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## PIER Working Paper 22-017

# Information Spillovers and Sovereign Debt: Theory Meets the Eurozone Crisis

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June 28, 2022

# Information Spillovers and Sovereign Debt: Theory Meets the Eurozone Crisis\*

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## Abstract

We develop a theory of information spillovers in sovereign bond markets in which investors can acquire information about default risk before trading in primary and secondary markets. If primary markets are structured as multi-unit discriminatory-price auctions, an endogenous winner's curse leads to strategic complementarities in information acquisition. As a result, shocks to default risk in one country may trigger crisis episodes with widespread information acquisition, sharp increases in the level and volatility of yields in risky countries, falling yields in safe countries, endogenous market segmentation, and arbitrage profits between primary and secondary markets. These predictions are consistent with the behavior of primary and secondary market yields, market segmentation, and measures of information acquisition during the Eurozone sovereign debt crisis.

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\*We thank German Sanchez for outstanding research assistance. We also thank Kurt Mitman (the editor), three anonymous referees and seminar participants at Michigan State, the Philadelphia Fed, USC Marshall, the St. Louis Fed for their insightful suggestions. This paper builds on a previous paper by the same authors titled "Debt Crises: For Whom the Bell Tolls." For comments on the earlier paper, we thank Vladimir Asriyan, Marco Bassetto, Anmol Bhandari, Massimo Giuliadori, Sebnem Kalemli-Ozcan, Patrick Kehoe, Monika Piazzesi, Christoph Trebesch, Alex Vardoulakis, Laura Veldkamp, Venky Venkateswaran and seminar participants at Arizona State, Banco Central de Chile, Cambridge, Carlson School at Minnesota, Cornell, Harvard, Johns Hopkins, McGill, NYU, Penn State, Richmond Fed, Stanford, UCL, Wharton, Yale, the NBER Conference on "Macroeconomics Within and Across Borders", the Barcelona GSE Summer Forum, the Conference for Junior Macroeconomists at the EIEF in Rome, the QED Frontier of Macroeconomics Conference, and the UVA Symposium on Financial Economics for very useful comments and insights. Cole and Ordoñez received support from the NSF through grant 1851707.

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# 1 Introduction

Governments typically finance large parts of their budgets by selling bonds in sequences of auctions. The most commonly-used protocol in these auctions is the discriminatory-price protocol in which accepted bids are executed at the bid price.<sup>1</sup> This leads to information rents for investors who know more about the fundamental value of bonds than others.<sup>2</sup> Information is particularly valuable during periods of heightened uncertainty in which default risk can vary substantially from auction to auction (such as when there are concerns about a country's solvency or policy stance). In such circumstances, investors may be more inclined to either acquire information (*get informed about the country*) or to withdraw from auctions in which others have an information advantage and move funds to other countries (*get out of the country*).

To understand the effects of information and rebalancing on equilibrium bond yields and portfolio fragmentation, we analyze portfolio choice and information acquisition in discriminatory-price auctions using a multi-country model with stochastic default risk and the option to trade in secondary markets. We show that the discriminatory-price protocol leads to a novel information-based channel of cross-country spillovers that originates in primary markets (and thus directly affects government revenues) and is reinforced by secondary market trading.

We use our theory to shed some light on a number of striking empirical patterns from the recent Eurozone sovereign debt crises. Chief among these is that yields for countries with very different public finances were quite similar prior to the crisis but diverged sharply thereafter. For example, Portugal and Italy paid a negligible premium over German bond yields prior to the crisis, but Portuguese and Italian yields spiked sharply and become quite volatile during the crisis while German yields fell and remained stable. These yield changes were accompanied by sharp changes in market integration: before the crisis, many investors held bonds in multiple countries, but during and after the crisis markets quickly fragmented, with Italian and Portuguese bonds predominantly held by domestic investors while German bonds

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<sup>1</sup>Brenner, Galai, and Sade (2009) collected data of sovereign bond primary markets in 48 countries. They show that 42 of these countries used auctions, with 24 using discriminatory-price auctions, 9 using uniform-price auctions and 9 using both (for different securities). This is consistent with earlier results by Bartolini and Cottarelli (2001).

<sup>2</sup>Milton Friedman famously argued that the U.S. should switch from largely relying on discriminating-price auctions to uniform-price auctions for this reason (Hearings before the Joint Economic Committee, 86th Congress, 1st Session, Washington, D.C., October 30, 1959, 3023-3026).

were increasingly held by non-resident investors. We also provide evidence that the information environment in sovereign bond markets changed during this period. We measure the information content of auctions by asking whether realized auction prices reveal information that is persistently priced in secondary markets. We find that auction prices contained information in periphery countries during the Eurozone crisis, but not before the crisis, and not in core countries. These patterns are difficult to jointly reconcile with existing models, but our theory is consistent with all of them.

Our model features two countries and a continuum of risk averse investors. In each country, a government faces an exogenous revenue requirement, which can be fulfilled by auctioning government bonds in a discriminatory-price auction that takes place in advance of a competitive secondary market. Auctions are multi-unit and sealed bid; hence investors must choose how many bids to submit before observing others' demand. Governments may default according to an exogenous stochastic process. Investors do not know the true default risk in either country, but they can learn it at a cost in one or both countries. Such is valuable at auction because informed investors can better target bids to fundamental bond values.

Since bonds are risky and bidders are risk averse, bonds offer a risk premium that naturally increases in the concentration of bond holdings. When all investors are uninformed, optimal bidding strategies lead to symmetric well-diversified portfolios and relatively low risk premia. In the presence of informed investors, however, portfolios are asymmetric. This is because investors face a trade-off between capturing infra-marginal risk premia and overpaying in bad states of the world (the winner's curse). Hence they bid less in auctions with many informed bidders, and their unwillingness to participate is reflected in lower prices. In equilibrium, informed investors hold disproportionately large positions in countries in which they are informed, and uninformed investors either shift to risk-free assets or to countries in which they are not at an informational disadvantage. In short, information asymmetries at auction work against the usual tendency to diversify portfolios across countries, and may induce segmentation based on investors' information.

Depending on the information environment, the cross-country spillovers induced by such portfolio re-allocations can be symmetric (yields co-move in both countries) or asymmetric (yields in one country decline in response to a yield increase in the other). With respect to symmetric spillovers, we confirm the well-known result that

higher default risk in one country leads to lower prices in all countries if preferences satisfy decreasing risk aversion and there is no asymmetric information. While this channel can help to rationalize yield correlations between e.g. Portugal and Italy during the Eurozone crisis, it cannot speak to the observed portfolio reallocation across investors, the increasing informativeness of primary market prices, or the *decrease* in yields in Germany and other core countries. With asymmetric information, we obtain co-movement in yields and endogenous market segmentation when both countries are risky (such as the periphery), but asymmetric spillovers when one country is relatively risky and informed while the other is a “safe haven with common ignorance” with low default risk and no informed investors (such as Germany). This allows us to speak to the divergent paths of periphery and core during the crisis.

To account for the observed changes in the information environment, as well as the sudden and sharp changes in periphery yields, within our model, we consider endogenous information acquisition. Since bidders are risk averse, the ability to accurately forecast marginal prices is more valuable if prices are more volatile, if they hold portfolios that are concentrated in a particular country, or if states of the world with high marginal utility are more likely. This means that the value of information is increasing in debt levels, portfolio concentration, and the level and variance of default risk, so that shocks to these variables can trigger information acquisition.

More generally, we show that the discriminatory-price auction protocol creates strategic interactions in information acquisition that allow for the co-existence of multiple information regimes. Informed investors bid more aggressively when default risk is high, and less aggressively when default risk is low. Hence an increase in the share of informed investors increases the spread between the high and low marginal price. This has two effects. One is the standard strategic substitutability in acquiring information in centralized markets (see e.g. [Grossman and Stiglitz \(1976\)](#)), which implies that an increase in the number of informed investors reduces information rents by making undervalued bonds more expensive. The second is a novel strategic complementarity. Because a higher price spread raises the winner’s curse, it is more valuable to become informed when others are as well. We find that the substitutability dominates when the share of informed investors is large, while the complementarity dominates when this share is small. This implies that information tends to be *asymmetric* in the sense that only a fraction of investors choose to acquire it.

The different information regimes driven by these strategic interaction have the

following features. In the *informed regime* in which a strictly positive share of investors acquire information, prices are volatile because they respond to underlying shocks, and they are low on average because the winner's curse deters bids by uninformed investors. In the *uninformed regime*, prices are stable because they are not sensitive to the underlying state, and they are higher than the average price in the informed regime because the lack of winner's curse encourages participation. Hence changes in the information regime generate discontinuous changes in pricing functions and portfolios. Given that the value of information depends on fundamentals such as default risk, regime changes and the associated yield shocks may be precipitated by relatively small fundamental shocks, such as an increase in the worst case risk of default, as in the sudden and large spikes during the Eurozone crisis.

The presence of a common pool of investors in turn creates the scope for cross-country *spillovers in information regimes* driven by market fragmentation in response to asymmetric information. When some investors acquire information in one country, the remaining uninformed investors reallocate funds to the other country. But when portfolios become concentrated in that "target country", investors have stronger incentives to acquire information about it. Accordingly, we show that a single fundamental shock in one country can lead to a switch in the information regime in both countries. We use this feature of the model to rationalize the patterns and timing of changes in yields and measures of information in Portugal and Italy during the Eurozone crisis. We also show that information spillovers do not occur if the "target country" is too safe; this allows us to rationalize the declining yields and lack of information production in Germany in response to information acquisition and spiking yields in Portugal and Italy.

Perhaps surprisingly, the information effects we document are strengthened by the presence of secondary markets. The key impediment to exploiting an information advantage at auction is that buying many bonds exposes an investor to excessive default risk. Since auction prices are made public at the end of the auction, secondary markets take place under symmetric information. Hence informed investors can sell high-quality bonds at high prices, allowing them to capture information rents at auction while remaining well-diversified *ex post*. For this interaction, it is critical that bidders are risk averse and that the auction is multi unit: if bidders were risk neutral, they would maximally exploit their information advantage irrespective of secondary market trading opportunities. This suggests a simple test of our theory: if some in-

vestors are better informed about bond prices than others, then auction prices should reveal information that is priced in secondary markets. In line with the idea that information acquisition occurred only once Portugal and Italy were sufficiently risky, we find that auction prices indeed reveal priced information in these countries *during the crisis*, but not before.

Our application to the Eurozone considers a sequence of auctions over time, and it relies on the natural assumption that there are distinct investor groups (i.e. Portuguese, Italian, German, and global) whose information costs are relatively low in their home countries but high abroad. In addition to matching the aforementioned facts, we are able to rationalize the intriguing observation that market segmentation persisted even after the crisis abated. This is because a switch to an informed regime persists as long as there is a *risk* of a bad shock in the future.

**Related Literature.** While our main application is the Eurozone crisis, our model can speak to general patterns of spillovers in sovereign bond markets. Previous work in the sovereign debt literature has explored such spillovers, but not from the perspective of endogenous heterogeneous information coupled with the interplay between primary and secondary markets. The most common view relies on real linkages, such as trade in goods or correlated shocks, that may transmit negative shocks from one country to the next. However, it is often difficult to empirically identify linkages that are powerful enough to induce the observed degree of spillovers. This led to a new set of explanations that rely on self-fulfilling debt crises either through feedback effects as in [Calvo \(1988\)](#) and [Lorenzoni and Werning \(2013\)](#) or rollover problems, as in [Cole and Kehoe \(2000\)](#), [Aguiar et al. \(2015\)](#), and [Bocola and Dovis \(2015\)](#). We explore a different form of spillovers which do not stem from country fundamentals (the supply side) but rather from the portfolio choices of a common pool of investors (the demand side).

Previous work has explored demand side spillovers based on changes in risk aversion ([Lizarazo \(2013\)](#) and [Arellano, Bai, and Lizarazo \(2017\)](#)), wealth ([Kyle and Xiong \(2001\)](#) or [Goldstein and Pauzner \(2004\)](#)), borrowing constraints ([Yuan \(2005\)](#)), short-selling constraints ([Calvo and Mendoza \(1999\)](#)), or exogenous private information in Walrasian markets ([Kodres and Pritsker \(2002\)](#)). [Broner, Gelos, and Reinhart \(2004\)](#) provide empirical evidence of the importance of portfolio effects for spillovers. This work is based on a common pool of investors in secondary markets. Our innovation is introducing a rich dual market structure that is explicit about the auction pro-

protocol used in primary markets and its implications for information acquisition and information-based contagion. Closer to our insight, [Van Nieuwerburgh and Veldkamp \(2009\)](#) use a model of information acquisition to study home bias and segmentation in financial markets. They consider competitive secondary markets and find that information acquisition is a strategic substitute. In our model, the auction protocol generates a strategic complementarity that leads to equilibrium multiplicity and contagion of information regimes.

Other work has studied the interaction of primary and secondary markets, but found that secondary markets increase primary market prices, either through incentives to signal private information ([Bukchandani and Huang \(1989\)](#)), or by providing commitment against default on foreign creditors ([Broner, Martin, and Ventura \(2010\)](#)). We find that secondary markets may contribute to lower prices at auction through endogenous information acquisition; we further provide evidence of this effect by measuring the primary-secondary market spread in the Eurozone crisis.

Our work provides theoretical underpinnings for the “wake-up call” literature. This idea was first suggested by [Goldstein \(1998\)](#) to explain contagion from Thailand (a relatively small and closed economy) to other Asian countries that shared the same economic weaknesses but were ignored by investors until the Thai “wake-up call” in 1997. This form of contagion, consistent with rational inattention, has found empirical support in [Giordano, Pericolli, and Tommasino \(2013\)](#), [Bahaj \(2020\)](#) and [Moretti \(2021\)](#) for the Eurozone crisis and in [Mondria and Quintana-Domeque \(2013\)](#) for the Asian crisis. These papers use a narrative approach based on news events to isolate changes in sovereign risk that are orthogonal to the economy’s fundamentals, and do not find evidence of fundamental linkages that can explain the co-movement of sovereign yields across periphery countries. [Ahnert and Bertsch \(2020\)](#) provide a global-games rational of the wake-up call hypothesis for currency crises or bank runs, in which investors move sequentially in secondary markets and become informed about the countries’ fundamental linkages. There is no portfolio choice or prices in their model, so their main focus is on contagion of default itself. Our focus is on price spillovers in primary markets.

With respect to information and market mechanisms, we share with [Milgrom \(1981\)](#) the strategy of exploiting the structure of an auction to provide an account of price formation and endogenous information acquisition even when prices are fully revealing ex post. He considers, however, a single auction in which bidders are re-



stricted in the units they can buy. We instead study flexible multi-unit bidding strategies and cross-auction linkages when there are many investors.

In relation to the auction literature, our model can be used to study information acquisition because we circumvent some of the standard challenges that arise when solving for equilibrium prices in multi-unit auction models.<sup>3</sup> This is because of three key characteristics: (i) the good being auctioned is perfectly divisible, (ii) the number of risk averse bidders is large, and (iii) there is uncertainty about the quality of the good. Given these three characteristics, the price-quantity strategic aspects of standard auction theory become less relevant, and a price-taking, or Walrasian, analysis emerges as a good approximation.<sup>4</sup>

In this context, studying risk-averse investors is important for the interpretation of the shading factor in bids (as argued by [Wilson \(1979\)](#)) and it is critical for thinking about the reaction of bond prices to shocks during periods with high volatility. Previous literature on auctions with risk averse bidders primarily focuses on risk aversion with respect to winning the auction rather than *ex post* risk in the objects for sale. An important exception is [Esö and White \(2004\)](#) who consider an auction with a single risky good with independent ex-ante signals and ex-post risk to bidders' valuations. They find that risk aversion reduces bids and that prices fall by more than the "fair" risk premium. Our work consider a multi-unit auction with ex-post risky objects where there is (correlated) asymmetric information about default risk and marginal valuations depend on quantities purchased.

More recent work tackles these challenges from an empirical perspective. [Hortaçsu and McAdams \(2010\)](#) develop a model based on [Wilson \(1979\)](#)'s model of a multi-unit discriminatory price auction with a finite set of potential risk-neutral bidders with symmetric and independent private values. Instead of computing the market clearing price analytically, they use a re-sampling technique to construct a non-parametric estimator of bidder valuations and apply it to data from Turkish treasury auctions.<sup>5</sup>

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<sup>3</sup>The main challenge is characterizing equilibria when bidders have a two-dimensional strategic problem involving both bid quantities and bid prices. See [Wilson \(1979\)](#), [Engelbrecht-Wiggans and Kahn \(1998\)](#), [Perry and Reny \(1999\)](#), [Kagel and Levin \(2001\)](#) and [McAdams \(2006\)](#).

<sup>4</sup>Recent auction literature shows that price-taking arises as the number of bidders get large. A recent example is [Fudenberg, Mobius, and Szeidl \(2007\)](#), who show that the equilibria of large double auctions with correlated private values are essentially fully revealing and approximate price-taking behavior when the number of risk neutral bidders goes to infinity. Another is [Reny and Perry \(2006\)](#) who show a similar result when bidders have affiliated values and prices are on a fine grid.

<sup>5</sup>[Kastl \(2011\)](#) extended [Wilson \(1979\)](#)'s model, which is based on continuous and differentiable functions, to more realistic discrete-step functions, showing that in such case only upper and lower

The model in this paper complements [Cole, Neuhann, and Ordoñez \(2022a\)](#), who study a single-country model with a fixed information environment and use rich bid-level data to provide evidence for asymmetric information about default risk in Mexican sovereign bond auctions.<sup>6</sup> In this paper, we allow for endogenous information acquisition and use a multi-country model with cross-auction linkages due to a common pool of investors. This allows for endogenous changes in information regimes in response to fundamental shocks as well as information-based spillovers. Both features are crucial for this paper’s application to the Eurozone crisis. To this end, we use primary and secondary market price data and information on bond holdings by country of origin (but not bidding data) from Portugal, Italy and Germany to assess spillovers and segmentation during the Eurozone crisis.

The next section describes our model of primary and secondary sovereign debt markets in two countries with a common pool of investors. Section 3 characterizes the equilibrium without secondary markets and describes the sources of information multiplicity in each country and the effects on informational spillovers. Section 4 studies the role of secondary markets for bond yields, information acquisition, and spillovers. Section 5 applies these results to the experiences of Portugal, Italy and Germany during the Eurozone crisis. Section 6 concludes.

## 2 Model

We study a economy with a single numeraire good, a measure one of ex-ante identical risk-averse investors with fixed per-capita wealth  $W$  and two countries, indexed by  $j \in \{1, 2\}$ . There is a single period with two dates. At the first date, country  $j$ ’s government needs to raise fixed revenue  $D_j \geq 0$  by auctioning sovereign bonds in the primary market. After the auction, investors can trade bonds in a competitive secondary market.

