occurs.

¹⁵This interest is covered, on average, by the expected income of 125ECU.

Figure 4: Defaults: Solvency limit vs. coordination failures



The figures show the total number of defaults by the type of default in each period, by treatment. In both Figures (a) and (b), the full lines show the number of insolvency defaults. The dashed line in Figure (a) shows the number of defaults due to coordination failure in the Baseline treatment, while in Figure (b), the dashed line shows the number of defaults that were avoided because the Central Bank stepped in.

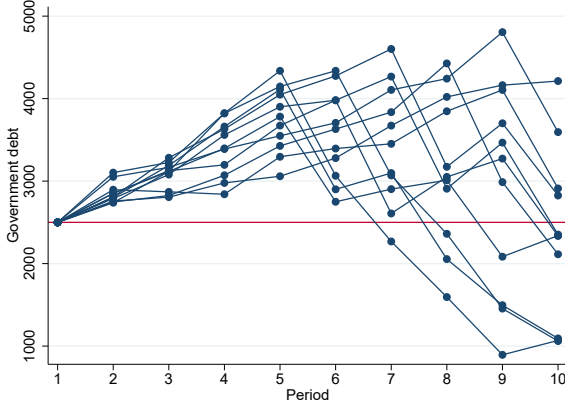
- The debt rises fast and crosses the insolvency threshold before the end of the experiment (no coordination default occurs before).
- As the debt rises, coordination default occurs before the debt reaches the insolvency threshold.

Figures 5 and 6 show the evolution of total government debt in each of the 11 independent groups, by treatments and by round. A sharp decline in the debt level is representative of a default, and corresponds to the 30% haircut.

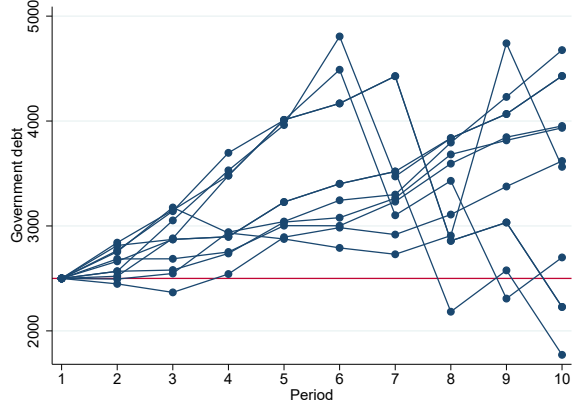
As we can see, in most of the groups, the total debt diverges (over time) from the stable path, albeit at different paces. This can be seen as a first coordination failure, driven by self-regarding and short-sighted investor behaviour, who fail to internalize the long-term risk, and bid for low bond prices at the outset of the game, despite the disciplining effect of the auction mechanism.

We observe debt levels rising fast for three of the groups in the CB treatment in Round 2, which reach the solvency default limit in period 5 (see Figure 5). Nonetheless, the average level of debt across all groups in the periods before the first default is smaller in the CB treatment (3,136 ECU) as compared to the Baseline treatment (3,373 ECU, p-value=0.01). In Round 3 (Figure 6), the debt accumulates, on average, at a slower pace. Therefore, in the CB treatment default does not

Figure 5: Evolution of Government Debt (Round 2)



(a) Baseline treatment



(b) CB Treatment

The figures show the evolution of government debt across the 10 periods in Round 2 for each of the 11 unique groups, by treatment.

occur at all in 4 of the 11 unique groups. In the other groups, default occurs in the last 3 periods of the investment game. Similarly to Round 2, average debt in Round 3 in the periods before the first default across all groups is lower in the CB treatment (3,207 ECU) as compared to the Baseline treatment (3,317 ECU), although the difference is not statistically significant in this case (p-value=0.21).

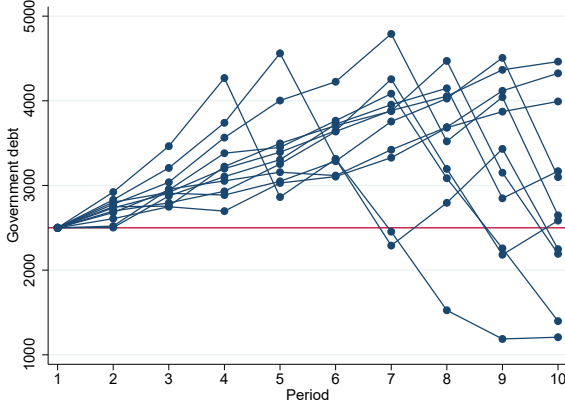
These results can be summarized as:

Result 2: *Apart from a few exceptions, at the outset of the game investors failed to coordinate on the low interest rate that ensures debt long-term stability. Furthermore, government debt in the periods before the first default is, on average, lower in the CB treatment as compared to the Baseline treatment.*

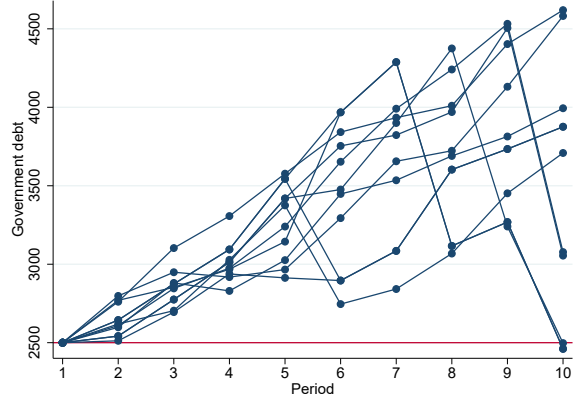
3.1.3 Interest rates

We can describe now the differences in (realized) interest rates across the two treatments. As hypothesized, we expect interest rates to be significantly lower in the CB treatment for two reasons: (1) the lack of strategic default risk in this game and (2) the presence of the central bank that purchases bonds at a high price leading to a slower accumulation of debt and a lower risk of default

Figure 6: Evolution of Government Debt (Round 3)



(a) Baseline treatment



(b) CB Treatment

The figures show the evolution of government debt across the 10 periods in Round 3 for each of the 11 unique groups, by treatment.

due to fundamentals.

The *average interest rate at which the government borrows funds* in each period is computed as the percentage difference between the total number of bonds traded and the value of those bonds:

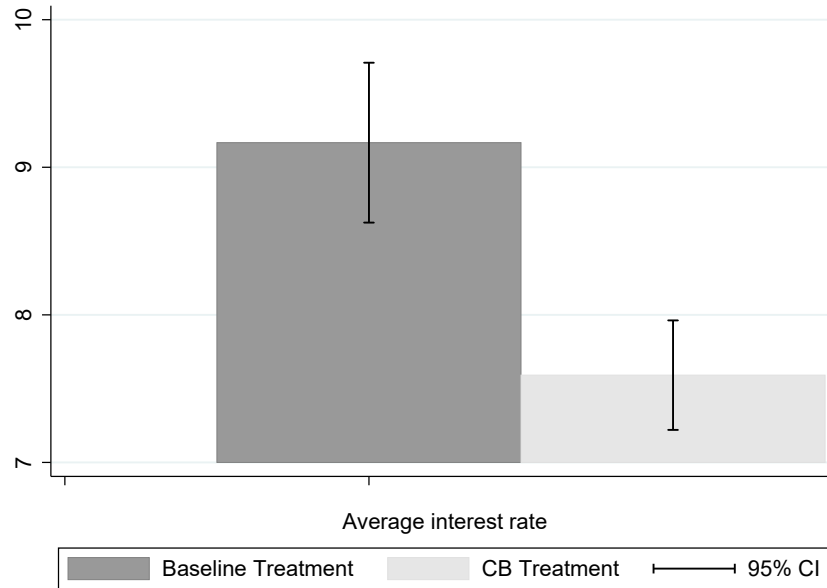
$$\text{Average interest rate}_t = \frac{\text{Number of bonds traded}_t - \text{Total value of bonds}_t}{\text{Total value of bonds}_t}, \quad (2)$$

where the “Number of bonds traded” is the total of bonds (with a face value of 1) that the group of five investors buys (and the government sells) at period t . The “Total value” of these bonds (or their monetary value) is the sum of the total number of bonds traded *at each price* multiplied by their price:

$$\text{Total value of bonds}_t = \sum_i (\text{Price}_{i,t} \times \text{Quantity}_{i,t}), \text{ where } i \in \{0.95, 0.9, 0.85, 0.8, 0.75, 0.7\}. \quad (3)$$

Since the government sells exactly the number of bonds needed to repay its current debt, the total value of bonds sold in a period is also equal to the next period’s debt, if enough bonds are sold and there is no default. As such, the number of government bonds sold becomes the debt to be repaid in the next period (to which a random government income is added). It is important to note that, in the CB treatment, the “Number of bonds traded” in Eq. (2) only refers to the successful bids of

Figure 7: Interest rates across treatments



the participants and excludes the bonds bought by the Central Bank at the price of 0.95. This way the average interest rate is not distorted by the higher price at which the Central Bank purchases bonds and only reflects the outcome of the auction for participants.

Figure 7 shows this average interest in each treatment in all the periods before the first default.¹⁶ We find that in the Baseline treatment, the government borrowed funds (sold bonds) at an average interest of 9.7%, while in the CB treatment, the average interest rate is significantly lower at 7.6% (p-value<0.001).

We can infer that:

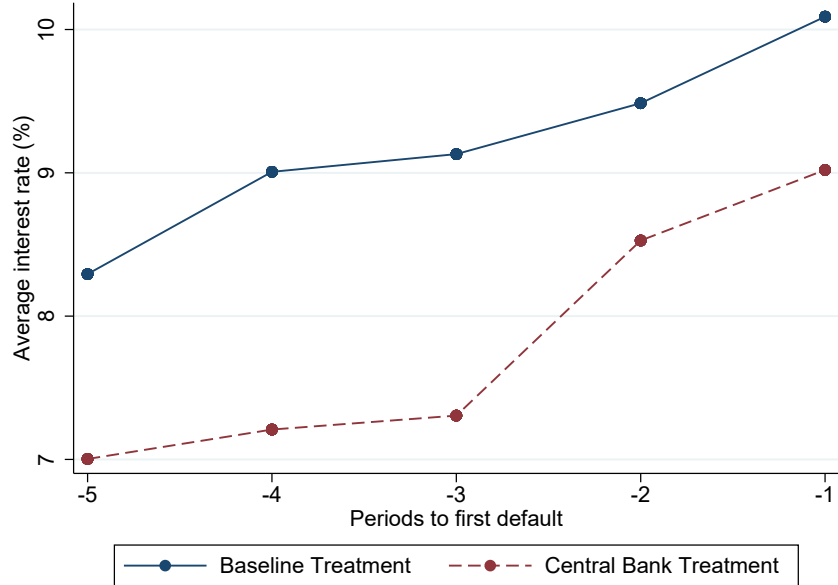
Result 3: *The average interest rate in the periods before the first default is lower by 2.1 percentage points in the CB treatment as compared to the Baseline treatment.*

This spread between interest rates in the two treatments is a proxy for the illiquidity (strategic) risk, which is only present in Baseline treatment. In the CB treatment, the direct intervention of the central bank in the bond market eliminates this strategic risk.¹⁷ This result corroborates our

¹⁶If a group did not default at that round, the sample includes all the ten periods.

¹⁷In many theoretical models of sovereign debt crises, such as [Lorenzoni and Werning \(2019\)](#), [Corsetti and Dedola \(2016\)](#), [Fontanier \(2023\)](#), the mere announcement of such an intervention should suffice to calm down investors, thus

Figure 8: Evolution of average interest rates across periods before default, by treatment



H3.

Figure 8 displays the evolution of average interest rates in the 5-period window before the first default. Specifically, for a default occurring at a round $t > 5$, we include the five periods before default; for $t < 5$, we consider only the t periods before. The figure shows that interest rates in the Baseline treatment are higher in all periods before default, but it also shows that interest rates increase steadily as the government approaches default. This result provides support for **H1** according to which participants correctly price default risk and require higher returns as the economy approaches default.