Bonds are zero-coupon and promise a unit payoff at date 2. Bonds are risky because they pay off only if the government does not default. In a default, the recovery rate is zero. Default is summarized by  $\delta_j \in \{0, 1\}$ , where  $\delta_j = 1$  denotes default and  $\delta_j = 0$  denotes repayment, and  $\vec{\delta} = [\delta_1, \delta_2]$ .

bounds on private valuations can be identified, which he does by exploiting the previously discussed resampling method on Czech bills auctions.

<sup>6</sup>[Cole, Neuhann, and Ordoñez \(2022b\)](#) uses additional data from Mexico to show that asymmetric information may support bond prices in particularly bad times.

Because we are interested in demand sided determinants of bond prices, we assume that default decisions follow an exogenous stochastic process. Specifically, country  $j$ 's default probability  $\kappa_j(\theta_j) = \Pr\{\delta_j = 1|\theta_j\}$  is a random variable that depends only on the realization of a country-specific fundamental  $\theta_j \in \{b, g\}$ . We let  $\kappa_j(g) < \kappa_j(b)$  and denote the probability of state  $\theta_j$  by  $f_j(\theta_j)$ . Hence the unconditional default probability is

$$\bar{\kappa}_j = f_j(b)\kappa_j(b) + f_j(g)\kappa_j(g).$$

To focus on information-based contagion rather than real linkages, we assume that  $\theta_j$  is independently distributed across countries and we define  $\vec{\theta} \equiv [\theta_1, \theta_2]$ . Fluctuations in  $\theta$  reflect variation in *private* information, while changes in  $[\kappa_j(g), \kappa_j(b)]$  or their probabilities, reflect variation in *public* information (that is, they are known to all). This distinction will be illustrated further in our discussion of the Eurozone crisis.

Investors have preferences over consumption at date 2 that are represented by a strictly concave utility function  $u$  that is twice continuously differentiable, satisfies the Inada conditions and features weakly decreasing absolute risk aversion (standard CRRA preferences have these properties). Investors can invest in government bonds or a risk-free asset whose net return is normalized to zero. There is no borrowing and no short-selling: investors cannot submit negative bids at auction, and can sell no more than the bonds acquired at auction when trading in the secondary market.

**Information acquisition.** Investors are born with the same common prior about the state of the world in each country. Before bidding for bonds in primary markets, investors can acquire information (learn the realization of  $\theta_1$  and/or  $\theta_2$ ) by paying a utility cost. We denote the decision to acquire information in country  $j$  by  $a_j \in \{0, 1\}$ . The associated cost is  $C(a_1, a_2) \geq 0$ , weakly increasing in each argument.

The information acquisition decision defines the investor's *type*, which we index by  $i \in \{(a_1, a_2) : a_1 \in \{0, 1\}, a_2 \in \{0, 1\}\}$ . Since investors are identical conditional on their information set, we study a representative investor of each type. The mass of type  $i$  (i.e. the share of investors that acquire information in the manner associated with type  $i$ ) is  $n^i \in [0, 1]$ , with  $\sum_i n^i = 1$ .

To transparently characterize portfolios and spillovers, we assume that markets are partially segmented in the sense that each investor is split into two traders at time zero. Each trader is tasked with trading and possibly acquiring information in one specific country, but traders cannot share information. This ensures that bids in country  $j$  are not contingent on the *realization* of  $\theta_{-j}$ . However, they will be contingent

on the information acquisition *strategy* in  $-j$ . This reduces the number of equilibrium prices from 16 to 8 without affecting the basic mechanisms.<sup>7</sup>

**Primary market.** Governments sell bonds using discriminatory multi-unit auctions. Investors can submit multiple bids, each of which represent a commitment to purchase a non-negative number of bonds at a particular price should the government decide to execute the bid. The government treats each bid independently, sorts all bids from the highest to the lowest bid price, and executes all bids at the bid price in descending order of prices until it generates revenue  $D_j$ . Since there is a fixed revenue target, the total number of bonds sold is an equilibrium object. The *marginal price* is the lowest accepted price for a given  $\theta_j$ , and we denote it by  $P_j(\theta_j)$ .

Since bonds pay off at least zero and at most one unit of the numeraire, the range of prices is  $[0, 1]$ . A *bidding strategy* maps any price in  $[0, 1]$  into a weakly positive bid quantity. Since investors have rational expectations with respect to the set of possible marginal prices, it is without loss of generality to restrict attention to bidding strategies that assign zero bids to any price that is not marginal in some state of the world.<sup>8</sup> Since marginal prices are indexed by the underlying state, it is without loss to directly define bidding strategies as functions of the underlying states. That is, if  $B'_j(P)$  is a bidding function mapping prices into quantities, we can define another bidding function  $B_j(\theta_j) \equiv B'(P(\theta_j))$  that maps  $\theta_j$  into quantities associated with the marginal price in  $\theta_j$ . Then, investors ultimately must decide *how much to bid at the lowest-accepted price associated with each possible realization of the bond's common value*.

Defining bidding strategies in this way does *not* imply that bids themselves can be made in a state-contingent manner. In particular, an uninformed investors must choose bids at the marginal prices associated with all possible states without knowing which state has been realized ex post. To capture this notion, it is useful to define *sets of executed states*  $\mathcal{E}_j^i(\theta_j)$  which are used to collect all bids by an investor of type  $i$  that are executed in country  $j$  when the state is  $\theta_j$ . Since each bid is associated with a state-specific marginal price, the elements of these sets are states of the world. For

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<sup>7</sup>Carlos Garriga interpreted our notion that investors split into two traders as a financial intermediary with separate divisions specialized in each country that only periodically re-balances portfolios and exchanges information.

<sup>8</sup>Excess demand at the marginal price is rationed pro-rata, but rationing does not occur in equilibrium. An investor can avoid rationing by offering an infinitesimally higher price, something the uninformed investors would strictly prefer when bidding at the higher price. Even if this were not an issue, for any equilibrium with rationing there is an equivalent equilibrium in which bidders scale down their bids by the rationing factor so long as the marginal prices are distinct, which they are here.

informed investors, the set includes only the realized state. For uninformed investors, the executed bid set includes the realized state and all states with marginal prices above the realized marginal price. That is,

$$\mathcal{E}_j^i(\theta_j) = \begin{cases} \{\theta_j\} & \text{if } i \text{ is informed in } j \\ \{\theta'_j : P_j(\theta'_j) \geq P_j(\theta_j)\} & \text{if } i \text{ is uninformed in } j. \end{cases}$$

Since the marginal price is realized only after bids have been submitted, we must distinguish between the bids made and the quantity of bonds acquired by the investor in a given state of the world. Let  $B_j^i(\theta_j)$  and  $\mathcal{B}_j^i(\theta_j)$  denote the bids and the *realized* quantity of country- $j$  bonds acquired by investor  $i$  in state  $\theta_j$ , respectively. Because only informed investors can submit state-contingent bids, we have

$$\mathcal{B}_j^i(\theta_j) = \begin{cases} B_j^i(\theta_j) & \text{if } i \text{ is informed in } j \\ \sum_{\theta'_j \in \mathcal{E}_j^i(\theta_j)} B_j^i(\theta'_j) & \text{if } i \text{ is uninformed in } j. \end{cases}$$

Thus investor  $i$ 's total expenditure on bonds in country  $j$  and state  $\theta_j$  is

$$X_j^i(\theta_j) = \begin{cases} P_j(\theta_j) B_j^i(\theta_j) & \text{if } i \text{ is informed in } j \\ \sum_{\theta'_j \in \mathcal{E}_j^i(\theta_j)} P_j(\theta'_j) B_j^i(\theta'_j) & \text{if } i \text{ is uninformed in } j. \end{cases}$$

The market-clearing condition in country  $j$  and state  $\theta_j$  is

$$\sum_i n^i X_j^i(\theta_j) = D_j. \quad (1)$$

and investment in the risk-free asset after the auction close satisfies

$$w^i(\vec{\theta}) = W - \sum_j X_j^i(\theta_j) \quad \text{for all } \vec{\theta}.$$

**Secondary market.** The secondary market opens once the primary market closes, and auction outcomes are public knowledge prior to secondary market trading. Hence the secondary market operates under symmetric information. If there are informed investors in the primary market, auction prices are fully revealing of the state ex-post; if no investor is informed, auction prices do not reveal information to anybody.

We denote with hats secondary market counterparts of primary market variables.

Quantities are  $\widehat{B}_j^i(\theta_j)$  and market-clearing prices are  $\widehat{P}_j(\theta_j)$ . Investors can sell no more than the total quantity of bonds acquired at auction,  $\widehat{B}_j^i(\theta_j) \geq -\mathcal{B}_j^i(\theta_j)$ . Secondary market expenditures are  $\widehat{X}_j^i(\theta_j) = \widehat{P}_j(\theta_j)\widehat{B}_j^i(\theta_j)$ . Secondary market clearing requires

$$\sum_i n^i \widehat{B}_j^i(\theta_j) = 0. \quad (2)$$

The final (upon primary and secondary markets closing) number of bonds held by the investor for each  $j$  and  $\theta_j$  is

$$\widehat{\mathcal{B}}_j^i(\theta_j) = \mathcal{B}_j^i(\theta_j) + \widehat{B}_j^i(\theta_j).$$

Final holdings of the risk-free asset are given by

$$\widehat{w}^i(\vec{\theta}) = w^i(\vec{\theta}) - \sum_j \widehat{X}_j^i(\theta_j) \quad \text{for all } \vec{\theta}.$$

**Decision problems.** Investors face two sequential decision problems. The first is the choice of an information acquisition strategy  $\{a_1, a_2\}$ . The second is a portfolio choice problem whereby each type chooses a bidding strategy  $\mathcal{S}^i$  to maximize expected utility derived from second-period consumption. The bidding strategy is a tuple of primary and secondary market bids for each  $j$  and  $\theta_j$ ,

$$\mathcal{S}^i \equiv \left\{ \left\{ \mathcal{B}_j^i(\theta_j), \widehat{B}_j^i(\theta_j) \right\}_{\theta_j \in \{g, b\}} \right\}_{j \in \{1, 2\}}$$

The resulting consumption profile given some realization of the states of the world and default decisions in each country is

$$c^i(\vec{\theta}, \vec{\delta}, \mathcal{S}^i) = \widehat{w}^i(\vec{\theta}) + (1 - \delta_1)\widehat{\mathcal{B}}_1^i(\theta_1) + (1 - \delta_2)\widehat{\mathcal{B}}_2^i(\theta_2) \quad \text{for all } \vec{\theta} \text{ and } \vec{\delta}.$$

Let  $\mathbb{E}^i$  denote the type-specific expectation operator that takes into account the information acquired by the investor. Then the portfolio choice problem is

**Definition 1** (Portfolio choice problem). *Type  $i$ 's portfolio choice problem is*

$$\begin{aligned} V^i &= \max_{\mathcal{S}^i} \mathbb{E}^i \left[ u(c^i(\vec{\theta}, \vec{\delta}, \mathcal{S}^i)) \right] \\ \text{s.t. } & B_j^i(\theta_j) \geq 0 \text{ and } \widehat{B}_j^i(\theta_j) \geq -\mathcal{B}_j^i(\theta_j) \quad \text{for all } j \text{ and } \theta_j \\ & w^i(\vec{\theta}) \geq 0 \text{ and } \widehat{w}^i(\vec{\theta}) \geq 0 \quad \text{for all } \vec{\theta}. \end{aligned}$$

The first pair of constraints ensures non-negative bids at auction and no short-selling in the secondary market. The second pair of constraints ensures that investors do not borrow at any date. Given a solution to the portfolio choice problem for every investor type, we can define the information acquisition problem.

**Definition 2** (Information acquisition problem). *Let  $\iota(a_1, a_2)$  denote the type induced by  $\{a_1, a_2\}$ . Then the information acquisition problem is*

$$\max_{\{a_1, a_2\}} V^{\iota(a_1, a_2)} - C(a_1, a_2).$$

**Equilibrium definition.** An equilibrium combines market clearing at auction and in the secondary market with solutions to investors' decision problems.

**Definition 3** (Equilibrium). *An equilibrium consists of pricing functions  $P_j : \{b, g\} \rightarrow [0, 1]$  and  $\widehat{P}_j : \{b, g\} \rightarrow [0, 1]$  for each  $j$ , an information acquisition strategy  $\{a_1, a_2\}$  for each investor, and bidding strategies  $\mathcal{S}^{\iota(a_1, a_2)}$  for all  $\{a_i, a_2\}$  on the path of play such that: (i)  $\mathcal{S}^{\iota(a_i, a_2)}$  solves type  $\iota(a_1, a_2)$ 's portfolio choice problem, (ii)  $\{a_1, a_2\}$  solves the information acquisition problem for each investor, and (iii) market-clearing conditions (1) and (2) hold.*

Throughout the paper we use a numerical example to illustrate the key economic mechanisms. Unless stated otherwise, we will use the following parameters.

**Definition 4** (Baseline Parameters for Numerical Examples). *Utility is  $U(\cdot) = \log(\cdot)$ . Countries are ex-ante symmetric. Wealth is  $W = 800$  and outstanding debt is  $D_j = 300$ . Default probabilities satisfy  $\kappa_j(g) = 0.1$ ,  $\kappa_j(b) = 0.35$ , and  $f_j(g) = 0.6$ . Hence  $\bar{\kappa}_j = 0.2$ .*

In the following, we first characterize equilibrium without secondary markets. This allows us to precisely characterize optimal bids at auction, and provides a benchmark to evaluate the effects of secondary market trading. The equilibrium definition is Definition 3, augmented with the requirement that all secondary market quantities are zero. We turn to the effects of secondary markets in Section 4.

### 3 Auction Equilibrium

We begin by discussing optimal bidding strategies when there are no secondary markets. The decision problem in our model of large auctions in two countries is reminiscent of classical portfolio choice problems and generates similar risk-return trade-offs. However, optimal portfolios are modified to account for the winner's curse, and this can lead to more concentrated bond holdings and larger required risk premia.

Given the discriminatory protocol, formulating a bidding strategy requires forming expectations about the states of the world in which a given bid will be accepted. Hence we define *acceptance sets*  $\mathcal{A}_j^i(\theta_j)$  that collect all states in which a bid in country  $j$  at some marginal price  $P_j(\theta_j)$  is accepted. For uninformed investors, the pay-your-bid protocol implies that a particular bid is accepted in all states with lower marginal prices; for informed investors a bid is accepted only in the state associated with the marginal price.<sup>9</sup> That is,

$$\mathcal{A}_j^i(\theta_j) = \begin{cases} \{\theta_j\} & \text{if } i \text{ is informed in } j \\ \{\theta'_j : P_j(\theta'_j) \leq P_j(\theta_j)\} & \text{if } i \text{ is uninformed in } j. \end{cases}$$

This set is a singleton for informed investors, but it may include multiple states when the investor is uninformed. This difference captures the winner's curse that bids at high prices (which are associated with low default risk) are also accepted when default risk is high.

Buying bonds leads to higher consumption after repayment and lower consumption after default. Optimal bidding strategies thus trade off the expected marginal utility loss from default against the expected marginal benefit of the yield earned after repayment, averaged across the states of the world in which the bid is accepted. This leads to a standard portfolio choice problem for informed investors who can perfectly forecast the price at which a given bid will be executed. It is more difficult for uninformed investors for whom the marginal rates of substitution in one state depends on their bidding strategy in other states of the world, and the winner's curse makes it costly to bid at high prices.

We can summarize the trade-off by defining  $i$ 's expected marginal utility for bids

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<sup>9</sup>For uninformed investors, acceptance sets are complements of executed bid sets. The former collect all states with marginal prices that are *lower* than the bid price, the latter collect all states with *higher* marginal prices. The sets overlap at the true state.



in country  $j$  given state  $\theta_j$  and default decision  $\delta_j$  by

$$m_j^i(\theta_j, \delta_j) = \mathbb{E}^i \left[ u'(c^i(\vec{\theta}, \vec{\delta})) \middle| \theta_j, \delta_j \right],$$

where the expectation is taken over states of the world and default decisions in country  $-j$ . Taking ratios of marginal utility given default and repayment in  $j$  yields the relevant *marginal rate of substitution* (MRS) for evaluating bids at  $P_j(\theta_j)$ , which is

$$M_j^i(\theta_j) = \frac{\sum_{\theta'_j \in \mathcal{A}_j^i(\theta_j)} f_j(\theta'_j) \kappa_j(\theta'_j) m_j^i(\theta'_j, 1)}{\sum_{\theta'_j \in \mathcal{A}_j^i(\theta_j)} f_j(\theta'_j) (1 - \kappa_j(\theta'_j)) m_j^i(\theta'_j, 0)}.$$

When an investor chooses a strictly positive quantity of bonds, the optimal quantity is such that marginal rate of substitution is equal to the bond yield. That is, if asterisks index the marginal investor, then bond prices satisfy

$$\frac{1 - P_j(\theta_j)}{P_j(\theta_j)} = M_j^*(\theta_j).$$

The next proposition demonstrates that informed investors are always marginal investors, and hence marginal prices are state-contingent if and only if some investors acquire information. When there are informed investors, the winner's curse may lead uninformed investors to stop bidding at high prices; hence uninformed investors are sure to bid only at the low marginal price. Finally, portfolio shares are invariant to differences in wealth.

**Proposition 1** (Marginal Investor and Prices). *Fixing information acquisition decisions, the following statements characterize equilibrium prices and bidding strategies:*

- (i) *If there are no informed investors in  $j$  then there exists a single marginal price  $\bar{P}_j$  that is the same in all states  $\theta_j$ , and uninformed investors are marginal in every state. That is,*

$$\frac{1 - \bar{P}_j}{\bar{P}_j} = M_j^i(g) = M_j^i(b) \quad \text{for all } i.$$

- (ii) *If there are informed investors in  $j$ , then the marginal price is strictly higher in the good state than in the bad state,  $P_j(g) > P_j(b)$ . While informed investors are marginal in every state, uninformed investors may not submit any bids at the high price. That is,*

uninformed investor optimality conditions satisfy

$$M_j^i(b) = \frac{1 - P_j(b)}{P_j(b)} \quad \text{and} \quad M_j^i(g) \geq \frac{1 - P_j(g)}{P_j(g)} \quad \text{for all } i \text{ such that } a_j^i = 0,$$

where the inequality is strict if and only if the short-sale constraint binds for  $B_j^U(g)$ .

(iii) Under homothetic utility, marginal rates of substitution  $M_j^i(\theta_j)$  are independent of wealth. Hence optimal bidding strategies and the utility difference between informed and uninformed investors scale with wealth.