Result 4: *Average interest rates increase in the periods before the first default in both treatments.*

We confirm the results above in a regression analysis that allows us to bring additional insights into the dynamics of interest rates. Table 2 reports the results from a series of panel random-effect models at the group level. In line with Figure 8, we focus the analysis on the five periods before the first default for each group. For groups that have not defaulted, we include the last five periods (out of the 10 periods of the game). This corresponds to a total of 213 observations (out of a total

the CB does not need to actually intervene (as it happened in the Euro-area context).

Table 2: Interest rates and proximity to default (group-level analysis)

Dependent variable: Average interest rate	(1)	(2)	(3)	(4)
CB Treatment	-1.655*	-0.509	-1.627*	-6.087**
	(0.882)	(1.165)	(0.924)	(2.585)
Proximity to first default	0.322***	0.113		
	(0.098)	(0.116)		
Proximity to first default \times CB treatment		0.393**		
		(0.184)		
Government debt (before 1st default)			0.001*	0.000
			(0.000)	(0.000)
Government debt \times CB treatment				0.001*
				(0.001)
Round	-0.681	-0.676	-0.734	-0.772
	(0.882)	(0.892)	(0.923)	(0.905)
Observations	213	213	213	213
Number of groups	44	44	44	44

The dependent variable is the average interest at the group level in each of the five periods before the first government default, in each group. Proximity to first default is a scalar between [-5, -1] for the five periods before the first default in a group in period $t = 0$. CB treatment is an indicator variable equal to one for the Central Bank treatment and zero for the Baseline treatment. Round is a dummy variable equal to zero for the second round and one for round three, respectively. Standard errors clustered at the group level in parenthesis. *, **, *** show significance at 10%, 5% and 1% levels.

of 880 groups \times rounds observations).

The dependent variable in Table 2 is the average interest rate in each of the five periods before the first default, for each group. The main covariates are a scalar from -5 to -1 for the periods before default (*Proximity to first default*) and an indicator variable (*CB Treatment*) equal to one for the Central Bank treatment and zero for the Baseline treatment. In an alternative specification, we replace *Proximity to first default* by the level of *Government Debt (before 1st default)*, i.e. the debt in each of the five periods before the first default occurred.

All specifications also include a Round dummy variable equal to zero for the second round (i.e. the first paid round) and one for round three, respectively. Standard errors in all specifications at the group level to control for potential within-group correlation of actions across the ten periods.

As observed in Figure 7 and in line with hypothesis **H3**, we find that interest rates are higher in the Baseline treatment compared to the CB treatment. The coefficient of the *CB treatment* dummy is negative, albeit weakly significant, throughout.

Furthermore, the positive and significant coefficient of the *Proximity of default* scalar in column (1) suggests that interest rates increase as the government approaches default, in line with the pattern observed in Figure 8 and H1. This result is further confirmed in column (3), where we replace the Proximity to default scalar with the actual debt level (before default). We find that the higher the debt level, the higher is the interest rate asked by investors.

We also interact the *Proximity of default* and *Government debt* variables with the CB treatment indicator and find that these interaction terms are positive and statistically significant (see columns (2) and (4)). This outcome is expected. Indeed, defaults in the CB treatment are only due to fundamental risk. The latter is more salient because the software displays the actual debt and the insolvency limit in each feedback screen. Investors can therefore monitor in real time how the debt approaches this limit and demand a higher risk premium. On the other hand, illiquidity defaults generally occur in more sudden and less foreseeable ways (similar to real-world rollover crises).

Result 5: *The increase in interest rates as the government approaches default is higher in the CB treatment compared to the Baseline treatment.*

Finally, in all specifications, the ‘Round’ dummy variable is not statistically significant, implying that learning effects, if any, are very small.

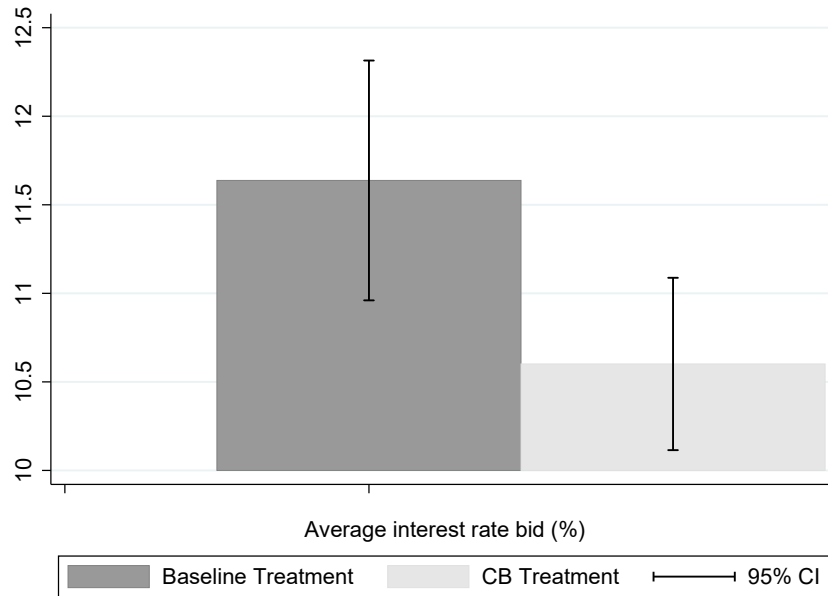
3.1.4 Bid rates

Our analysis so far has focused on the actual interest rate obtained by investors as a result of the auction mechanism that also represents the actual borrowing cost of the government. An alternative variable of interest is the average bid rate or the weighted average of all prices of the total bids submitted by the participants (using the quantity bid as a weight). This average bid rate should be larger than the actual average interest rate (as it also includes bids at the lowest prices which were not adjudicated).

Figure 9 shows the average interest rate bid by players for each treatment, in all periods before the first default. Same as before, we compute the average bid rate at the group level as the percentage difference between the total number of bonds bid and the value of these bonds.¹⁸ Figure 9 confirms

¹⁸Appendix Figure 10 shows the total quantity bid by all groups at each bond price across all periods. We observe that players submitted bids at all prices listed in the auction, with sizable larger quantities for the highest three prices (0.9; 0.85 and 0.8).