The proposition shows that, in our model of simultaneous auctions with many investors, bidding strategies trade off risk and return as in a canonical portfolio choice problem. The key modification introduced by the auction protocol is that bids at all possible prices jointly determine state-contingent marginal rates of substitution. Conditional on this change, optimal portfolios give rise to standard asset pricing relationships: marginal investors bid such that bond yields are equal to state-contingent marginal rates of substitution, taking into account execution prices and their portfolio composition in the other country.

If no investor acquires information, marginal rates of substitution are independent of the state and this relationship holds for all investors in every state. If some investors acquire information, only informed investors are marginal in every state, and uninformed investors instead may cease to bid at the high price in order to escape the winner's curse. However, all investors always submit bids at the low price, which are not subject to the winner's curse. Finally, bidding strategies inherit the wealth-scaling property of portfolio choice under homothetic utility. This implies that portfolio shares are invariant to wealth heterogeneity, so that in our model all portfolio differences are driven by differential information.

To provide further intuition about price determination in our model, the following analytical example provides an illustration by considering the special case where investors hold no bonds in Country 2.

**Example 1.** Let  $D_2 = 0$ . For informed investors, the relevant MRS in state  $\theta_1$  is

$$M_1^i(\theta_1) = \frac{\kappa_1(\theta_1)u'(W - P_1(\theta_1)B_1^i(\theta_1))}{(1 - \kappa_1(\theta_1))u'(W + (1 - P_1(\theta_1))B_1^i(\theta_1))}.$$

and is state-separable, i.e. it does not depend on bids at the other marginal price.

For uninformed investors,  $i \in \mathcal{U}_1$ , the relevant MRS for bids at  $P_1(g)$  is

$$M_1^i(g) = \frac{f_1(g)\kappa_1(g)u'(W - P_1(g)B_1^i(g)) + f_1(b)\kappa_1(b)u'(W - P_1(g)B_1^i(g) - P_1(b)B_1^i(b))}{f_1(g)(1 - \kappa_1(g))u'(W + (1 - P_1(g))B_1^i(g)) + f_1(b)(1 - \kappa_1(b))u'(W + (1 - P_1(g))B_1^i(g) + (1 - P_1(b))B_1^i(b))}$$

and is not separable across states, while the relevant MRS for bids at  $P_1(b)$  is

$$M_1^i(b) = \frac{\kappa_1(b)u'(W - P_1(g)B_1^i(g) - P_1(b)B_1^i(b))}{(1 - \kappa_1(b))u'(W + (1 - P_1(g))B_1^i(g) + (1 - P_1(b))B_1^i(b))}$$

and takes into account that uninformed bids at  $P_1(g)$  are also accepted in the bad state.

The example highlights that information introduces portfolio differences across informed and uninformed in *all* states even though the winner's curse only applies to bids at the high price. This is because high-priced bids are accepted in all states, thereby altering marginal incentives to bid at the low price even though such bids are effectively state-contingent.

### 3.1 Within-Country Effects of Asymmetric Information

The previous section derived general properties of optimal strategies and equilibrium prices. We now characterize in detail the effects of asymmetric information on portfolios and prices in a specific country (say Country 1). To isolate within-country effects, we assume that all investors are uninformed and hold a fixed portfolio of bonds in the other country (Country 2). Let superscripts  $I$  and  $U$  denote informed and uninformed investors in Country 1, respectively, and define  $\bar{P}_1$  to be the equilibrium price that obtains in Country 1 when there are no informed investors in Country 1. We index equilibrium outcomes by  $n_1$ , the share of informed investors in Country 1. The case with  $n_1 = 0$  is the *uninformed regime*, the one with  $n_1 > 0$  is the *informed regime*.

The next result characterizes prices as a function of the share of informed investors. We find that an increase in the share of informed investors exposes the gov-

ernment to risk in the sense that informed regime prices track the underlying state, while uninformed equilibrium are independent of the realized state.

**Proposition 2** (Portfolios and Price Dispersion). *Assume there are  $n_1$  informed investors in Country 1, and let all investors hold the same portfolio in country 2. Then in Country 1:*

1. *The high-state marginal price  $P_1(g)$  is strictly increasing in the share of informed investors in Country 1 and converges to the uninformed equilibrium price as  $n_1 \rightarrow 0$ .*
2. *The bad-state marginal price  $P_1(b)$  is strictly lower than the uninformed equilibrium price  $\bar{P}_1$  for all  $n_1 > 0$  and  $\lim_{n_1 \rightarrow 0} P_1(b) < \bar{P}_1$ .*

Comparative statics of the high price are straightforward. Since informed investors do not face the winner's curse, they must more at high prices than uninformed investors. Hence the high price monotonically increases in the share of informed investors.

Comparative statics of the low marginal price with respect to  $n_1$  are driven by three effects. First, uninformed investors spend more on bonds in the bad state than informed investors because their bids at the high price are also executed in the bad state. Since the high price is increasing in  $n_1$ , uninformed expenditures are *increasing* in  $n_1$ , which puts upward pressure on the bad price. Second, informed investors spend less in the bad state which puts downward pressure on  $P_1(b)$ . Third, uninformed investors react to the increase in the high price by submitting fewer high-price bids. Since such bids are also executed in the bad state, this also contributes to a decline in  $P_1(b)$ . The overall effect depends on number of uninformed bids submitted at the high price, which in turn responds endogenously to the extent of the winner's curse. As a result,  $P_1(b)$  may be non-monotonic in  $n_1$ .

The behavior of prices in the limit where the share of informed investors approaches zero is determined as follows. As  $n_1 \rightarrow 0$ , market clearing requires uninformed investors to buy all debt in both states. In the high state, all bids are executed at the marginal price and so expenditures can converge to  $D$  only if the price converges to the uninformed price. Since all high-priced bids are also accepted in the low state, market clearing in the bad state then requires that expenditures at the low price must converge to zero. Given that bids at the low price must always be interior for any  $n_1 > 0$  by Proposition 1, this can occur only if the limit of  $P_1(b)$  is strictly

below the uninformed price. This observation turns out to be an important driver of information rents.

Figure 1 illustrates equilibrium prices using our numerical example. We plot marginal prices in Country 1, holding prices and bids in Country 2 fixed at the level that would obtain in an equilibrium where there are no informed investors. When there are uninformed investors, some bids are executed at the high price even when the state is bad. Hence we also show  $P_1^{avg}(b)$ , the quantity-weighted average execution price in the bad state, and  $E[P_1]$ , the unconditional average price. To provide a benchmark, the horizontal line shows the uninformed equilibrium price  $\bar{P}_1$ . The marginal price  $P_1(g)$  is monotonically increasing in  $n_1$ , and converges to  $\bar{P}_1$  as the share of informed investors approaches zero.  $P_1(b)$  is strictly decreasing and expected

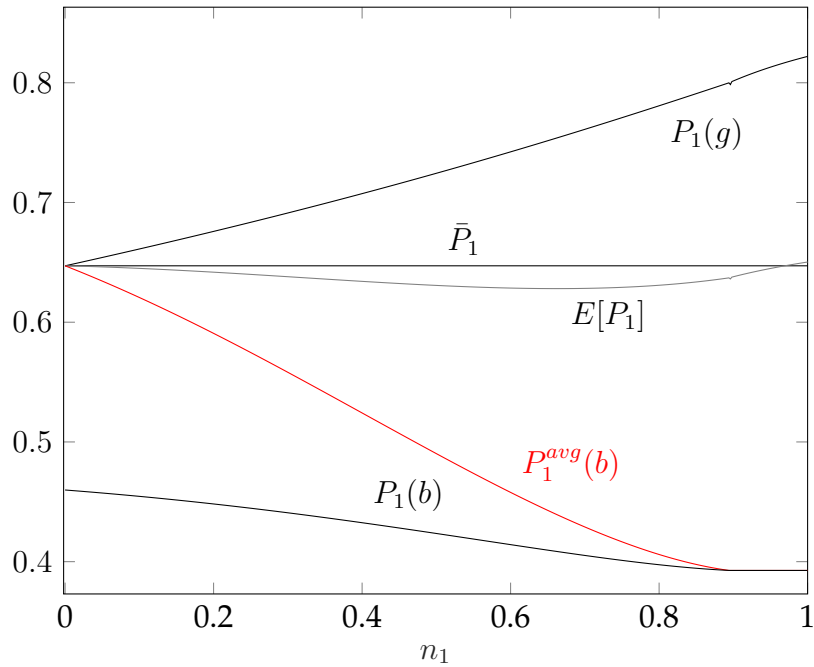


Figure 1: Prices in Country 1 as a function of  $n_1$  given a fixed bond portfolio in Country 2.

average prices lies strictly below the uninformed equilibrium price unless the share of informed investors is very close to one. This is because the discount the government must offer to risk-averse investors in the bad state is greater than the premium it can charge in the good state. Once price differences between states become sufficiently large, uninformed investors withdraw from bidding at the high price, and the price of bonds with high default risk becomes insensitive to the share of informed investors.

The intuition for these effects be seen in our analytical example as well.

**Example 1 (Continued).** Let  $u(\cdot) = \log(\cdot)$ . In the uninformed regime with a unique marginal price, uninformed demand is  $\bar{B}_1^U = \frac{(1-\bar{\kappa}_1-\bar{P}_1)W}{P_1(1-\bar{P}_1)}$  and the marginal price is such that  $\bar{P}_1\bar{B}_1^U = D$ . Hence the uninformed equilibrium price is

$$\bar{P}_1 = 1 - \frac{\bar{\kappa}_1 W}{W - D}.$$

In the informed regime, informed investor demand is  $B_1^I(\theta_1) = \frac{(1-\kappa_1(\theta_1)-P_1(\theta_1))W}{P_1(\theta_1)(1-P_1(\theta_1))}$  and, by market-clearing, prices in the limit with no information are given by

$$\lim_{n_1 \rightarrow 0} P_1(g) = \bar{P}_1 \quad \lim_{n_1 \rightarrow 0} P_1(b) = 1 - \frac{\kappa_1(b)W}{W - D + \frac{\kappa_1(b) - \bar{\kappa}_1}{1 - \bar{\kappa}_1} D}.$$

As  $n \rightarrow 0$  the uninformed investor becomes the only type with positive mass and hence must just be indifferent as to bidding 0 at the low price  $P(b)$  given that it buys all of the government's bonds at the high price  $P(g)$ .

In the full-information limit where  $n_1 \rightarrow 1$ , informed regime prices satisfy

$$\lim_{n_1 \rightarrow 1} P_1(g) = 1 - \frac{\kappa_1(g)W}{W - D} \quad \lim_{n_1 \rightarrow 1} P_1(b) = 1 - \frac{\kappa_1(b)W}{W - D}.$$

Hence bonds offer a risk premium that depends on the level of debt relative to investor wealth. Moreover, price differences in the limit  $n_1 \rightarrow 0$  depend on the variance of default probabilities through  $\kappa_1(b) - \bar{\kappa}_1$ .

### 3.2 Endogenous Asymmetric Information

The previous section studied equilibrium prices given a fixed share of informed investors. We now characterize how the share of informed investors is determined within a given country. To focus on within-country effects, we maintain from the previous section the assumption that all investors are uninformed in Country 2, and let  $K \equiv C(1, 0)$  denote the marginal cost of acquiring information in Country 1. Fixing Country 2 portfolios, the value of information in Country 1 is

$$\Delta V(n_1) = V^I(n_1) - V^U(n_1).$$

In the informed regime,  $\Delta V(n_1)$  is the *equilibrium* difference in expected utility obtained by informed and uninformed investors. In the uninformed regime,  $\Delta V^0$  denotes the *counterfactual* expected utility gain achieved by a single deviating investor who becomes informed when all other investors remain uninformed.

It is individually optimal to acquire information if the value of information exceeds its cost. Hence there exists an equilibrium without information acquisition if and only if  $\Delta V^0 \leq K$ , and an equilibrium with information acquisition if and only if  $\Delta V(n_1) \geq K$  for some  $n_1 > 0$ . Since all investors are ex-ante symmetric, an equilibrium with an interior share of informed investors must satisfy  $\Delta V(n_1^*) = K$ .

The next result shows that information acquisition is a strategic complement if the share of informed investors is sufficiently small, and that the value of information is strictly higher when there is a small strictly positive share of investors than when all investors are uninformed. This allows for the co-existence of the informed and uninformed regime for certain information costs.

**Proposition 3** (Complementarity and Multiplicity). *There exists a threshold share of informed investors  $\bar{n}_1 > 0$  such that the value of information is strictly higher if  $n_1 \in (0, \bar{n}_1]$  than if  $n_1 = 0$ . The informed and uninformed regime co-exist if and only if  $K \in [\bar{\Delta}V, \max_{n_1} \Delta V(n_1)]$ . The maximal share of informed investors is decreasing in  $K$ .*

The reason for this result is that, in a discriminatory-price auction, investors may have *greater* opportunities to exploit their information advantage when there are other informed investors. When no investors is informed, prices are not state-contingent and the only benefit of information is the ability to adjust quantities. When some investors are informed, marginal prices are distinctly lower in the bad state.<sup>10</sup> This exposes uninformed investors to the winner’s curse, and it allows informed investors to capture a higher risk premium in the bad state while also avoiding the winner’s curse. Thus, the presence of informed investors can create “better deals” that raise the value of being informed.

Our example allows us compute the value of information in closed form, and shows that fundamental volatility in default risk raises the value of information by

<sup>10</sup>In Cole, Neuhann, and Ordoñez (2022a) we augment the one-country auction model with a demand shock similar to Grossman and Stiglitz (1980), and show this smooths the discontinuity in the value of information at  $n = 0$  while preserving the strategic complementarity in information acquisition as well as the scope for equilibrium multiplicity.

increasing the spread between state-contingent prices for any given share of informed investors: risk-increasing fundamental shocks can induce information acquisition.

**Example 1 (Continued).** *In the uninformed regime, uninformed investors' consumption is  $(1 - \bar{\kappa}_1)W/\bar{P}_1$  after repayment and  $\bar{\kappa}_1W/(1 - \bar{P}_1)$  after default. The counterfactual informed investor's consumption is  $(1 - \kappa_1(\theta_1))W/\bar{P}_1$  after repayment and  $\kappa_1(\theta_1)W/(1 - \bar{P}_1)$  after default. Hence the value of information is*

$$\bar{\Delta}V = \sum_{\theta_1} f_1(\theta_1) \left[ \log(\kappa_1(\theta_1)^{\kappa_1(\theta_1)}(1 - \kappa_1(\theta_1))^{1 - \kappa_1(\theta_1)}) - \log(\bar{\kappa}_1^{\bar{\kappa}_1}(1 - \bar{\kappa}_1)^{1 - \bar{\kappa}_1}) \right],$$

and is strictly positive and strictly increasing in a mean-preserving spread of default probabilities around  $\bar{\kappa}_1$  by the strict convexity of  $\log(\kappa^\kappa(1 - \kappa)^{1 - \kappa})$  on  $(0, 1)$ .

Next consider the limit of the informed regime as  $n_1 \rightarrow 0$ . Market clearing requires that uninformed investors continue to purchase essentially all bonds in all states. Since the high price converges to the uninformed price, they achieve the same utility as in the uninformed regime. This is not true for informed investors, who may submit bids at two distinct marginal prices. The resulting consumption profile in state  $\theta_1$  is  $(1 - \kappa_1(\theta_1))W/P_1(\theta_1)$  after repayment and  $\kappa_1(\theta_1)W/(1 - P_1(\theta_1))$  after default. Hence the value of information is

$$\lim_{n_1 \rightarrow 0} \Delta V(n_1) = \Delta V(0) + f_1(b) \lim_{n_1 \rightarrow 0} \log \left( \frac{\bar{P}_1}{P_1(b)} \right)^{1 - \kappa_1(b)} \left( \frac{1 - \bar{P}_1}{1 - P_1(b)} \right)^{\kappa_1(b)}.$$

It is easy to verify that the second term is strictly positive because  $\lim_{n_1 \rightarrow 0} P_1(b) < \bar{P}_1$ .

Figure 2 illustrates this dependence of the value of information on fundamental default risk. We compute the value of information in the uninformed regime and in the informed regime in the limit  $n_1 \rightarrow 0$  as a function of the bad-state default probability  $\kappa_1(b)$ . An equilibrium with information exists if the value of information exceeds its cost  $K$  for some value of  $n_1$ . The solid black lines show the value of information in both the informed and uninformed regimes. An increase in  $\kappa_1(b)$  raises default risk and increases the variance of default risk across states. The regions in which an informed equilibrium exists expand as default risk increases.

Figure 3 illustrates the proposition for the whole range of  $n_1$  using our baseline numerical example. We plot the value of information in the uninformed and informed regime. The value of information jumps at  $n_1 = 0$  as the information regime switches from uninformed to informed. Within the informed regime, it is



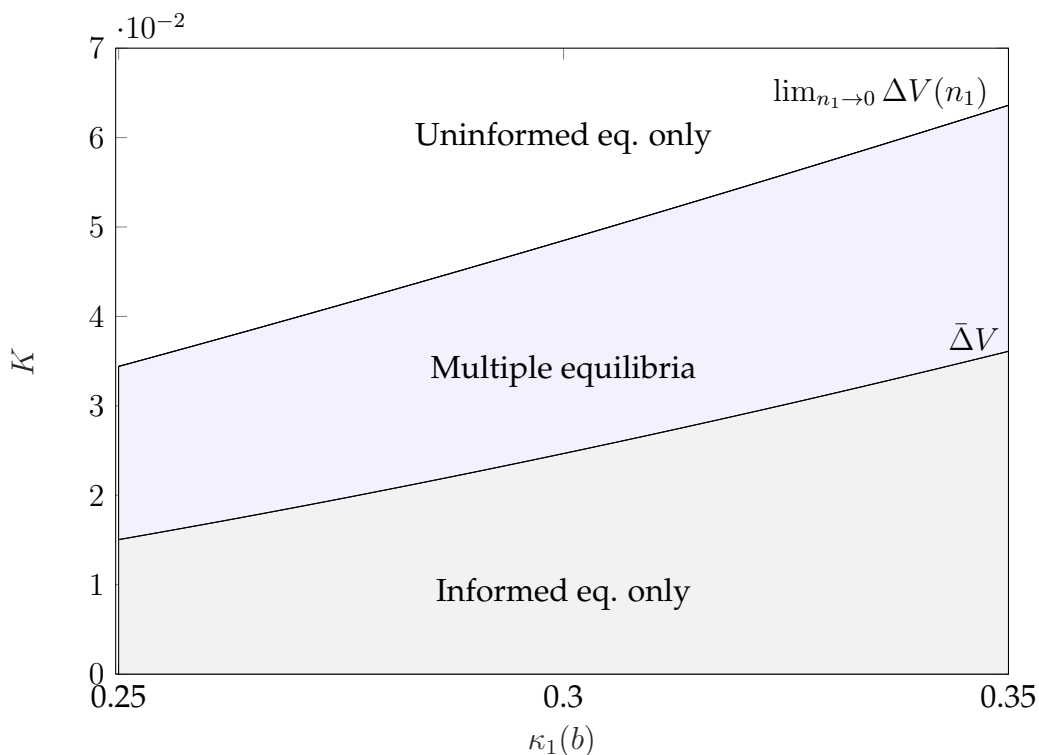


Figure 2: Information regimes in Country 1 given  $\kappa_1(b)$ .

non-monotonic due to the interaction of two forces. On the one hand, an increase in  $n_1$  raises the price spread  $P_1(g) - P_1(b)$  and, thus, the severity of the winner's curse for the uninformed investor. This raises the value of information and leads to a strategic complementarity in information acquisition. On the other hand, an increase in  $n_1$  strengthens competition for good bonds among informed investors, dissipating rents on infra-marginal bond purchases. The first force dominates if  $n_1$  is small, and the second force dominates if  $n_1$  is large. This is due to a composition effect: the share of uninformed bids at the high price declines in  $n_1$ . This implies that the *equilibrium* share of informed investors will typically be interior in an informed equilibrium; hence endogenous information acquisition generates *asymmetric* information.