Figure 9: Average interest rates bid by treatment



our previous result (R5): investors ask (bid) for a lower interest rate, on average, in the CB treatment compared to the Baseline treatment. While the difference in the two interest rates is smaller (11.6% versus 10.6%) compared to the difference by treatment in average interest in bonds traded (9.7% versus 7.6%), it is still statistically significant at conventional levels ($p=0.01$).

Furthermore, in line with intuition, the average bid rate is bigger than the average actual interest rate in both treatments ($p\text{-value} < 0.001$).

3.2 Individual level analysis

In this section, we analyze investment behaviour from the perspective of the individual investor. This individual-level analysis allows us to test whether the patterns uncovered in the group analysis are robust to controlling for the personal characteristics of participants.¹⁹ Same as before, we restrict our analysis to the five periods before a first default or the last five periods if a default never occurred (a total of 1,034 observations).²⁰

¹⁹For instance, it could be that roll-over default is not a coordination problem after all, but just the outcome of poor financial literacy by some subjects.

²⁰More specifically, out of the 44 groups in rounds 2 and 3, 27 had at least 5 observation periods before the first failure (i.e., 27 groups \times 5 subjects per group = 135 observations), 31 had at least 4 observation periods (i.e., 155 observations), and all 32 had at least 3 observation periods before the first failure (i.e., 160 observations \times 3 periods).

3.2.1 Interest rates

Firstly we use the individual data to confirm the main results from the group data analysis. To do so, we run a set of random effect regression models in which the dependent variable is the average *interest rate obtained* by an individual j at period t . This interest rate is computed as the percentage difference between the total number of bonds bought by the investor, and the value of those bonds, which is also the gain of the investor (if no default occurs):

$$\text{Interest rate}_{j,t} = \frac{\text{Number of bonds bought}_{j,t} - \text{Value of bonds bought}_{j,t}}{\text{Value of bonds bought}_{j,t}} \quad (4)$$

where

$$\text{Value of bonds bought}_{j,t} = \sum_i \text{Price}_{i,j,t} \times \text{Quantity}_{i,j,t}, \text{ for } i \in \{0.95, 0.9, 0.85, 0.8, 0.75, 0.7\}. \quad (5)$$

The key explanatory variables are the same as in the group-level analysis in Table 2, i.e., *Proximity to first default* and, in the alternative specification, the level of *Government debt (before the 1st default)* in the group to which the individual j belongs. We include now the set of individual-specific variables: age, gender, study major, risk tolerance, financial literacy, and practical experience with financial investment.²¹ We also include the round dummy variable.

Table 3 presents the coefficients of the key variables of interest.²² The individual level regressions corroborate the results at the group level: individuals require lower interest rates in the CB treatment compared to the Baseline, and interest rates increase as the debt nears default (a confirmation of **H2** and **H3**). Furthermore, most of the personal characteristics are not statistically significant (see Appendix Table 7). Only age is weakly significant (positive correlation), and students from the finance major would ask on average for a lower interest rate (suggesting their bids are closer to the optimal interest rate that ensures no default).

These individual-level results remain robust when using bid rates instead of actual interest rates (480 observations). 12 groups had no default and we include the last 5 periods (12 groups \times 5 subjects per group \times 5 periods = 300 observations). Out of the resulting 1070 observations, there were 36 instances where no investment was made, leaving 1,034 observations to be included in the regression.

²¹The elicitation method was described in Section 2.

²²The full-specification results are presented in Appendix Table 7.

Table 3: Interest rates and proximity to default (individual-level analysis)

Dependent variable: Average interest rate	(1)	(2)	(3)	(4)
CB treatment	-1.706** (0.664)	-0.650 (0.875)	-1.769*** (0.686)	-8.667*** (1.935)
Proximity to first default	0.274*** (0.074)	0.078 (0.102)		
Proximity to first default \times CB treatment		0.364** (0.146)		
Government debt (before 1st default)			0.001** (0.000)	-0.000 (0.000)
Government debt \times CB treatment				0.002*** (0.001)
Round	-0.932* (0.525)	-0.935* (0.527)	-0.979* (0.544)	-1.009* (0.534)
Observations	1034	1034	1034	1034
R-squared	0.076	0.075	0.051	0.072
Controls	Yes	Yes	Yes	Yes

The dependent variable is the realized interest rate at the individual level in the five periods before the first government default. CB treatment is an indicator variable equal to one for the Central Bank treatment and zero for the Baseline treatment. Proximity to first default is a scalar between $[-5, -1]$ for the five periods before the first default in a group in period $t = 0$. Government debt refers to the total amount of debt held by the government by period. Round is a dummy variable equal to 1 for round 3 and 0 for round 2. Control variables include gender, age, risk tolerance, financial literacy, and practical expertise with investment. The field of study is categorized into Economics, Finance, Management and Business Administration, Science, or other majors. Standard errors clustered at the individual level in parenthesis. *, **, *** show significance at 10%, 5% and 1% levels.

(see Appendix Table 8).

3.2.2 The decision to bid

Individual data allow us to study more in-depth the decision of the individual whether to participate in the auction and at which price, conditional on their information set. In our Hypothesis 4, we conjectured that higher debt levels should lead to a lower likelihood of investing, particularly in the Baseline treatment where coordination failure cannot be ruled out. This is because default is costly for investors who bid in the defaulting period.