### 3.3 Cross-Country Spillovers: Prices versus Portfolios

We now study cross-country spillovers. We first consider the case without asymmetric information. Similar to existing literature, we find that changes in risk appetite driven by fundamental shocks in one country can affect prices in the other country,

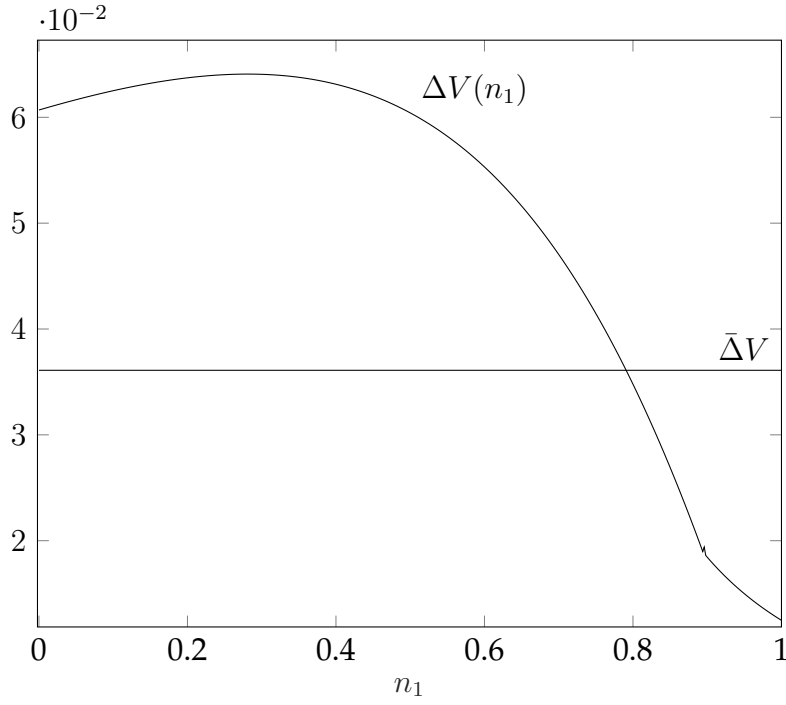


Figure 3: The value of information in Country 1 as a function of  $n_1$ .

but also that such shocks cannot generate segmentation or “reverse spillovers” of the type observed during the Eurozone crisis. We then show that the existence of asymmetric information in one country can rationalize these two phenomena.

### 3.3.1 Spillovers with symmetric information

Under symmetric information, all investors are identical. Dropping superscripts indicating types, define the *net marginal benefit* of investing in country  $j$  is the difference between the yield and the marginal rate of substitution, i.e.

$$F_j = \frac{1 - P_j}{P_j} - M_j, \quad (3)$$

where equilibrium requires that  $F_j = 0$  for all  $j$ . We can then define *default risk spillovers* as a decline in the net benefit of investing in country  $j$  when there is a increase in default risk in country  $-$ , i.e.  $\partial F_j / \partial \kappa_{-j} < 0$ .

**Proposition 4.** *With symmetric information, there is default risk contagion if and only if preferences satisfy decreasing absolute risk aversion. Default risk contagion has the same sign*

for any fundamentals, and all investors always hold identical portfolios.

Absent asymmetric information, the model thus cannot generate the divergent paths of the core and periphery yields or the changes in non-domestic bond holdings observed during the Eurozone crisis. This result obtains because, absent asymmetric information, the model behaves similarly to standard frameworks: there is a single marginal price at auction; hence there is no salient difference to Walrasian markets. This clarifies why existing models cannot speak to observed facts on portfolio segmentation and divergence of yields observed in several sovereign debt crises.

### 3.3.2 Spillovers with asymmetric information: Segmentation

We now show that asymmetric information can lead to sharp changes in portfolios away from the benchmark degree of diversification that obtains under symmetric information. For simplicity, we assume that no investor is informed in Country 2, but a fraction  $n_1$  is informed in Country 1. To highlight that this channel is independent of the risk-based mechanisms discussed in the previous proposition, we study a second-order approximation of the optimal portfolio problem. Specifically, we consider constant relative risk aversion (CRRA) preferences with a risk-aversion coefficient  $\gamma$ , and approximate around zero bond holdings. We recover optimal portfolios that are functions of the mean return and return volatility of bonds at a given marginal price only. We find that informed investors hold disproportionately more bonds in Country 1, while uninformed investors hold more in Country 2.

We simplify notation by using  $I$  to index investors with information in Country 1, and  $U$  to index investors without any information. The realized rate of a return on a country- $j$  bond bought in state  $\theta_j$  at price  $P_j(\theta_j)$  given default decision  $\delta_j$  is  $R_j(\theta_j, \delta_j) = \frac{1-\delta_j-P_j(\theta_j)}{P_j(\theta_j)}$ . We define  $\widehat{R}_j^i(\theta_j) \equiv \mathbb{E}[R_j(\theta_j, \delta_j)|\mathcal{F}^i]$  and  $\widehat{\sigma}_j^i(\theta_j) \equiv \sqrt{\mathbb{V}^i[R_j(\theta_j, \delta_j)]}$  to be the expected return and standard deviation of a Country- $j$  bond purchased at marginal price  $P_j(\theta_j)$  given  $i$ 's information set. These may differ across differentially informed investors. The associated Sharpe ratio is

$$S_j^i(\theta_j) = \frac{\widehat{R}_j^i(\theta_j)}{\widehat{\sigma}_j^i(\theta_j)}.$$

It is immediate that uninformed investors expect a lower Sharpe ratio when bidding at the high price as long as expected default probabilities are below 50%. This is

because uninformed bids at the high price are also accepted in the bad state, which implies that bonds bought at this price have higher expected default risk than those bought by informed investors at the same price. We restrict attention, quite realistically, to default risk below 50%, since otherwise the variance is decreasing in  $\kappa_j$ .

**Lemma 1.** *Let  $\bar{\kappa}_1 < \frac{1}{2}$ . For  $\theta_1 = g$ ,  $S_1^I(\theta_1) > S_1^U(\theta_1)$  and  $\frac{\partial(S_1^I(\theta_1) - S_1^U(\theta_1))}{\partial P_1(g)} < 0$ .*

We denote portfolio shares scaled by the coefficient of risk aversion by

$$\omega_j^i(\theta_j) \equiv \frac{\gamma P_j(\theta_j) B_j^i(\theta_j)}{W}.$$

To simplify notation, let  $s_j^i(\theta_j) \equiv \frac{S_j^i(\theta_j)^2}{1 + S_j^i(\theta_j)^2}$  denote a scaled version of the state-contingent Sharpe ratio and  $s_j^i \equiv \sum_{\theta_j} f_j(\theta_j) s_j^i(\theta_j)$  its expectation over states for country  $j$ . Given that investors are ex-ante symmetric, we define *market segmentation* as the difference in equilibrium portfolio weights. Next we formally characterizes optimal portfolios.

**Proposition 5 (Segmentation).** *Up to second order, investor  $i$ 's optimal portfolio satisfies*

$$\omega_1^i(g) = \frac{s_1^i(g)}{\widehat{R}_1^i(g)} \left( \frac{1 - s_2^i}{1 - s_1^i s_2^i} \right), \quad \omega_1^i(b) = \frac{s_1^i(b)}{\widehat{R}_1^i(b)} \left( \frac{1 - s_2^i}{1 - s_1^i s_2^i} \right), \quad \text{and} \quad \omega_2^i = \frac{s_2^i}{\widehat{R}_2^i} \left( \frac{1 - s_1^i}{1 - s_1^i s_2^i} \right).$$

*If  $\bar{\kappa}_1 < \frac{1}{2}$ , then portfolios display segmentation:  $\omega_1^U(g) < \omega_1^I(g)$ ,  $\omega_2^U > \omega_2^I$  and  $\frac{\partial(\omega_2^U - \omega_2^I)}{\partial P_1(g)} < 0$ .*

Given an information set and the associated Sharpe ratios, portfolios address standard risk and return trade-offs: bond purchases are increasing in Sharpe ratios, and portfolio weights are determined by relative Sharpe ratios. Asymmetric information leads to market segmentation, with informed investors buying primarily in Country 1 while uninformed investors retreat to Country 2. Segmentation worsens as more investors become informed in Country 1, as the gap in the Sharpe ratios perceived by informed relative to uninformed investors increases.

Figure 4 illustrates this result using the baseline numerical example from Definition 4. As the share of informed investors in Country 1,  $n_1$ , increases, informed investors invest less in Country 2 and more in Country 1 in order to exploit their information advantage. Uninformed investors, instead, withdraw from Country 1 due to adverse selection and invest more in Country 2. Informed investor expenditures in Country 1 are decreasing in  $n_1$  because there is more competition for information

rents as the share of informed investors increases. This reduces the profitability of investing in Country 1.

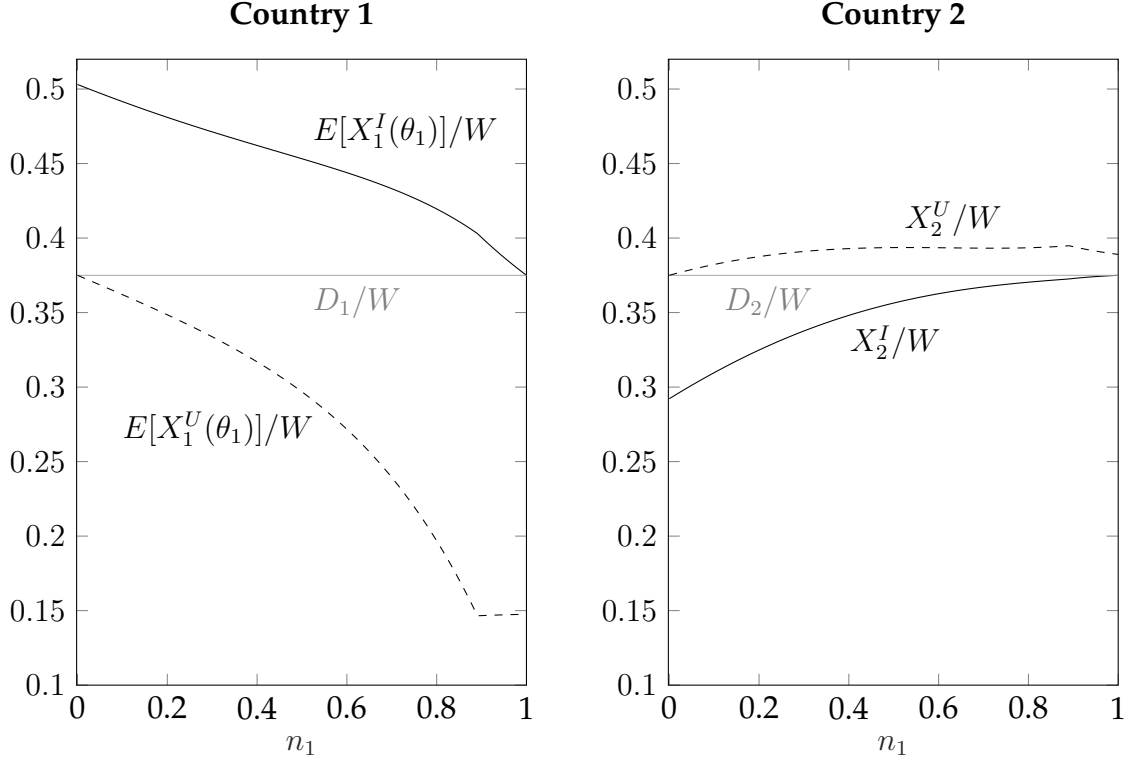


Figure 4: Portfolio shares across countries and investors as a function of  $n_1$ . Portfolio shares are defined as the cross-state average of expenditure ratios in each country over wealth  $W$ . Solid lines depict benchmark expenditure shares  $D/W$  that obtain in either the uninformed regime ( $n_1 = 0$ ) or the informed regime where all investors are informed in Country 1 ( $n_1 = 1$ ).

Since default risk is independent across countries, optimal risk management calls for investors to hold diversified portfolios. Through its effects on segmentation, asymmetric information then raises the risk premium by inducing inefficient diversification. Figure 5 shows this effect for both countries: although no investor acquires information in Country 2, that country's bond price is lower than in the regime without information in either country. Hence segmentation generates yield spillovers.

### 3.3.3 Spillovers with asymmetric information: Information Contagion

In the previous section, we showed that an increase in the share of informed investors in Country 1 induces the remaining uninformed investors to reallocated funds to

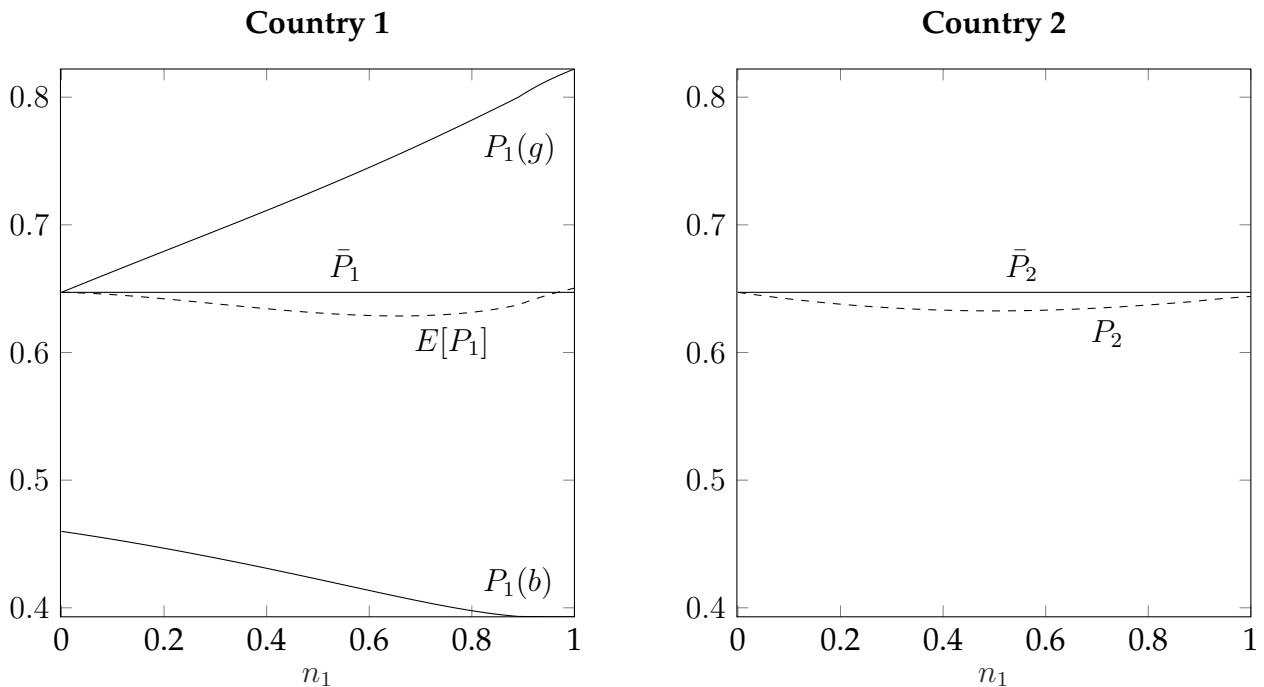


Figure 5: Prices in informed equilibrium as a function of  $n_1$ .

Country 2. We now argue that such portfolio concentration raises the value of acquiring information in Country 2. The key mechanism is that an increase in country-specific risk exposure makes overpaying for bonds more costly.

To isolate the role of risk exposure in determining the value of information, it is useful to study the *marginal* value of information  $mv_j(\epsilon)$  for an investor that is uninformed in Country  $j$ . We define this value to be the marginal increase in utility achieved by allowing the investor to replace some quantity  $\epsilon$  of her non-contingent bids in country  $j$  with bids at the appropriate state-contingent marginal price, holding consumption after repayment fixed.

This object captures the value of information as facilitating state-contingent bidding, while also allowing us to hold fixed the degree of expenditure that would obtain if the investor were not acquire information. Specifically, if we evaluate the marginal value near  $\epsilon = 0$ , we can measure investor  $i$ 's *exposure* to country  $j$  given the original bidding strategy as her *expenditures*  $X_j^i(\theta_j)$  on country  $j$  bonds in state  $b$  under this strategy. We then have the following result.

**Proposition 6.** (*Value of information and investor exposure*) *The marginal value of informa-*

tion for uninformed investor  $i$  in country  $j$  in a neighborhood around  $\epsilon = 0$  is

$$mv_j^i(0) = f_j(b)\kappa_j(b)\Delta_j\mathbf{E}_{-j}u'(W - X_j^i(b) + (1 - \delta_{-j})B_{-j}^i(\theta_{-j})) > 0.$$

where  $\Delta_j \equiv P_j(g) - P_j(b)\frac{1-P_j(g)}{1-P_j(b)} > 0$  measures how much cheaper it is to buy dollar of consumption after repayment by paying  $P(b)$  rather than  $P(g)$ . For any risk averse utility function, the marginal value is strictly increasing in the investor's exposure to country  $j$ , i.e.

$$\frac{\partial mv_j^i(\epsilon)}{\partial X_j^i(b)}\Big|_{\epsilon=0} = -f_j(b)\kappa_j(b)\Delta_j\mathbf{E}_{-j}u''(W - X_j^i(b) + (1 - \delta_{-j})B_{-j}^i(\theta_{-j})) > 0.$$

Information is thus most valuable when the investor has high exposure to the country under the uninformed strategy. This is because paying the right price is particularly valuable when marginal utility is high after a default, which is the case when the investor portfolios are strongly exposed to default risk in the country. This immediately implies the following corollary linking the segmentation result from Proposition 5 to spillovers in information regimes. In our application to the Eurozone crisis, this mechanism leads to information acquisition in Italy in response to a negative shock to Portugal.

**Corollary 1** (Spillovers in Information Regimes). *If a switch to the informed regime in Country 1 induces uninformed investors to increase their expenditures in Country 2, the benefit of acquiring information in Country 2 also increases.*

We complement this theoretical result by computing the total value of information in our numerical example. We focus on the case with  $n_1$  informed investors in Country 1 and no informed investors in Country 2. Given that there is asymmetric information in Country 1, we compute the value of information in Country 2 as a function of  $n_1$  for an investor who is informed in Country 1 (denoted by  $\hat{\Delta}V^{\{1,1\}}(n_1)$ ) and for one who is uninformed in Country 1 (denoted by  $\hat{\Delta}V^{\{0,1\}}(n_1)$ ). Figure 6 plots these two functions in black. For comparison, the gray lines show the value of information in Country 1 from Figure 3.

The incentive to acquire information in Country 2 is always strictly higher when there is some information in Country 1, and the additional incentive to become informed in the second country is smaller than the incentive to become informed in the first country. The intuition is that a country without informed investors becomes a “safe haven with symmetric ignorance” where uninformed investors do not face

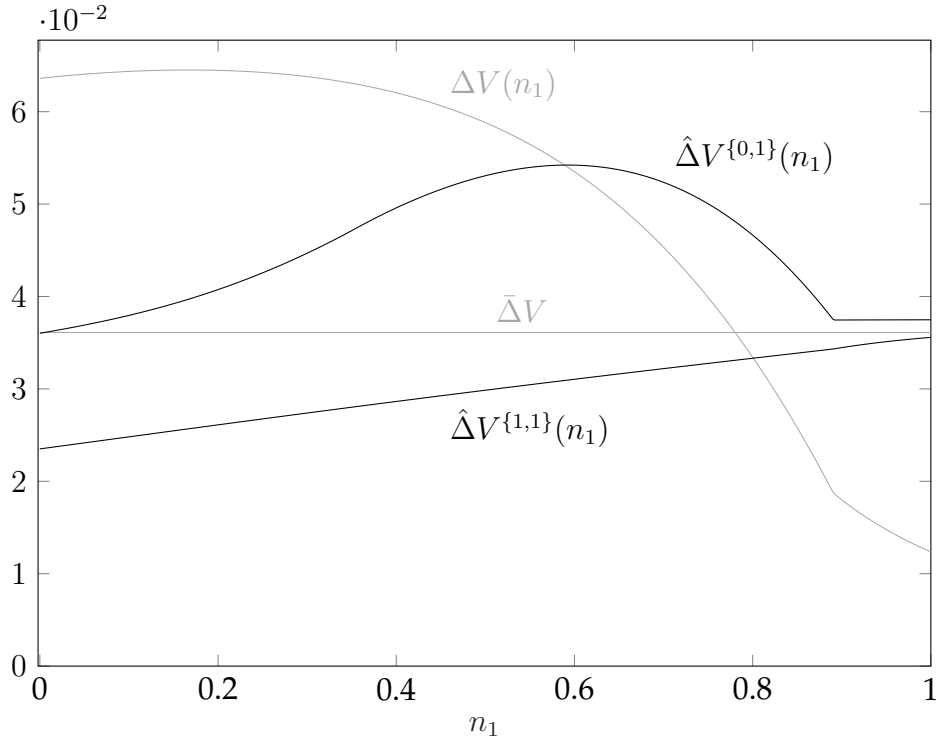


Figure 6: Value of Information as a function of  $n_1$ .

adverse selection. Thus information acquisition in Country 1 leads to a migration of uninformed capital to Country 2. Since Country 2 now represents a higher share of uninformed investors' portfolio, the existence of informed investors in one country begets further information acquisition in the other. This creates a novel channel of contagion through spillovers in the informational regime, which is only driven by segmentation forces and absent under symmetric information. We later show that this effect can help rationalize key facts from the Eurozone crisis, in particular the joint behavior of market segmentation and auction informativeness.

## 4 Secondary Markets

Many sovereign bonds can be readily traded in secondary markets once the auction closes. We now study how secondary markets affect bids and prices at auction. Since auction prices and allocations are disclosed at the end of the auction, agents are able to infer all private information impounded into bids prior to participating in the secondary market. Hence secondary markets take place under symmetric information,



and the only motive for trade is reallocating differential risk exposure acquired at auction. This implies that secondary markets only play a role if there is asymmetric information: when no investor acquires information prior to the auction, the information environment is the same in both markets, and prices and allocations are unchanged relative to the auction without an aftermarket.

We therefore focus on the case with asymmetric information. To see why there might be gains from trade ex-post, observe that informed investors may want to sell in the secondary market in order to exploit their information advantage at auction, while uninformed investors may want to buy in the secondary market in order to avoid the winner's curse at auction. This suggests an equilibrium where information rents stem from the ability to buy cheap at the auction and sell high at in secondary markets. We show that such an equilibrium may obtain, but only if there are not too many informed investors. In particular, the critical threshold is

$$\hat{n}_j = \frac{D_j}{W - D_{-j}},$$

which is the share of informed investors beyond which informed investors are able to buy entire stock of debt outright. When the share of informed investors exceeds this threshold, all arbitrage rents are competed away.

**Proposition 7.** *Let  $n_j > 0$ . Then the equilibrium with secondary markets satisfies:*

- (i) *If and only if  $n_j < \hat{n}_j$ , informed investors earn strict arbitrage profits in the high state by buying at  $P_j(g)$  at auction and selling at  $\hat{P}_j(g) > P_j(g)$  in the secondary market. This arbitrage persists in the limit with no informed investors,  $\lim_{n_1 \rightarrow 0} (P_j(g) - \hat{P}_j(\theta_j)) < 0$ .*
- (ii) *There are no arbitrage profits in the low state,  $P_j(b) = \hat{P}_j(b)$  for any  $n_j$ . This is because there is no winner's curse when bidding at low prices.*
- (iii) *Any equilibrium with endogenous information acquisition must offer a strict arbitrage in the high state,  $n_1 < \hat{n}_1$ . Moreover, in the limit as  $n_1 \rightarrow 0$ , the value of information is strictly higher with secondary markets than without. Hence there are information costs for which an informed equilibrium exists only if there are secondary markets.*

The reason secondary markets can raise the value of information is that the ability to re-trade bonds means informed investors can buy more "underpriced" bonds at auction without having to hold the associated default risk to maturity; that is, there

is a separation between trading on information and risk exposure. This gain does not come at the expense of uninformed investors, who are willing to pay a markup in the secondary market to avoid the winner's curse at auction. Instead, the government suffers a revenue loss because fewer investors participate at the auction. The two key features of our model that give rise to this mechanism are risk aversion, which imposes a cost to holding large concentrated positions in the bond, and the multi-unit protocol, which allows bidders to adjust the intensive margin.

Figure 7 illustrates this effect by computing prices with and without secondary markets. When investors can trade in secondary markets, primary market prices are strictly lower *in all states* compared to both the uninformed equilibrium and the auction equilibrium without secondary markets as long as the share of informed investors is sufficiently small. This is because uninformed investors have the option to trade under symmetric information by waiting out the auction. But when there are relatively few informed investors, the auction can clear only if some uninformed investors can be persuaded to participate in the auction. Given the benefit to waiting for the secondary market, this requires a sizable price discount at auction. Since this mechanism primarily affects the good state where uninformed investors face adverse selection at auction, even the good-state auction price is lower than in the uninformed equilibrium price. Secondary markets amplify also spillovers even though there is no asymmetric information in Country 2. This is because the ability to earn risk-free arbitrage profits motivates informed investors to reallocate more funds to Country 1 than they would without secondary market. Hence prices must fall in Country 2.

The model with secondary market also produces clear testable implications that we can take to the data. Since information rents now stem from cross-market arbitrage, we can use the presence of cross-market price differences to detect asymmetric information at auction. Indeed, when information must be acquired at a cost, such arbitrage profits must necessarily exist. This is formalized in the following corollary, which we use extensively in our application to the Eurozone.

**Corollary 2.** *The presence of asymmetric information at auction can be detected using the price spread between primary and secondary markets. This spread is zero when bad news is realized, and positive when good news is realized.*

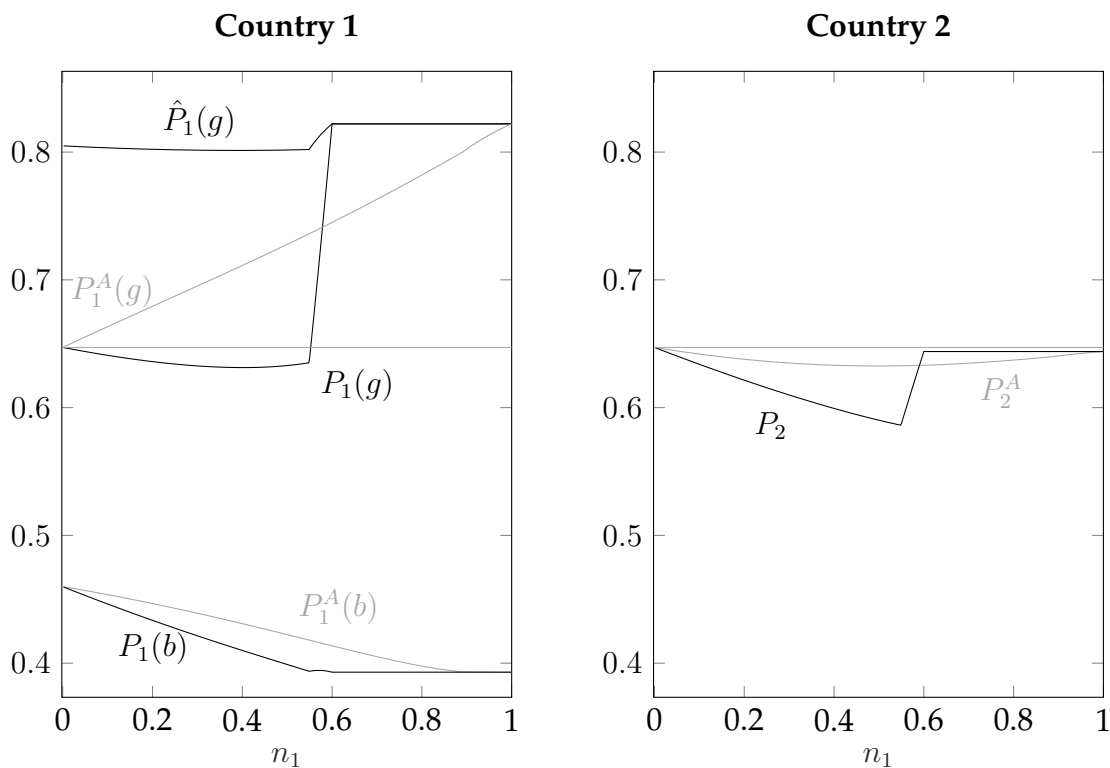


Figure 7: Prices in primary and secondary markets as a function of  $n_1$ . We show both the prices at the auction ( $\hat{P}_1(\theta)$ ) and in the secondary markets ( $P_1(\theta)$ ) We also show the corresponding prices in the model without secondary markets ( $P_1^A(\theta)$ ) in grey. The horizontal line shows the uninformed equilibrium prices. In Country 2, nobody is informed, so there is a single price schedule in which primary and secondary market prices coincide.

## 5 Information Spillovers in the European Debt Crisis

We now show that our theory of information spillovers offers a natural account for a number of key empirical regularities from the Eurozone sovereign debt crisis. We focus on three countries, Portugal, Italy, and Germany, that used discriminatory auctions to sell relatively short-term debt during the crisis and entered the crisis with different fundamentals: Portugal was highly indebted and at risk of insolvency, Italy was less fragile but sufficiently indebted to raise doubts about its ability to roll over its debt, and Germany's fiscal position was sound throughout. We focus on the following facts.

**Fact 1 (Yields).** *Prior to the crisis, yields were low and stable in all countries. During the crisis, average yields and yield volatility increased sharply in Portugal and Italy before eventually settling down. Conversely, German yields were low and stable throughout.*

**Fact 2 (Cross-market spread).** *The spread between primary and secondary market yields on auction days is sharply positive during the crisis for Portugal and Italy, but not for Germany. The spread declines once yields return to pre-crisis levels.*

**Fact 3 (Persistent Segmentation).** *The share of bonds held by non-resident investors in Portugal and Italy was high prior the crisis, fell during the crisis, and remained persistently low thereafter. The non-resident share of German bonds increased during the crisis.*

**Fact 4 (Auction Informativeness).** *Prior to the crisis, the unexpected component in auction prices had little or no explanatory power for subsequent secondary market yields. During the crisis, they have strong explanatory power in Portugal and Italy but not in Germany.*

Fact 1 is shown in Figure 8, Facts 2 and 3 are shown in Figure 9. To establish Fact 4, we regress the *unexpected* change in secondary prices for country  $i$  at the end of auction day  $t$  (denoted by  $\Delta \log \text{Sec}_{i,t}$ ) on the *unexpected* change of primary prices that same auction day (denoted as  $\Delta \log \text{Prim}_{i,t}$ ). To be more precise we define  $\Delta \log P_{i,t} = \log(P_{i,t}) - \log(\hat{P}_{i,t})$ , where  $P \in \{\text{Prim}, \text{Sec}\}$  and  $\hat{P}_{i,t}$  is the predicted primary or secondary price based on the observed secondary prices during the last three days before auction day. Primary market surprises are informative when secondary prices react to them. Table 1 shows our estimated elasticities. We find that the primary market surprise is informative in the periphery during the crisis but not (or less informative) before the crisis, and is never informative in Germany.

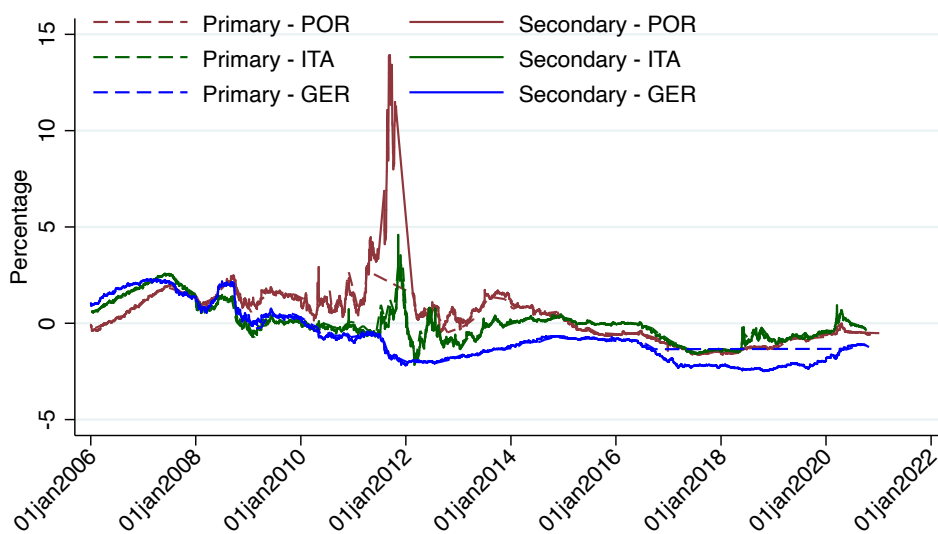


Figure 8: Real Yields (one-year bonds).

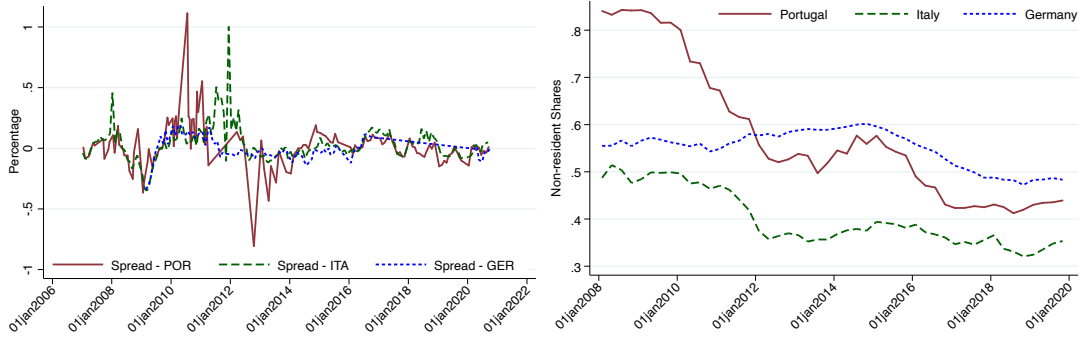


Figure 9: Cross-market spreads and Segmentation.

Dependent variable: $\Delta \log \text{Sec}_{i,t}$ : One-year Sovereign Bond						
Country	Portugal		Italy		Germany	
Period	Before	After	Before	After	Before	After
$\Delta \log \text{Prim}_t$	0.068 (0.069)	0.127*** (0.043)	0.200*** (0.065)	0.512*** (0.054)	-0.080 (0.081)	0.068 (0.043)
Observations	45	103	46	129	10	77
$R^2$	0.022	0.080	0.178	0.418	0.107	0.118

Dependent variable: $\Delta \log \text{Sec}_{i,t}$ : Half-year Sovereign Bond						
Country	Portugal		Italy		Germany	
Period	Before	After	Before	After	Before	After
$\Delta \log \text{Prim}_t$	0.012 (0.049)	0.049* (0.029)	0.093 (0.082)	0.111*** (0.033)	-0.048 (0.033)	0.003 (0.016)
Observations	45	106	46	129	10	77
$R^2$	0.001	0.026	0.028	0.080	0.207	0.001

Table 1: Elasticity of secondary market prices to information released at auction.

To account for these facts, we study a repeated version of our model, modified along three dimensions. First, we consider a richer default risk process with *public regimes* that capture commonly known variation in the default risk distribution due to, for instance, macroeconomic news. Within each regime, there are *three* possible quality shocks,  $\theta \in \{b, m, g\}$ . We use the bad state to capture “disaster” that worries investors even when it does not materialize on path (e.g. a scenario in which Portugal is not bailed out.). This allows us to generate variation in default risk while preserving the winner’s curse on path. Formally, we will assume state *b* is considered by investors but is never realized in sample.

To match the transition from the pre-crisis period to the height of the crisis, we

consider three regimes: *tranquil* (t), *alarming* (a), and *crisis* (c), which have increasing levels of average default risk and increasingly poor worst cases. Parameters are given in Table 2 and are chosen to generate yields roughly in line with the data. In all regimes, the probability of the good state is  $f(g) = 0.6$  and the probability of the medium state is  $f(m) = 0.3$ .