We investigate this in Table 4 which shows the number of times investors shun away the public bonds (i.e., made no bid for bonds, at any price). We find that the number of no-bids in the default periods is much higher than the no-bids in the no-default periods (70 vs. 22, $p < 0.001$). This large difference is mainly driven by the Baseline treatment, as expected. Table 4 also shows the number of times investors bid less than 50% of their income (including 0). Out of the 109 instances

Table 4: Descriptive statistics (Individual bid decision)

	All Subjects		Baseline		CB Treatment	
	(1)	(2)	(3)	(4)	(5)	(6)
	Default periods	No-default periods	Default periods	No-default periods	Default periods	No-default periods
Number of no bids (out of total periods)	70 (390)	22 (1810)	51 (265)	11 (835)	19 (125)	11 (975)
p-value (t-test)	0.000***		0.000***		0.000***	
p-value (Wilcoxon rank-sum test)	0.000***		0.000***		0.000***	
p-value (Two-sample test of proportions)	0.000***		0.000***		0.000***	
Nb. of bids < 50% of income (out of)	109 (390)	99 (1810)	67 (265)	24 (835)	42 (125)	75 (975)
p-value (t-test)	0.000***		0.000***		0.000***	
p-value (Wilcoxon rank-sum test)	0.000***		0.000***		0.000***	
p-value (Two-sample test of proportions)	0.000***		0.000***		0.000***	

The table shows the number of individual decisions with no bids or where bids were less than half of the available income. p-value corresponds to a Two-sample t-test with equal variances, Two-sample Wilcoxon rank-sum (Mann-Whitney) test and Two-sample test of proportions comparing the number of no-bid in default periods versus no-default periods. *, **, *** show significance at 10%, 5% and 1% levels.

in which investors cut their bids to less than 50% of their income, most of them (70) were cases with zero bids. This behaviour is expected, as investors in the defaulting period are subject to a haircut in the next periods, regardless of the amount they invested in the default period.

Building on this observation, we use a random effects conditional logit model to test **H4**. The independent variable is an indicator equal to one if the participant bid part of their income (at any price), and zero if they made no bid. Since decisions not to bid are rare (Table 4), we include in this analysis the full set of observations (N=2,200).

Table 5 presents the output of several regression models. In columns (1) and (2) we first investigate if the likelihood of investing is indeed lower closer to default. To do so we include as key explanatory variables an indicator variable equal to one if default occurred in a period t and zero otherwise. In column (2) we include a dummy for the period before the default period. Both dummy variables are negative and significant indicating that investors are less likely to make bids if they expect default to occur.

In column (3), we replace the dummy variables with a continuous measure of the level of indebtedness of the government computed as the total amount of debt held by the government in a specific period divided by the total available income of the five investors (*Debt-to-income* ratio). We opt for this measure as opposed to the actual debt level used in previous sections as in these full-sample regressions the debt level is mechanically reduced after default due to the haircut. Again, we ob-

Table 5: Individual probability to bid

	(1)	(2)	(3)
Dependent variable: $1\{Bid > 0\}$			
CB treatment	-0.001 (0.015)	0.004 (0.019)	0.076 (0.091)
Period of default	-0.086*** (0.014)		
Period of default \times CB Treatment	0.014 (0.019)		
One period to default		-0.081*** (0.016)	
One period to default \times CB treatment		0.018 (0.020)	
Debt-to-income ratio			-0.362*** (0.063)
Debt-to-income ratio \times CB treatment			-0.073 (0.106)
Period	-0.005*** (0.002)	-0.006*** (0.002)	-0.002 (0.002)
Round	-0.016 (0.010)	-0.010 (0.010)	-0.014 (0.011)
Observations	2200	2200	2200
Controls	Yes	Yes	Yes

The table presents the marginal effects from a conditional logit model. The dependent variable is an indicator equal to one if the participant made a bid, and zero otherwise. CB treatment is an indicator variable equal to one for the Central Bank treatment and zero for the Baseline treatment. The variables Period of default and One period to default are dummy variables representing, respectively, the occurrence of a default and one period prior to default. The debt-to-income ratio refers to the proportion of government debt relative to all investor's income. Round is a dummy variable equal to 1 for round 3 and 0 for round 2. Control variables include gender, age, risk tolerance, financial literacy, and practical expertise with investment. The field of study is categorized into Economics, Finance, Management and Business Administration, Science, or other majors. Standard errors clustered at the individual level in parenthesis. *, **, *** show significance at 10%, 5% and 1% levels.

serve that the probability of bidding is significantly lower as the debt-to-income ratio increases, in line with hypothesis **H4**.²³

The full specification of Table 5 is detailed in Appendix Table 10. The results indicate that most personal characteristics are not statistically significant. Only age shows significance, with a negative correlation. Contrary to intuitive reasoning, risk-tolerant subjects placed bids less frequently than risk-averse subjects.

We can summarize the results above as follows:

²³As a robustness check, Appendix Table 9 presents results from a similar regression analysis, but this time including only the five periods prior to the first default (a total of $N = 1,070$ observations). The coefficient of the debt level variable is positive, albeit weakly significant.

Result 6: *Investors are less likely to make any bid if the government is very close to default.*

Note, however, that this effect is not stronger in the Baseline treatment as we would expect. This would suggest that the main factor generating the large number of defaults in the Baseline treatment is not necessarily the concerns about others not investing, but rather the rising premium and the snowball effect this has in pushing up the speed of debt accumulation.

4 Conclusion

A common explanation for sovereign debt crises is self-fulfilling beliefs: if investors perceive a higher risk of a country defaulting on its debt, they demand higher interest rates. This increases the country's debt burden, which, in turn, makes default more likely. Spikes in sovereign bond spreads in Europe during 2010-12, which were disconnected from macroeconomic fundamentals, support this view and highlight an increasingly common debt rollover problem faced by many advanced and developing countries ([Bacchetta et al., 2018](#)).

However, the empirical analysis of sovereign bond pricing is often challenging, given the multiplicity of factors affecting both the debt trajectory and investors' beliefs. In this paper, we address this question using a controlled laboratory experiment. Particularly, we introduce a novel bond investment game that simulates a primary market for sovereign bonds. In the game, the government sells one-period bonds to a group of investors through a discriminatory price auction. As such, the government faces the risk of defaulting due to investors' failure to coordinate to purchase bonds (rollover crisis). At the same time, the government can also face an insolvency crisis when its debt levels become so high that they cannot be funded with the available income of investors. A key feature of the game is that a feedback loop exists between the selling price of sovereign bonds in primary markets and the subsequent probability of sovereign default. If players bid too low prices for the bonds (demand too high yields), debt accumulates fast, and the government reaches the debt threshold before the game ends. Our experiment thus tests players' understanding of this crucial mechanism between bond prices (yields) and the risk of subsequent default.