Second, we assume that there are distinct groups of investors indexed by their home country. The only difference between them is their cost of information acquisition: it is low and symmetric in their home country, but high abroad. These assumptions allow us to account for home-bias in investing. We pick information costs such that investors never acquire information abroad. Since the value of information is decreasing in the share of informed investors, this is an assumption about foreigners' cost of information *relative* to domestic investors. Thus, the key equilibrium choice is whether investors acquire information at home.

Third, we allow for trading frictions in the secondary market as in (Passadore and Xu 2020) and (Chaumont 2021). These frictions introduce a risk for informed investors of not finding buyers in secondary markets, and for uninformed investors of not finding sellers, thereby preventing full re-balancing after primary markets and perfect ex-post diversification across countries, which would be counterfactual. For simplicity, we model these frictions as a fixed probability  $\rho$  that a given investor can access the secondary market.

	Tranquil regime	Alarming regime	Crisis regime
$\kappa(g)$	0.1%	0.5%	3%
$\kappa(m)$	0.5%	3%	7%
$\kappa(b)$	1.25%	7%	25%

Table 2: Default Risk Across Public Regimes

We then conduct two event studies: *within-periphery spillovers*, whereby a shock to Portugal triggers information acquisition in Italy, and *core-periphery spillovers*, where we consider the effects on Germany of shocks to Portugal and Italy. In the latter, we treat Portugal and Italy as a joint “periphery” to maintain our two-country structure. We use the following common parameters throughout the analysis. To focus on spillovers in information regimes, we mute risk-based spillovers using log utility.

Parameter	Interpretation	Value
$D$	Country debt levels	300
$W$	Investor wealth	1000
$\gamma$	Coefficient of relative risk aversion	1
$\rho$	Secondary market liquidity	0.75

Table 3: Common parameters used in both event studies.

## 5.1 Event Studies

### 5.1.1 Event Study 1: Spillovers from Portugal to Italy

We now study spillovers from Portugal to Italy. We focus on three phases: the tranquil period prior to the crisis, the initial shock in Portugal, and the wider crisis. Table 4 describes public regimes for each phase. Portugal’s default risk process steadily worsens over time and reaches the crisis regime in Phase 3. Italy’s experience is delayed: it enters the alarming regime in the last phase.

	Phase 1	Phase 2	Phase 3
Portugal	Tranquil	Alarming	Crisis
Italy	Tranquil	Tranquil	Alarming

Table 4: Regimes in the within-periphery simulation.

There are three groups of investors: Portuguese (P), Italian (I), and Foreign (F). To match portfolio shares during the initial phase, we choose their masses to be  $n_F = 0.3$ ,  $n_P = 0.2$  and  $n_I = 0.5$ . (Since all investors are symmetric when no one acquires information, the Portuguese non-resident share in Phase 1 is simply  $(n_I + n_F)/n_P$ .)

Our theoretical results show that the value of information is increasing in default risk, and that there may be spillovers in information regimes. In the present example, an intermediate cost of domestic information acquisition triggers the pattern of information acquisition shown in Table 5: no investor acquires information when Italy and Portugal are in either the tranquil or the alarming regime, but information is acquired in *both* countries once Portugal enters the crisis regime.

Figure 10 shows simulated yields and portfolios for all possible realizations of the underlying quality shock  $\theta$ , where vertical lines indicate the three phases. We now show that transitions across these three phases can rationalize the key facts.

	Phase 1	Phase 2	Phase 3
Portuguese	Uninformed.	Uninformed	<b>Informed in Portugal</b>
Italian	Uninformed	Uninformed	<b>Informed in Italy</b>
Foreign	Uninformed	Uninformed	Uninformed

Table 5: Optimal information acquisition in the within-periphery simulation.

In Phase 1, yields are low and invariant to the state because default risk is low and no investor is informed. Moreover, markets are well-integrated because all investors behave symmetrically and they hold the same per-capita portfolio shares in both countries. In Phase 2, Portugal's yield rises due to an increase in default risk. However, the continued absence of informed investors implies stable yields and well-integrated markets. This insulates Italy from the Portuguese shock: there is only a negligible increase in borrowing cost due to weak risk-based spillovers.

In Phase 3, spillovers are substantial because the additional increase in default risk leads to a shock in the incentives to acquire information acquisition in *both countries*. When Portugal is in the alarming regime in Phase 2, no investor acquires information in either Portugal or Italy. But in Phase 3, the additional increase in Portuguese default risk leads investors to acquire information. Since investors who are uninformed in Portugal now hold a larger share of their portfolio in Italy, they acquire information about Italy. This is an information regime spillover effect: had there been no information acquisition in Portugal, there also would not have been information acquisition in Italy, holding the path of fundamental shocks fixed.

As in the data, this leads to a spike in average yields and yield *volatility*: average yields are high because default risk has increased and the winner's curse leads to poor risk sharing, and volatility is high because yields are highly sensitive to the realized shock. The advent of the winner's curse further induces market segmentation: because foreign investors can no longer bid in Portugal or Italy without fear of adverse selection, they withdraw from the auction. Because prices are higher in the secondary market, they also purchase fewer bonds later on. This fragmentation is simultaneously reflected in high average yields and a substantial primary-secondary market spread, in line with empirical record.

Two additional observations are also congruent with the data. First, news about the quality shock is reflected in auction prices. Since auction prices are observable, this news is impounded into secondary market prices, which generates the predictabil-



ity result we establish empirically. Second, the non-resident share is low when *either* the good or the medium quality shock are realized. In fact, segmentation is more pronounced ex-post when the realized news is good because uninformed investors are particularly wary of bidding at high marginal prices. Accordingly, a natural outcome of our model is that markets remain *persistently segmented* even as yields start to fall once the height of the crisis passes (as can be captured by an increase of prices to  $P(g)$  from  $P(b)$ ). Put differently, continued fears of potential bad shocks can lead foreign investors to pull back from Portugal and Italy for extended periods of time even when the *realized* shocks are good. This is consistent with the data, where non-resident shares are persistently low despite an eventual decline in yields.

The right panels also show the counterfactual where Italian investors do not acquire information at home. We find that the information spillover has striking effects: in its absence, average yields would have been lower, yield volatility would have been muted, there would have been no primary-secondary market spread, and the non-resident share would have *increased*. All of these effects are counterfactual.

### 5.1.2 Event Study 2: Reverse Spillovers to Germany

We now turn to the core-periphery event study in order to analyze the effects of shocks to the periphery on core yields and portfolios. The periphery is a combination of Portugal and Italy; the core is represented by Germany. We again consider three phases: the tranquil period prior to the crisis, the initial shock to the periphery, and the full crisis. Table 6 describes the assumed regimes for each phase. The periphery behaves like Portugal in the previous event study, with steadily worsening default risk culminating in the crisis regime. Germany experiences no fundamental regime shifts: it is in the tranquil regime throughout.

Table 6: Regimes in the core-periphery event study.

	Phase 1	Phase 2	Phase 3
Periphery	Tranquil	Alarming	Crisis
Germany	Tranquil	Tranquil	Tranquil

There are three groups of investors: German (G), Periphery (P) and Foreign (F). Their masses are  $n_F = 0.15$ ,  $n_G = 0.5$ , and  $n_P = 0.35$ , respectively, which are chosen

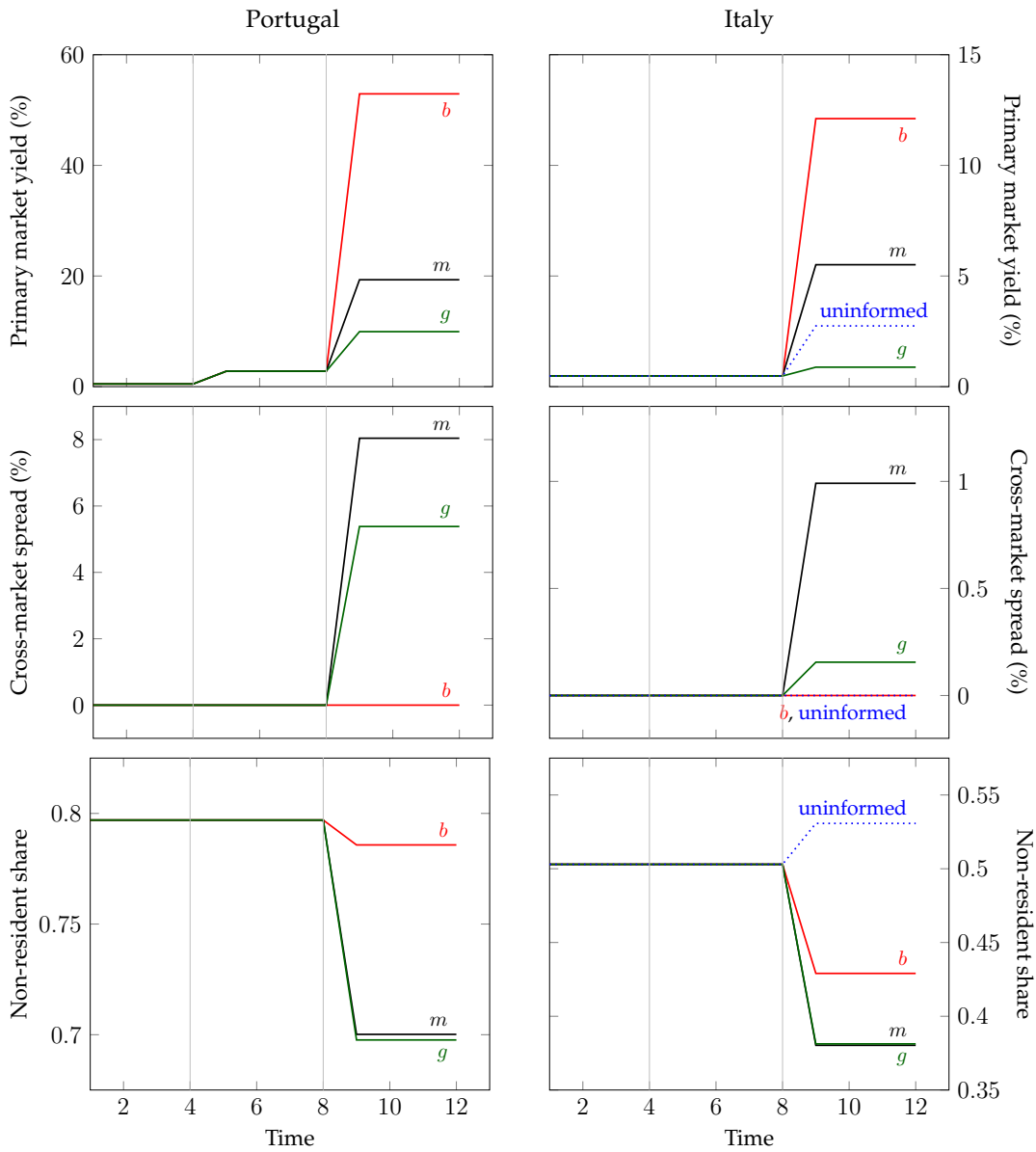


Figure 10: Portugal-Italy event study: primary market yields, the primary-secondary market spread, and non-resident shares for all quality shocks.

to match non-resident shares in the tranquil period prior to the crisis.<sup>11</sup> We conduct a similar information acquisition exercise before: taking as given that no investor acquires information abroad, do German and periphery investors want to acquire information in their countries? Given the *same* cost of domestic information acquisition as in the previous event study, we now find that there is no information regime

<sup>11</sup>As before, all investors choose identical portfolios in Phase 1; hence the periphery non-resident share is  $(n_F + n_G)/n_P$  in the initial phase.

spillover: while the shock to the periphery induces information acquisition there, tranquil fundamentals in Germany are sufficient to ensure the uninformed equilibrium there. These choices are summarized in Table 7.

Table 7: Optimal information acquisition in the core-periphery simulation.

Investor type	Phase 1	Phase 2	Phase 3
Periphery	Uninformed.	Uninformed	<b>Informed in Periphery</b>
German	Uninformed	Uninformed	Uninformed
Foreign	Uninformed	Uninformed	Uninformed

Figure 11 shows the resulting outcomes in solid lines, and a counterfactual with information acquisition in Germany in dashed lines. As before, vertical lines indicate transition across the three phases.

The behavior of the periphery is similar to the first event study. Yields rise as the periphery enters the alarming regime in Phase 2, but volatility and the cross-market spread remain muted because there is no information acquisition. This changes in Phase 3, where the additional increase in fundamental risk leads to information acquisition. Yields are now highly sensitive to fundamentals, and the auction price reveals the state. Hence auction prices contain information about subsequent secondary market prices, and there is a cross-market spread that allows informed investors to earn rents at auction. Finally, the winner’s curse induces a sharp fall in non-resident share as uninformed investors pull back out of fear of overpaying at auction.

The key difference is in the behavior of Germany: since it did not experience a shock to its own fundamentals, the shock in the periphery is *not* enough to trigger a spillover of the information regime. Hence yields and yield volatility remain low, and auction prices do not reveal any additional information because no one is informed. Accordingly, auction prices do not predict subsequent secondary market prices, and there is no cross-market spread. In fact, yields fall slightly because the lack of winner’s curse means Germany can serve as a “safe haven” for non-resident investors. Accordingly, its non-resident share actually *increases* during Phase 3.

Our counterfactuals reveal that these effects are driven almost entirely by lack of informational spillovers. Had there been information acquisition in Germany, average yields and yield volatility would have risen and the non-resident share would have *fallen*.

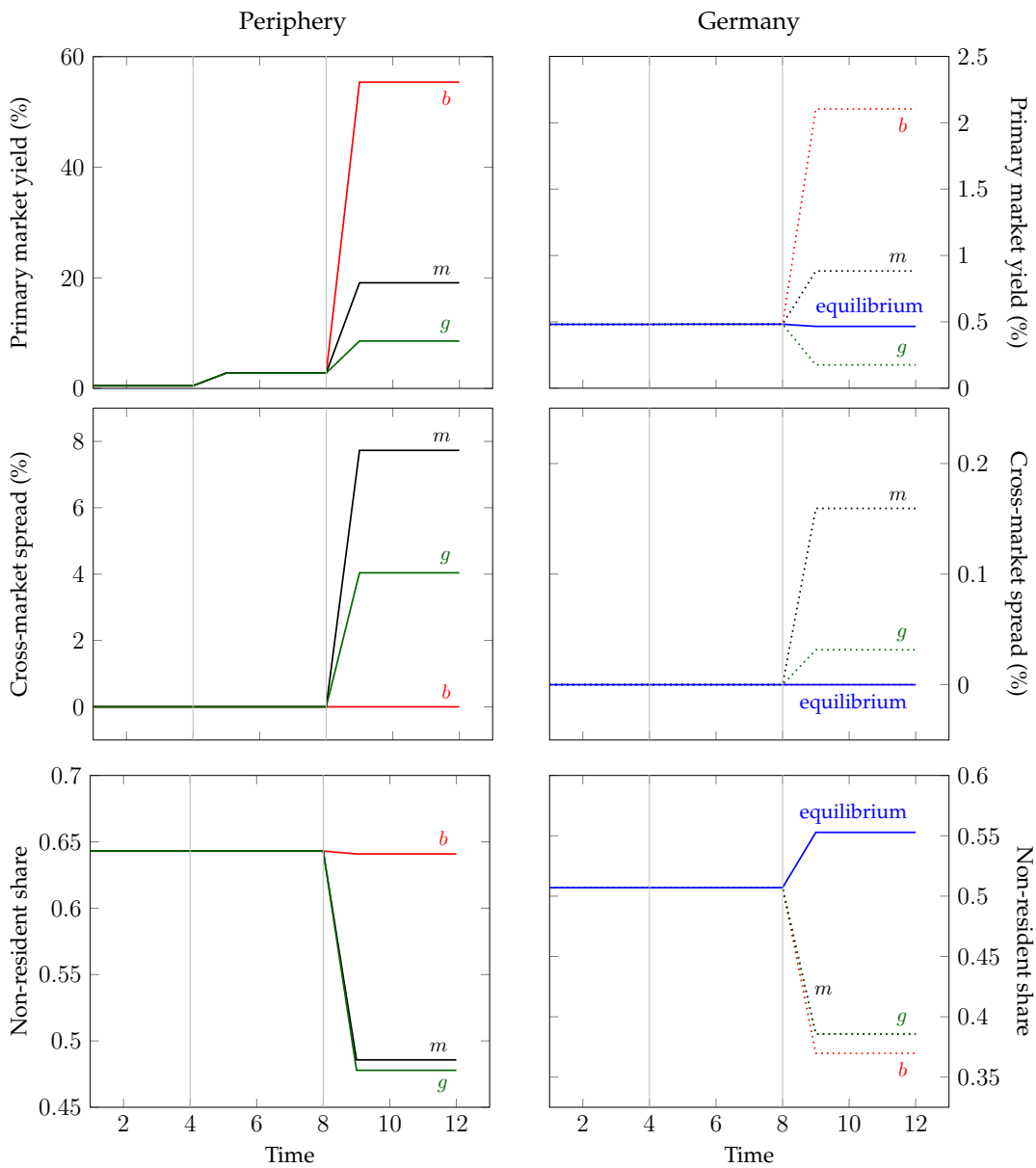


Figure 11: Periphery-Germany event study: primary market yields, the primary-secondary market spread, and non-resident shares for all quality shocks.

## 6 Conclusion

This paper constructs a simple model of portfolio choice with information acquisition by an international pool of risk-averse investors who can buy sovereign debt issued by a number of different countries in primary markets, and traded later in secondary markets. There are three novelties in our approach. First, we allow for endogenous asymmetric information about fundamental default risk. Second, we focus on pri-

mary markets and the role of commonly-used discriminatory price protocols in determining the equilibrium degree of information asymmetry and its impact on yields and spillovers. Third, we explore the implications of secondary markets, and their interaction with primary markets and asymmetric information.

The auction protocol generates information rents that can induce sudden switches in the degree of asymmetric information in response to fundamental shocks. We show that this leads to a theory of yield shocks that also speaks to evidence of retrenchment in capital flows during sovereign bond crises. Our multi-unit auction with risk-averse investors give rise to rich interactions with secondary markets. Specifically, the ability to offload default risk boosts the value of information at auction and induces an arbitrage spread between primary and secondary markets. This spread can be used to detect the presence of asymmetric information at auction even absent bidding data.

We apply our model to the recent Eurozone sovereign debt crisis and show that it can rationalize the key facts from that episode, which include yield contagion among the periphery, falling yields in the core, a pullback of foreign ownership of periphery bonds but an increase in foreign ownership of core bonds, and a wider spread between auction and secondary market.