We parametrize the game such that a stable debt path is always possible if investors coordinate on demanding low interest rates. However, in the experiment, most groups diverged from this path and set public debt on a rising trajectory. This can be seen as an initial coordination failure: because

at the beginning of the game, some investors demand high interest rates (despite the disciplining effect of the discriminatory price auction), government debt deviates from the stable long-term path. This “original sin”²⁴ triggers default at later stages of the game.

We design two treatments that will allow us to disentangle the role of the two types of government default to the overall risk premium. While in a baseline treatment, both roll-over crises and fundamental default can occur, in a second treatment we allow a central bank to intervene as a bondholder-of-last-resort, which eliminates strategic risk. As such, in the experiment, the interest rate spread between the baseline and the treatment with a central bank, is an approximation of “illiquidity” risk. We find that the average interest rate is indeed higher in the baseline treatment and that participants learn to price this risk premium in their bids.

Our experimental results confirm the possibility that countries with relatively high debt can face belief-driven crises without large changes in fundamentals, which has been an important policy concern since the 2010-12 Euro area crisis. An initial deviation from a stable debt path leads to rising risk premia and a snowball effect that ultimately triggers an insolvency crisis. In this setting, central bank interventions can only postpone the critical outcome of default, without preventing it. Higher interest rates, as debt levels rise, represent a negative externality for the economy as a whole, as they may crowd out private investment and weaken the balance sheets of institutional bondholders (banks, insurance companies, pension funds, and even the central bank). Taken together, these risks call for the implementation of rigorous public debt management rules and a limited reliance on the central bank’s debt monetization power.

Our experiment captures in a stylized manner many key features of the primary markets for sovereign bonds. As with any lab experiment, it imposes some restrictions to avoid excessive complexity in subjects’ decision-making. Some of these restrictions determine the boundaries of our conclusions. Naturally, the predetermined action rule for the government and the central bank assumed in the experiment might not hold in times of crisis. As the Euro-area 2010-12 sovereign bond crisis has shown, governments embraced fiscal austerity to signal their commitment to rigorous management of their long-run fiscal policy. On the other hand, the fact that the European Central Bank changed its policy from no bail-out to conditional bail-out might have created the seeds for

²⁴A term inspired by the exchange rate literature (Eichengreen et al., 2005).

moral hazard. These kinds of strategic interactions might be addressed in further experimental research.

Despite these limitations, our paper can be seen as a first attempt to study sovereign bond market crises in an experimental lab setting and provides a direct measure for the rollover risk that can be of interest to investors and policymakers. We provide new evidence on how sovereign debt crises can unfold and contribute to understanding some key empirical puzzles observed during these episodes, such as the high volatility of yields which is not always aligned with country fundamentals.

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A Appendix

A.1 Instructions

The instructions of the experiment are available at:

[Instructions \(French Version\)](#)

[Instructions \(English Version\)](#)

A.2 Additional results

Table 6: Personal characteristics of the subjects, by treatment

	Baseline	CB treatment	p-value	z
Age	20.13 (1.991)	20.24 (2.090)	0.786	-0.271
Tolerance to risk (out of 10)	6.13 (2.350)	6.18 (2.091)	0.823	-0.224
Financial literacy (out of 10)	3.73 (2.663)	3.73 (2.745)	0.954	0.057
Practical experience (out of 10)	3.33 (2.749)	3.51 (2.728)	0.769	-0.293
Female (%)	55	45	0.343	0.949
Field of study (%) (Eco, Fin, MBA, Sci, Other)	(27, 9, 5, 29, 29)	(22, 4, 2, 47, 25)	0.539	-0.614
Observations	55	55		

The table presents the p-values and the z-statistics of two-sided Mann-Whitney-U tests. Risk tolerance, financial literacy, and practical expertise with investment are self-reported measures, using 0-10 scales. The field of study includes categories: Economics, Finance, Management and Business Administration, Science, or Other.

Table 7: Interest rates and proximity to default - individual data (full specification)

Dependent variable: Interest rate earned	(1)	(2)	(3)	(4)
CB treatment	-1.706** (0.664)	-0.650 (0.875)	-1.769*** (0.686)	-8.667*** (1.935)
Proximity to first default	0.274*** (0.074)	0.078 (0.102)		
Proximity to first default \times CB Treatment		0.364** (0.146)		
Government debt (before 1st default)			0.001** (0.000)	-0.000 (0.000)
Government debt \times CB treatment				0.002*** (0.001)
Round	-0.932* (0.525)	-0.935* (0.527)	-0.979* (0.544)	-1.009* (0.534)
Risk tolerance	0.098 (0.118)	0.098 (0.118)	0.103 (0.121)	0.098 (0.118)
Practical experience	0.022 (0.128)	0.022 (0.128)	0.009 (0.133)	0.014 (0.130)
Financial literacy	-0.040 (0.145)	-0.042 (0.145)	-0.037 (0.149)	-0.043 (0.146)
Age	0.415* (0.251)	0.415* (0.250)	0.439* (0.262)	0.426* (0.252)
Gender (Female)	-0.115 (0.597)	-0.117 (0.600)	-0.177 (0.606)	-0.201 (0.598)
Economics Major	0.347 (0.784)	0.362 (0.790)	0.419 (0.815)	0.423 (0.796)
Finance Major	-1.674** (0.787)	-1.718** (0.795)	-1.655** (0.811)	-1.716** (0.784)
Management Major	-0.001 (3.758)	-0.048 (3.728)	0.219 (3.966)	0.111 (3.784)
Science Major	0.402 (0.650)	0.401 (0.653)	0.378 (0.667)	0.328 (0.659)
Observations	1034	1034	1034	1034
R-squared	0.076	0.075	0.051	0.072

The table presents panel regressions with random effects, with standard errors clustered at the individual level. The dependent variable is the realized interest rate at the individual level in the five periods before the first government default. CB treatment is an indicator variable equal to one for the Central Bank treatment and zero for the Baseline treatment. Proximity to first default is a scalar between [-5, -1] for the five periods before the first default in a group in period $t = 0$. Government debt refers to the total amount of debt held by the government by period. Round is a dummy variable equal to 1 for round 3 and 0 for round 2. Control variables include gender, age, risk tolerance, financial literacy, and practical expertise with investment. The field of study is categorized into Economics, Finance, Management and Business Administration, Science, or other majors (the latter being the reference category). Constant term included but not reported. Standard errors clustered at the individual level in parenthesis. *, **, *** show significance at 10%, 5% and 1% levels.

Table 8: Bid rates and proximity to default - individual data (full specification)

Dependent variable: Bid rate	(1)	(2)	(3)	(4)
CB Treatment	-1.808** (0.766)	-0.471 (0.965)	-1.730** (0.750)	-10.107*** (2.667)
Proximity to first default	-0.199* (0.105)	-0.443*** (0.146)		
Proximity to first default \times CB treatment		0.455** (0.207)		
Government debt (before 1st default)			-0.001*** (0.000)	-0.002*** (0.000)
Government debt \times CB treatment				0.002*** (0.001)
Round	-1.553** (0.689)	-1.556** (0.693)	-1.505** (0.680)	-1.544** (0.675)
Risk tolerance	0.255 (0.161)	0.255 (0.162)	0.253 (0.160)	0.248 (0.158)
Practical experience	-0.006 (0.163)	-0.008 (0.164)	0.003 (0.161)	0.003 (0.160)
Financial literacy	-0.057 (0.170)	-0.057 (0.171)	-0.056 (0.167)	-0.060 (0.165)
Age	0.769*** (0.258)	0.772*** (0.259)	0.761*** (0.256)	0.759*** (0.254)
Gender (Female)	0.300 (0.734)	0.293 (0.737)	0.384 (0.721)	0.356 (0.714)
Economics Major	1.000 (0.989)	1.012 (0.996)	0.941 (0.966)	0.949 (0.947)
Finance Major	-1.944 (1.256)	-1.996 (1.262)	-2.024 (1.232)	-2.091* (1.215)
Management Major	1.120 (3.861)	1.114 (3.861)	1.160 (3.838)	1.285 (3.830)
Science Major	-0.235 (0.788)	-0.235 (0.792)	-0.221 (0.774)	-0.291 (0.766)
Observations	1058	1058	1058	1058
R-squared	0.094	0.093	0.111	0.128

The table presents panel regressions with random effects, with standard errors clustered at the individual level. The dependent variable is the bid rate (required interest rate) at the individual level in the five periods before the first government default. CB treatment is an indicator variable equal to one for the Central Bank treatment and zero for the Baseline treatment. Proximity to first default is a scalar between [-5, -1] for the five periods before the first default in a group in period $t = 0$. Government debt refers to the total amount of debt held by the government by period. Round is a dummy variable equal to 1 for round 3 and 0 for round 2. Risk tolerance, financial literacy, and practical expertise with investment are self-reported measures, using 0-10 scales. The field of study includes categories: Economics, Finance, Management and Business Administration, Science, or Other (the latter is the reference). Constant term included but not reported. Standard errors clustered at the individual level in parenthesis. *, **, *** show significance at 10%, 5% and 1% levels.

Table 9: Individual probability to bid (full specification, 5 periods before 1st default)

	(1)	(2)	(3)	(4)
Dependent variable: $\mathbb{1}\{Bid > 0\}$				
CB treatment	0.003 (0.008)	-0.005 (0.017)	0.004 (0.008)	0.452** (0.206)
Proximity to first default	-0.005 (0.003)	-0.004 (0.004)		
Proximity to first default \times CB treatment		-0.004 (0.006)		
Government debt (before 1st default)			-0.000* (0.000)	-0.000 (0.000)
Government debt \times CB treatment				-0.000* (0.000)
Round	-0.006 (0.007)	-0.006 (0.007)	-0.005 (0.008)	-0.006 (0.008)
Risk tolerance	-0.010** (0.004)	-0.010** (0.004)	-0.010** (0.004)	-0.011** (0.004)
Practical experience	-0.004* (0.002)	-0.004* (0.002)	-0.004* (0.002)	-0.004* (0.002)
Financial literacy	0.004* (0.002)	0.004* (0.002)	0.004* (0.002)	0.004** (0.002)
Age	-0.004 (0.002)	-0.004 (0.003)	-0.003 (0.002)	-0.003 (0.002)
Gender (Female)	0.007 (0.007)	0.007 (0.007)	0.007 (0.007)	0.008 (0.007)
Economics Major	-0.025* (0.015)	-0.025* (0.015)	-0.024* (0.014)	-0.025* (0.015)
Finance Major	-0.047** (0.023)	-0.047** (0.023)	-0.047** (0.023)	-0.051** (0.023)
Science Major	-0.016 (0.016)	-0.016 (0.016)	-0.014 (0.016)	-0.014 (0.016)
Observations	1070	1070	1070	1070

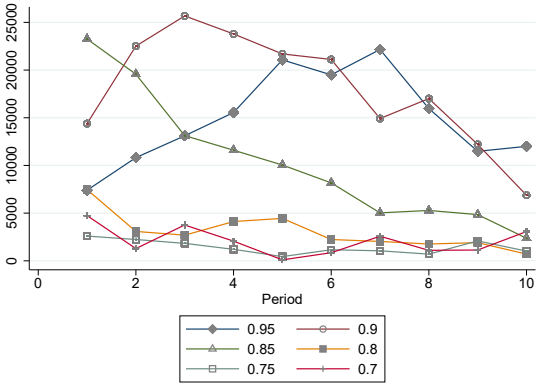
The dependent variable is a binary indicator set to 1 if the individual has made bids in the five periods preceding the first government default. CB treatment is an indicator variable equal to one for the Central Bank treatment and zero for the Baseline treatment. Proximity to first default is a scalar between [-5, -1] for the five periods before the first default in a group in period $t = 0$. Government debt refers to the total amount of debt held by the government by period. Round is a dummy variable equal to 1 for round 3 and 0 for round 2. Risk tolerance, financial literacy, and practical expertise with investment are self-reported measures, using 0-10 scales. The field of study includes categories: Economics, Finance, Science, Management and Business Administration, or Other (with the latter two serving as the reference categories to avoid omitted variable bias in the regression). Standard errors clustered at the individual level in parenthesis. *, **, *** show significance at 10%, 5% and 1% levels.