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# A Appendix: Proofs

## A.1 Proof of Proposition 1

The stated conditions for optimal bids are the first-order conditions from the decision problem. Given the convexity of constraints and the strict concavity of the objective function, first-order conditions are necessary and sufficient for optimality. By investors' risk aversion,  $P_j(\theta_j) < 1 - \kappa_j(\theta_j)$  whenever there are informed investors in  $j$ , and  $P_j(g) = P_j(b) < 1 - \bar{\kappa}_j$  if there no informed investors. Hence bonds offer a strictly positive risk premium when bidding at the state-contingent price.

*Statement (i):* If no investor is informed, no bid can be contingent on the state. Since it is never optimal to bid at prices above the marginal price, the marginal price in each state must be the same. When there is no symmetric information, all investors face the same gamble with positive excess returns. Since default risk is uncorrelated across countries, the first-order condition holds with equality.

*Statement (ii):* Assume for a contradiction that  $P_j(g) = P_j(b)$ . Since all uninformed bids are accepted in every state and informed bids are accepted contingent on the state, market-clearing then implies that informed investors must bid the same in both states. This is inconsistent with bid optimality given  $\kappa_j(g) < \kappa_j(b)$ .

It is trivial that informed investors must bid in every state, and that, due to the winner's curse, the short-sale constraint may bind for uninformed investors in the good state. It remains to be shown that uninformed investors' short-sale constraint never binds in the bad state (that is, uninformed investors always bid at the low price). Suppose first that the uninformed do not bid at the high price. Then  $m_j^i(b, 1) = m_j^i(b, 0)$  if  $B_j^i(b) = 0$  for some uninformed type  $i$ , which implies that it is strictly optimal to bid a positive amount because the bond offers a strictly positive risk premium. Next, assume that the uninformed do bid at the high price. For a contradiction, let  $B_j^i(b) = 0$ . Then  $m_j^i(g, \delta_j) = m_j^i(b, \delta_j)$  since bids at the high price are accepted in all states. The first-order condition for bids at the high price is

$$-\bar{\kappa}_j m_j^i(g, 1) + (1 - \bar{\kappa}_j) m_j^i(g, 0) y_j(g) = 0. \quad (4)$$

By the first-order condition for bids at the low price, it is strictly optimal for an uninformed investor to bid at  $P_j(b)$  if and only if

$$-\kappa_j(b) m_j^i(g, 1) + (1 - \kappa_j(b)) m_j^i(g, 0) y_j(0) > 0.$$

Combining these conditions shows that bidding at  $P_j(b)$  is strictly optimal if

$$\frac{1 - \kappa_j(b)}{\kappa_j(b)} y_j(b) > \frac{1 - \bar{\kappa}_j}{\bar{\kappa}_j} y_j(g).$$

From the first-order conditions of some informed type  $t$  we have

$$\frac{m_j^t(g, 1)}{m_j^t(g, 0)} = \frac{(1 - \kappa_j(g))}{\kappa_j(g)} y_j(g) \quad \text{and} \quad \frac{m_j^t(b, 1)}{m_j^t(b, 0)} = \frac{(1 - \kappa_j(b))}{\kappa_j(b)} y_j(b).$$

If the uninformed do not bid at the low price, the auction can clear only if informed expenditures are the same in both states. This implies  $m_j^t(g, 1) = m_j^t(b, 1)$ , i.e. marginal utility after default is invariant in the state. Since  $\kappa_j(b) > \kappa_j(g)$ , the convexity of marginal utility implies that  $m^t(b, 0) < m^t(g, 0)$ . Hence

$$\frac{m_j^t(b, 1)}{m_j^t(b, 0)} > \frac{m_j^t(g, 1)}{m_j^t(g, 0)} \Rightarrow \frac{(1 - \kappa_j(b))}{\kappa_j(b)} y_j(b) > \frac{(1 - \kappa_j(g))}{\kappa_j(g)} y_j(g) > \frac{(1 - \bar{\kappa}_j)}{\bar{\kappa}_j} y_j(g).$$

*Statement (iii):* Because of the power function form for utility,

$$m_j^i(\theta_j, \delta_j) = \mathbb{E}^i \left[ u'(W) u'(\tilde{c}^i(\vec{\theta}, \vec{\delta})) \middle| \theta_j, \delta_j \right],$$

where  $\tilde{c}^i \equiv \frac{c^i}{W}$  is consumption per unit of wealth. Hence  $M_j^i(\theta_j)$  is independent of  $W$ , which implies that optimal portfolio shares are also independent of  $W$ .

Assuming the standard CRRA power function  $u(c) = \frac{c^{1-\gamma}}{1-\gamma}$ , where  $\gamma$  is the coefficient of risk aversion, the payoff from the portfolio problem then takes the form  $V^i = (1 - \gamma)u(W)\mathbb{E}^i \left[ u(\tilde{c}^i(\vec{\theta}, \vec{\delta}, \mathcal{S}^i)) \right]$ . Thus, the utility difference between an informed vs. an uninformed investors is given by

$$(1-\gamma)u(W)[V^I - V^U] - K = (1-\gamma)u(W) \left[ \mathbb{E}^i \left[ u(\tilde{c}^I(\vec{\theta}, \vec{\delta}, \mathcal{S}^I)) \right] - \mathbb{E}^U \left[ u(\tilde{c}^U(\vec{\theta}, \vec{\delta}, \mathcal{S}^U)) \right] \right] - K$$

where  $K$  is the utility cost of being informed. **Q.E.D.**

## A.2 Proof of Proposition 2

*Statement (i):* Let  $B_2$  denote investors' bids in Country 2 given marginal price  $P_2$ , both of which are assumed to be fixed. We show that informed investors spend strictly more than uninformed investors in the high state and weakly less in the bad state. This implies that an increase in  $n_1$  leads to a strict increase in  $P_1(g)$ .

Assume first that uninformed investors submit bids in all states, so that all first-order conditions for optimal bids hold with equality. We show that  $P_1(b)B_1^I(b) < P_1(g)B_1^U(g) + P_1(b)B_1^U(b)$ . For a contradiction, suppose not. Then for any  $\tilde{W} \in \{W - P_2B_2, W + (1 - P_2B_2)\}$ , marginal utility after default satisfies

$$P_1(b)\kappa_1(b)u'(\tilde{W} - P_1(b)B_1^I(b)) \geq P_1(b)\kappa_1(b)u'(\tilde{W} - P_1(g)B_1^I(g) - P_1(b)B_1^U(b)).$$

First-order conditions for bids at  $P_1(b)$  then imply that, for any  $\tilde{W} \in \{W - P_2B_2, W + (1 - P_2B_2)\}$ , marginal utility after repayment satisfies

$$u'(\tilde{W} + (1 - P_1(b))B_1^I(b)) \geq u'(\tilde{W} + (1 - P_1(g))B_1^U(g) + (1 - P_1(b))B_1^U(b)).$$

By the concavity of  $u(\cdot)$ , we have

$$B_1^I(b) - (B_1^U(g) + B_1^U(b)) \leq P_1(b)B_1^I(b) - (P_1(g)B_1^U(g) + P_1(b)B_1^U(b)).$$

We have assumed for a contradiction that  $P_1(b)B_1^I(b) \geq P_1(g)B_1^U(g) + P_1(b)B_1^U(b)$ . Moreover,  $P_1(b) < 1$  by investors' risk aversion. Hence the right-hand side of the preceding inequality satisfies

$$P_1(b)B_1^I(b) - (P_1(g)B_1^U(g) + P_1(b)B_1^U(b)) < B_1^I(b) - \left(\frac{P_1(g)}{P_1(b)}B_1^U(g) + B_1^U(b)\right).$$

Since  $P_1(g) \geq P_1(b)$ , the contradiction obtains.

Next, we show that informed investors spend more than uninformed investors in the good state,  $P_1(g)B_1^I(g) > P_1(g)B_1^U(g)$ . For any fixed repayment or default decision in Country 2 and associated risk-free holdings  $\tilde{W} \in \{W - P_2B_2, W + (1 - P_2B_2)\}$ , uninformed investors' first-order condition for bids at  $P_1(g)$  can be written as

$$\begin{aligned} & f_1(b) \left[ P_1(g)\kappa_1(b)u'(\tilde{W} - P_1(g)B_1^U(g) - P_1(b)B_1^U(b)) \dots \right. \\ & \left. - (1 - P_1(g))(1 - \kappa_1(b))u'(\tilde{W} + (1 - P_1(g))B_1^U(g) + (1 - P_1(b))B_1^U(b)) \right] \\ & = f_1(g) \left[ (1 - P_1(g))(1 - \kappa_1(g))u'(\tilde{W}(1 - P_1(g))B_1^U(g)) - P_1(g)\kappa_1(g)u'(\tilde{W} - P_1(g)B_1^U(g)) \right]. \end{aligned}$$

Since  $P_1(g) \geq P_1(b)$ , the first-order condition for bids at  $P_1(b)$  implies that the left-hand side is positive. This implies

$$\frac{(1 - \kappa_1(g))u'(\tilde{W} + (1 - P_1(g))B_1^U(g))}{\kappa_1(g)u'(\tilde{W} - P_1(g)B_1^U(g))} > \frac{P_1(g)}{(1 - P_1(g))}.$$

Comparing with informed investors' FOC for bids at  $P_1(g)$  implies the result.

Lastly, assume that the short-sale constraint binds for uninformed bids at  $P_1(g)$ . Then uninformed investors' decision problem for bids at  $P_1(b)$  is identical to that of informed investors (else the only difference is that the uninformed know bids at  $P_1(g)$  are also going to be accepted). Hence they choose the same bidding strategy at  $P_1(b)$ .

*Statement (ii):* We show that  $P_1(b) < \bar{P}_1$  for all  $n_1 > 0$ . Suppose for a contradiction that  $P_1(b) \geq \bar{P}_1$ . By definition,  $\bar{P}_1$  is the price at which uninformed investors are willing to spend  $D_1$  on bonds given that the acquired bonds default with probability

$\bar{\kappa}_1$ . Recall also that  $P_1(g) \geq P_1(b)$ . Hence if  $P_1(b) \geq \bar{P}_1$ , first-order conditions for bid optimality imply that  $X_1^U(b) = P_1(g)B_1^U(g) + P_1(b)B_1^U(b) < D_1$ . The first statement of this proposition showed that  $X_1^U(g) \leq X_1^U(b)$ . Hence  $n_1 X_1^I(b) + (1 - n_1)X_1^U(b) < D_1$ , a contradiction with the market-clearing condition.

Now consider the limit as  $n_1 \rightarrow 0$ . By Proposition 1, uninformed investors must always bid at the low price (that, is their first-order condition must hold with equality.) To clear the market in the high state when as the share of informed investors shrinks to zero, it must be that  $\lim_{n_1 \rightarrow 0} P_1(g)B_1^U(g) = D_1$ . Since uninformed bids at the high price are also accepted in the bad state, we must have that  $\lim_{n_1 \rightarrow 0} P_1(g)B_1^U(g) = 0$ . Since the price must be bounded away from zero, this implies  $\lim_{n_1 \rightarrow 0} B_1^U(g) = 0$  and so  $m_j^i(g, \delta_j) = m_j^i(b, \delta_j)$  in the limit. First-order optimality for bids at the high price requires

$$\bar{\kappa}_j m_j^i(g, 1) + (1 - \bar{\kappa}_j) m_j^i(g, 0) y_j(g) = 0,$$

while the analogue condition for bids at the low price is

$$\kappa_j(b) m_j^i(g, 1) + (1 - \kappa_j(b)) m_j^i(g, 0) y_j(b) = 0,$$

Since  $\kappa_j(b) > \bar{\kappa}_j$ , these conditions jointly hold only if  $y_j(b) > y_j(g)$ . **Q.E.D.**

### A.3 Proof of Proposition 3

In the uninformed equilibrium, prices are invariant to the state,  $P_1(g) = P_1(b) = \bar{P}_1$ . Let  $\bar{B}_1 = D_1/\bar{P}_1$  denote the equilibrium bids of uninformed investors in the uninformed equilibrium. Proposition 2 shows that the informed equilibrium satisfies  $\lim_{n_1 \rightarrow 0} P_1(g) = \bar{P}_1$ ,  $\lim_{n_1 \rightarrow 0} P_1(b) < \bar{P}_1$ ,  $\lim_{n_1 \rightarrow 0} P_1(b) < \bar{P}_1$ ,  $\lim_{n_1 \rightarrow 0} B_1^U(g) = \bar{B}_1$  and  $\lim_{n_1 \rightarrow 0} B_1^U(b) = 0$ . Hence in the limit as  $n_1 \rightarrow 0$ , uninformed investors purchase bonds only at  $P_1(g)$  and obtain the same utility as in the uninformed equilibrium. Hence we must show that informed investors do strictly better in the limit of the informed equilibrium as  $n_1 \rightarrow 0$ . By the fact that  $\lim_{n_1 \rightarrow 0} P_1(g) = \bar{P}_1$ , informed investors face the same decision problem (and obtain the same utility advantage over uninformed investors) in the good state. In the bad state, informed investors face a strictly lower marginal price in the limit of the uninformed equilibrium than in the uninformed equilibrium. Hence they are strictly better in the informed equilibrium if and only if the short-sale constraint does not bind at  $P_1^0(b) \equiv \lim_{n_1 \rightarrow 0} P_1(b)$ . We now show that this constraint does not bind. Recall that  $P_1^0(b)$  is such that uninformed investors are willing to purchase a vanishingly small number of bonds in a neighborhood around  $n_1 = 0$ . This requires  $P_1(b) < 1 - \kappa_1(b)$ . Since informed investors can make state-contingent bids and hold only uncorrelated risks in Country 2, it is strictly optimal to purchase bonds at  $P_1^0(b)$ .

The previous arguments have shown that  $\Delta \bar{V} < \lim_{n_1 \rightarrow 0} \Delta V(n_1)$ , and we can find a cost of information such that it is strictly sub-optimal to acquire information if no other investor does so, but strictly optimal to acquire information if some other

investors do so as well. Since  $K$  is the cost of acquiring information, it is trivial that the share of informed investors in any equilibrium with endogenous information acquisition is weakly increasing in  $K$ . **Q.E.D.**

#### A.4 Proof of Proposition 4

We first show that there is no contagion given CARA. WLOG, consider a representative uninformed investor and drop superscripts indicating types. By market-clearing,  $B_j = \frac{D_j}{P_j}$  for  $j$ , and risk-free holdings satisfy  $w = W - D_1 - D_2$ . The consumption profile given default decisions  $\delta_1$  and  $\delta_2$  is

$$c(\delta_1, \delta_2) = w + (1 - \delta_1)B_1 + (1 - \delta_2)B_2.$$

Expected marginal utility conditional on  $\delta_j$  is

$$m_j(\delta_j) = \bar{\kappa}_{-j}u'(w + (1 - \delta_j)B_j) + (1 - \bar{\kappa}_{-j})u'(w + (1 - \delta_j)B_j + B_{-j})$$

First-order conditions for bids in Country 1 and Country 2 are, respectively,

$$(1 - \bar{\kappa}_1)(1 - P_1)m_1(0) - \bar{\kappa}_1P_1m_1(1) = 0 \quad (5)$$

$$(1 - \bar{\kappa}_2)(1 - P_2)m_2(0) - \bar{\kappa}_2P_2m_2(1) = 0. \quad (6)$$

Let  $y_j \equiv (1 - P_j)/P_j$  denote  $j$ 's yield and redefine the appropriate ratio of marginal utilities (or ratio of state prices) as  $M_j = \frac{\kappa_j}{1 - \kappa_j} \widetilde{M}_j$ , with

$$\begin{aligned} \widetilde{M}_j &\equiv \frac{m_j(1)}{m_j(0)} = \frac{\bar{\kappa}_{-j}u'(w) + (1 - \bar{\kappa}_{-j})u'(w + B_{-j})}{\bar{\kappa}_{-j}u'(w + B_j) + (1 - \bar{\kappa}_{-j})u'(w + B_j + B_{-j})} \\ &= \frac{u'(w + B_{-j})}{u'(w + B_j + B_{-j})} \frac{1 + \bar{\kappa}_{-j} \left[ \frac{u'(w)}{u'(w + B_{-j})} - 1 \right]}{1 + \bar{\kappa}_{-j} \left[ \frac{u'(w + B_j)}{u'(w + B_j + B_{-j})} - 1 \right]} \end{aligned}$$

If preferences satisfy CARA, then  $u'(c) = \gamma e^{-\gamma c}$  and the second term of the previous line is equal to one for any default probabilities and debt levels. Hence

$$\widetilde{M}_j = e^{\gamma B_j}$$

Given this result, we can express the pricing equation for each country as

$$\frac{1 - P_j}{P_j} = \frac{\bar{\kappa}_j}{1 - \bar{\kappa}_j} e^{\gamma \frac{D_j}{P_j}}$$

which is independent of country  $-j$ .