Table 10: Individual probability to bid (full specification)

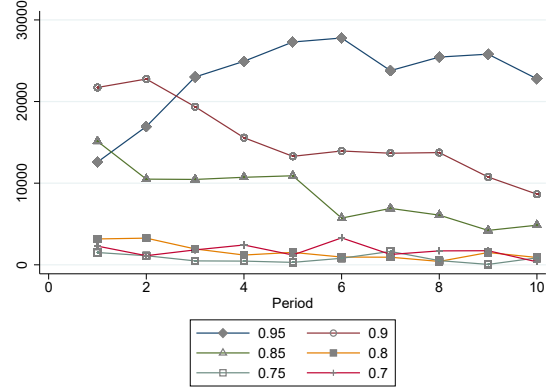
	(1)	(2)	(3)
Dependent variable: $\mathbb{1}\{Bid > 0\}$			
CB treatment	-0.001 (0.015)	0.004 (0.019)	0.076 (0.091)
Period of default	-0.086*** (0.014)		
Period of default \times CB treatment	0.014 (0.019)		
One period to default		-0.081*** (0.016)	
One period to default \times CB treatment		0.018 (0.020)	
Debt-to-income ratio			-0.362*** (0.063)
Debt-to-income ratio \times CB treatment			-0.073 (0.106)
Period	-0.005*** (0.002)	-0.006*** (0.002)	-0.002 (0.002)
Round	-0.016 (0.010)	-0.010 (0.010)	-0.014 (0.011)
Risk tolerance	-0.006** (0.003)	-0.007** (0.003)	-0.007** (0.003)
Practical experience	-0.001 (0.003)	-0.000 (0.003)	0.000 (0.003)
Finance literacy	-0.003 (0.003)	-0.004 (0.003)	-0.004 (0.003)
Age	-0.005** (0.002)	-0.005** (0.002)	-0.005* (0.002)
Gender (Female)	0.001 (0.011)	-0.001 (0.011)	0.003 (0.011)
Economics Major	-0.016 (0.014)	-0.016 (0.014)	-0.014 (0.015)
Finance Major	-0.015 (0.025)	-0.011 (0.024)	-0.022 (0.026)
Management Major	-0.002 (0.038)	0.012 (0.037)	-0.003 (0.040)
Science Major	-0.004 (0.012)	-0.005 (0.012)	0.001 (0.013)
Observations	2200	2200	2200

The table presents the marginal effects from a conditional logit model. The dependent variable is an indicator equal to one if the participant made a bid, and zero otherwise. CB treatment is an indicator variable equal to one for the Central Bank treatment and zero for the Baseline treatment. The variables Period of default and One period to default are dummy variables representing, respectively, the occurrence of a default and one period prior to default. The debt-to-income ratio refers to the proportion of government debt relative to all investors' income. Round is a dummy variable equal to 1 for round 3 and 0 for round 2. Control variables include gender, age, risk tolerance, financial literacy, and practical expertise with investment. The field of study is categorized into Economics, Finance, Management and Business Administration, Science, or other majors (the latter is the baseline category). Standard errors clustered at the individual level in parenthesis. *, **, *** show significance at 10%, 5% and 1% levels.

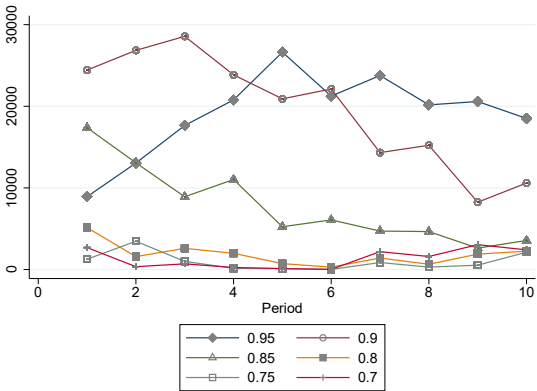
Figure 10: Total bids at different prices



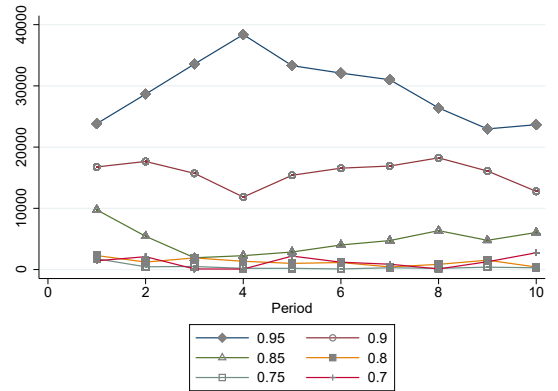
(a) Baseline treatment (Round 2)



(b) CB Treatment (Round 2)



(c) Baseline Treatment (Round 3)



(d) CB Treatment (Round 3)

The figures show the sum of the bids by all players at each listed price, by period.

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3 avenue Bernard-Hirsch
CS 50105 Cergy
95021 Cergy-Pontoise Cedex
France
Tél. +33 (0)1 34 43 30 00
www.essec.edu

ESSEC Executive Education

CNIT BP 230
92053 Paris-La Défense
France
Tél. +33 (0)1 46 92 49 00
www.executive-education.essec.edu

ESSEC Asia-Pacific

5 Nepal Park
Singapore 139408
Tél. +65 6884 9780
www.essec.edu/asia

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ESSEC Afrique

Plage des Nations - Golf City
Route de Kénitra - Sidi Bouknadel (Rabat-Salé)
Morocco
Tél. +212 (0)5 37 82 40 00
www.essec.edu

CONTACT

Research Center
research@essec.edu