Now return to the general case and write  $F_j = y_j - \frac{\kappa_j}{1-\kappa_j} \widetilde{M}_j$ . Then

$$\frac{\partial F_j}{\partial \bar{\kappa}_{-j}} = -\frac{\bar{\kappa}_j}{1-\bar{\kappa}_j} \frac{\partial \widetilde{M}_j}{\partial \bar{\kappa}_{-j}}.$$

Hence the sign is the opposite of the sign of  $\frac{\partial \widetilde{M}_j}{\partial \bar{\kappa}_{-j}}$ . We will show that that the latter is strictly positive if and only if preferences satisfy DARA. Hence  $\frac{\partial F_j}{\partial \bar{\kappa}_{-j}} < 0$ . Differentiating  $\widetilde{M}_j$  with respect to  $\bar{\kappa}_{-j}$  yields

$$\frac{\partial \widetilde{M}_j}{\partial \bar{\kappa}_{-j}} = \frac{\left( u'(w) - u'(w + B_{-j}) \right) - \left( u'(w + B_j) - u'(w + B_j + B_{-j}) \right) \widetilde{M}_j}{m_j(0)}$$

Observe that

$$\frac{\partial \widetilde{M}_j}{\partial \bar{\kappa}_{-j}} > 0 \Leftrightarrow \frac{\left( u'(w) - u'(w + B_{-j}) \right)}{\left( u'(w + B_j) - u'(w + B_j + B_{-j}) \right)} > \widetilde{M}_j.$$

After some algebra, this condition can be rewritten as

$$\frac{\partial \widetilde{M}_j}{\partial \bar{\kappa}_{-j}} > 0 \Leftrightarrow \frac{u'(w) - u'(w + B_{-j})}{u'(w + B_{-j})} > \frac{u'(w + B_j) - u'(w + B_j + B_{-j})}{u'(w + B_j + B_{-j})}$$

We now show this holds if  $u$  satisfies decreasing absolute risk aversion (DARA). Let

$$\Omega = \frac{u'(\tilde{W}) - u'(\tilde{W} + B)}{u'(\tilde{W} + B)}.$$

Then the claim is equivalent to  $\Omega$  strictly decreasing in  $\tilde{W}$  for any  $B, \tilde{W} > 0$ . This holds by definition of DARA since

$$\frac{\partial \Omega}{\partial \tilde{W}} < 0 \Leftrightarrow \frac{-u''(\tilde{W})}{u'(\tilde{W})} > \frac{-u''(\tilde{W} + B)}{u'(\tilde{W} + B)}.$$

**Q.E.D.**

## A.5 Proof of Lemma 1

The return of a Country-1 bond bought at the high price (in state  $g$ ) in case of default is  $-1$  (with expected probability  $\kappa_1^i(g)$ ) and in case of repayment  $\frac{1-P_1(g)}{P_1(g)}$  (with expected probability  $1 - \kappa_1^i(g)$ ). This implies that the expected return of such bond is  $\widehat{R}_1^i(g) =$

$\frac{1-\kappa_1^i(g)-P_1(g)}{P_1(g)}$  and the standard deviation is  $\widehat{\sigma}_1^i = \frac{\sqrt{\kappa_1^i(g)(1-\kappa_1^i(g))}}{P_1(g)}$ . Since  $\kappa_1^I(g) = \kappa_1(g)$  and  $\kappa_1^U(g) = \bar{\kappa}_1$ , the difference in Sharpe ratios can be written as

$$S_1^I(g) - S_1^U(g) = \frac{1 - \kappa_1(g)}{\sqrt{\kappa_1(g)(1 - \kappa_1(g))}} - \frac{1 - \bar{\kappa}_1}{\sqrt{\bar{\kappa}_1(1 - \bar{\kappa}_1)}} - P_1(g) \left( \frac{1}{\sqrt{\kappa_1(g)(1 - \kappa_1(g))}} - \frac{1}{\sqrt{\bar{\kappa}_1(1 - \bar{\kappa}_1)}} \right)$$

If  $\bar{\kappa}_1 < \frac{1}{2}$ , then  $S_1^I(g) - S_1^U(g) > 0$  and strictly decreasing in  $P_1(g)$ . **Q.E.D.**

## A.6 Proof of Proposition 5

Let  $n_1 \in (0, 1)$ . There are 8 possible states: for each  $\theta_j \in \{g, b\}$ , each country may default ( $d$ ) or repay ( $r$ ). Since there is no information in Country 2, we can proceed as if there were only one state with default probability  $\bar{\kappa}_2$ . Simplify notation by writing state-contingent consumption as  $\{c_{rr}^i(\theta), c_{rd}^i(\theta), c_{dr}^i(\theta), c_{dd}^i(\theta)\}$ . Then  $i$ 's objective function can be written as

$$V^i = f_1(g) \left\{ \begin{array}{l} \kappa_1(g) \left[ \bar{\kappa}_2 U(c_{dd}^i(g)) + (1 - \bar{\kappa}_2) U(c_{dr}^i(g)) \right] \\ + (1 - \kappa_1(g)) \left[ \bar{\kappa}_2 U(c_{rd}^i(g)) + (1 - \bar{\kappa}_2) U(c_{rr}^i(g)) \right] \end{array} \right\} \\ + f_1(b) \left\{ \begin{array}{l} \kappa_1(b) \left[ \bar{\kappa}_2 U(c_{dd}^b) + (1 - \bar{\kappa}_2) U(c_{dr}^b) \right] \\ + (1 - \kappa_1(b)) \left[ \bar{\kappa}_2 U(c_{rd}^b) + (1 - \bar{\kappa}_2) U(c_{rr}^b) \right] \end{array} \right\}$$

We compute a second-order Taylor approximation of the objective function around  $B_j^i(\theta_j) = 0$  for all  $i$ , all  $j$ , and all  $\theta_j$ . For informed investors, the associated first-order conditions with respect to  $B_1^i(g)$ ,  $B_1^i(b)$  and  $B_2^i$  are, respectively,

$$0 = f_1(g)(1 - \kappa_1(g) - P_1(g))U'(W) \\ + f_1(g) \left[ \kappa_1(g)(-P_1(g))^2 + (1 - \kappa_1(g))(1 - P_1(g))^2 \right] U''(W) B_1^I(g) \\ + f_1(g)(1 - \kappa_1(g) - P_1(g))(1 - \bar{\kappa}_2 - P_2)U''(W) B_2^I \quad (7)$$

$$0 = f_1(b)(1 - \kappa_1(b) - P_1(b))U'(W) \\ + f_1(b) \left[ \kappa_1(b)(-P_1(b))^2 + (1 - \kappa_1(b))(1 - P_1(b))^2 \right] U''(W) B_1^I(b) \\ + f_1(b)(1 - \kappa_1(b) - P_1(b))(1 - \bar{\kappa}_2 - P_2)U''(W) B_2^I \quad (8)$$

$$\begin{aligned}
0 = & (1 - \bar{\kappa}_2 - P_2)U'(W) \\
& + \left[ \bar{\kappa}_2(-P_2)^2 + (1 - \bar{\kappa}_2)(1 - P_2)^2 \right] U''(W)B_2^I \\
& + f_1(g)(1 - \bar{\kappa}_2 - P_2)(1 - \kappa_1(g) - P_1(g))U''(W)B_1^I(g) \\
& + f_1(b)(1 - \bar{\kappa}_2 - P_2)(1 - \kappa_1(b) - P_1(b))U''(W)B_1^I(b)
\end{aligned} \tag{9}$$

Define informed expected rates of return by  $\tilde{r}_1^I(g) = \frac{1 - \kappa_1(g) - P_1(g)}{P_1(g)}$ ,  $\tilde{r}_1^I(b) = \frac{1 - \kappa_1(b) - P_1(b)}{P_1(b)}$  and  $\tilde{r}_2^I = \frac{1 - \bar{\kappa}_2 - P_2}{P_2}$  and let  $\sigma_1^I(g)$ ,  $\sigma_1^I(b)$ , and  $\sigma_2^I$  denote the associated standard deviations. The first term of the RHS of (7) can be rewritten in terms of returns as

$$f_1(g)(1 - \kappa_1(g) - P_1(g))U'(W) = f_1(g)\tilde{r}_1(g)P_1(g)U'(W)$$

and the second term as

$$f_1(g) \left[ \kappa_1(g)(-P_1(g))^2 + (1 - \kappa_1(g))(1 - P_1(g))^2 \right] U''(W)B_1^I(g) = f_1(g)\mathbb{E} \left[ (r_1^I(g))^2 \right] P_1(g)^2 U''(W)B_1^I(g)$$

All other terms in equations (7)-(9) can be analogously rewritten. Let  $U(c) = \frac{c^{1-\gamma}-1}{1-\gamma}$ , and define the state-contingent portfolio weights  $\omega_1^I(g) = \frac{P_1(g)B_1^I(g)}{W}$ ,  $\omega_1^I(b) = \frac{P_1(b)B_1^I(b)}{W}$ , and  $\omega_2^I = \frac{P_2B_2^I}{W}$ . Since  $Var(x) = \mathbb{E}[x^2] - (\mathbb{E}[x])^2$ , the system of equations is

$$\tilde{r}_1^I(g) = \gamma\omega_1^I(g) \left( (\sigma_1^I(g))^2 + (\tilde{r}_1^I(g))^2 \right) + \gamma\omega_2^I (\tilde{r}_1^I(g)\tilde{r}_2^I) \tag{10}$$

$$\tilde{r}_1^I(b) = \gamma\omega_1^I(b) \left( (\sigma_1^I(b))^2 + (\tilde{r}_1^I(b))^2 \right) + \gamma\omega_2^I (\tilde{r}_1^I(b)\tilde{r}_2^I) \tag{11}$$

$$\tilde{r}_2^I = \gamma\omega_2^I \left( (\sigma_2^I)^2 + (\tilde{r}_2^I)^2 \right) + f_1(g)\gamma\omega_1^I(g)\tilde{r}_1^I(g)\tilde{r}_2^I + f_1(b)\gamma\omega_1^I(b)\tilde{r}_1^I(b)\tilde{r}_2^I \tag{12}$$

Optimality conditions for uninformed investors are analogous, modulo adjusting expected returns and standard deviations to take into account that bids  $P_1(g)$  are also accepted in the bad state. To facilitate comparisons of optimal portfolios, going forward we denote expected returns for a given information set simply by  $R_g$ ,  $R_b$  and  $R_2$ . Let  $\sigma_g$ ,  $\sigma_b$ , and  $\sigma_2$  denote the associated standard deviations, and  $S_g$ ,  $S_b$  and  $S_2$  the Sharpe ratios. Optimal portfolios then satisfy the following system of equations, with the only differences across types accounted for by differences in expected returns and volatility:

$$\begin{aligned}
\omega_g &= \left( \frac{R_g}{\sigma_g^2 + R_g^2} \right) (1 - \omega_2 R_2) \\
\omega_b &= \left( \frac{R_b}{\sigma_b^2 + R_b^2} \right) (1 - \omega_2 R_2) \\
\omega_2 &= \left( \frac{R_2}{\sigma_2^2 + R_2^2} \right) (1 - f_1(g)\omega_g R_g - f_1(b)\omega_b R_b)
\end{aligned}$$



Multiplying by  $R_i(1/\sigma_i^2)$ , dividing by  $(1/\sigma_i^2)$  and defining  $s = \frac{S^2}{1+S^2}$ , which is strictly increasing in  $S$ , we can rewrite these expressions as

$$\begin{aligned} R_g \omega_g &= s_g (1 - R_2 \omega_2) \\ R_b \omega_b &= s_b (1 - R_2 \omega_2) \\ R_2 \omega_2 &= s_2 (1 - f_1(g) R_g \omega_g - f_1(b) R_b \omega_b) \end{aligned}$$

Then plug in the first two equations into the third to give:

$$R_2 \omega_2 = s_2 \left( 1 - f_1(g) s_g (1 - R_2 \omega_2) - f_1(b) s_b (1 - R_2 \omega_2) \right)$$

It follows that

$$\begin{aligned} \omega_2 &= \frac{1}{R_2} \left( \frac{1 - f_1(g) s_g - f_1(b) s_b}{\frac{1}{s_2} - f_1(g) s_g - f_1(b) s_b} \right) \\ \omega_g &= \frac{s_g}{R_g} \left( \frac{\frac{1}{s_2} - 1}{\frac{1}{s_2} - f_1(g) s_g - f_1(b) s_b} \right) \\ \omega_b &= \frac{s_b}{R_b} \left( \frac{\frac{1}{s_2} - 1}{\frac{1}{s_2} - f_1(g) s_g - f_1(b) s_b} \right) \end{aligned}$$

Since  $\frac{\partial \omega_g}{\partial S_g} > 0$ , then from Lemma 1,  $\omega_1^I(g) > \omega_1^U(g)$ . Since  $\frac{\partial \omega_2}{\partial S_g} < 0$ , then from Lemma 1,  $\omega_2^I < \omega_2^U$  and  $\frac{\partial(\omega_2^U - \omega_2^I)}{\partial P_1(g)} < 0$ . **Q.E.D.**

## A.7 Proof of Proposition 6

An informed equilibrium exists when the equilibrium value of information exceeds the cost of information. We assume that some investors are informed in a given country (say Country 2), and compute the marginal value of information for an informed investor. Denote the original bidding strategy of the investor by  $\{B_2^0(g), B_2^0(b)\}$ . Recall that these bids are not state-contingent because only informed investors can submit state-contingent bids.

To capture a marginal increase in the benefits of information, consider the following marginal increase in the state-contingency of bids. In every state let the investor take some number  $\epsilon$  of his bids at the price associated with the unrealized state and replace with them with  $\tilde{B}_2(\theta_j)$  bids at the state-contingent price  $P_2(\theta_2)$ , where  $\tilde{B}_2(\theta_j)$  is chosen such that the investor's consumption after repayment remains unchanged. That is, the investor can increase the state-contingency of  $\epsilon$  bids, and does so in a manner that raises payoffs when marginal utility is high (i.e. in the state where the country defaults.)

Given that only bids at the high price are accepted in the goods state, the adjustment leaves consumption unchanged conditional on  $\theta_2 = g$ . In the bad state, consumption is unchanged conditional on repayment by construction. This requires

$$\begin{aligned} & W - P_2(g)(B_2^0(g) - \epsilon) - P_2(b)(B_2^0(b) + \tilde{B}_2(b)) + (B^0(g) - \epsilon) + B(b) \\ &= W - P(g)B^0(g) - P(b)B_2^0(b) + B^0(g) + B_2^0(b). \end{aligned}$$

Letting  $X_2^0(b)$  denote expenditures at the original bidding strategy and  $\tilde{X}_2(b)$  expenditures after the adjustment, we have

$$\tilde{X}_2(b) = X_2^0(b) - \epsilon\Delta_p$$

where  $\Delta_j \equiv P_2(g) - P_2(b)\frac{1-P_2(g)}{1-P_2(b)} > 0$ . This implies that the adjustment leads to lower expenditures because it is cheaper to buy at  $P_2(b)$  than at  $P_2(g)$ . Next, consider the effect on expected utility. By construction, utility *only* changes due to the adjustment if Country 2 is in the bad state, and *only* if the Country defaults. Hence the change in utility depends only on marginal utility in this state of the world. Differentiating utility with respect to  $\epsilon$  around  $\epsilon = 0$  then gives the change in utility  $mv_2(0)$  as

$$mv_2(0) = f_2(b)\kappa_2(b)\Delta_2\mathbf{E}_1u'(W - X_2(b) + (1 - \delta_1)B_1(\theta_1)) > 0.$$

where we take expectations over default and the state of the world in Country 1. The remainder then follows directly.

## A.8 Proof of Proposition 7

*Statement (i):* By auction market-clearing,  $P_j(g) \leq \hat{P}_j(g)$  because all investors would prefer to trade in the secondary market if  $P_j(g) > \hat{P}_j(g)$ .

If  $P_j(g) < \hat{P}_j(g)$ , it is strictly optimal for informed investors to spend all wealth not invested in Country 2 at the auction in Country 1 if  $\theta_1 = g$  and to sell bonds in the secondary market. We now use this observation to construct an equilibrium where this leads to no arbitrage if and only if  $n_1 \geq \hat{n}_1$ . Let  $\hat{P}_1(g)$ ,  $\hat{B}^I(g)$ , and  $B_2^I$  denote the equilibrium good-state price and informed bids in the equilibrium in which all investors are informed and there are no secondary markets. In this equilibrium, informed investors spend  $\hat{P}_2\hat{B}_2^I$  in Country 2. By auction-clearing,  $\hat{P}_2\hat{B}_2^I = D_2$ . By the budget constraint, informed investors have  $W - D_2$  in capital to invest in Country 1. In order for informed buy the entire supply of bonds in Country 1 at price  $\hat{P}_1$  if  $\theta_1 = g$ , we require that  $n_1(W - D_2) \geq \hat{P}_1B_1^I(g) = D_1$ , where the last equality follows from auction clearing. This holds iff  $n_1 \geq \hat{n}_1$ .

By market-clearing in Country 2, there does not exist an equilibrium with no arbitrage in the good state if  $n_1 < \hat{n}_1$ . We now argue that there does exist an equilibrium with arbitrage. Given the winner's curse at auction, uninformed investors prefer to

buy in the secondary market rather than bid at  $P_1(g)$  if  $\hat{P}_j(g) - P_j(g)$  is sufficiently small. Moreover,  $\hat{P}_j(g) - P_j(g)$  is decreasing in the number of uninformed bids submitted at auction relative to the quantity of bonds bought by uninformed investors in the secondary market. Hence there exists an equilibrium with  $P_j(g) < \hat{P}_j(g)$  in which the arbitrage spread is such that uninformed investors are either indifferent to buying in either market or strictly prefer to buy in the secondary market.

Lastly, we show that the arbitrage persists in the limit as the share of informed investors shrinks to zero. In the limit  $n_1 \rightarrow 0$ , almost all investors are ex-ante identical. This implies that there exist essentially zero gains from trade ex-post. By market-clearing, it then follows trivially that auction prices must converge to the limiting prices of the auction-only equilibrium. Now consider the limit of secondary market prices. Suppose for a contradiction that  $\lim_{n_1 \rightarrow 0} \hat{P}_1(g) = \lim_{n_1 \rightarrow 0} P_1(g)$ . Since  $\lim_{n_1 \rightarrow 0} P_1(b) < \lim_{n_1 \rightarrow 0} P_1(g)$ , for  $n_1$  sufficiently small it is strictly optimal for any uninformed investor to submit zero bids at  $P_1(g)$  and purchase bonds only in the secondary market. Since  $n_1 W < D_1$  for  $n_1$  sufficiently small, we have a contradiction with market clearing.

*Statement (ii):* If  $P_j(b) > \hat{P}_j(b)$ , it is strictly optimal to submit zero bids at auction, so the auction cannot clear. Now suppose that  $P_j(b) < \hat{P}_j(b)$  and recall that uninformed bids at  $P_j(b)$  are accepted if and only if  $\theta_j = b$ . Then it is strictly optimal for all investors to buy bonds at the auction and sell in the secondary market. Hence the secondary market cannot clear.

*Statement (iii):* By the first statement, there is no arbitrage if  $n_1 \geq \hat{n}_1$ . But absent arbitrage, the value of information is zero because the uninformed can avoid the winner's curse without paying higher prices in the secondary market.

Next, we show that the value of information is strictly higher in the limit without informed investors. Recall from above that  $\lim_{n_1 \rightarrow 0} \hat{P}_j(\theta_j) = \lim_{n_1 \rightarrow 0} P_j^A(\theta_j)$  and  $\lim_{n_1 \rightarrow 0} \hat{P}_1(g) > \lim_{n_1 \rightarrow 0} P_1(g)$ . That is, the auction prices with secondary markets converge to the auction-only prices as  $n_1 \rightarrow 0$ . By the Inada condition, in the auction-only equilibrium it is strictly optimal to hold a strictly positive final position in the risk-free asset, say  $\tilde{W}$ . When there are secondary markets, the following is a feasible portfolio that generates strictly higher utility than the optimal auction-only portfolio: (1) buy the same portfolio at auction, (2) in addition spend  $\tilde{W}$  on bonds in state  $g$  in Country 1, and (3) sell the additional bonds purchased with  $\tilde{W}$  in the secondary market at a strict profit. This portfolio has higher average returns and lower volatility than the original portfolio, and so it is strictly preferred. Since uninformed investors obtain the same utility as in the auction equilibrium in the limit  $n_1 \rightarrow 0$ , the result follows. **Q.E.D.**

## B Further Background on the Eurozone Crisis

In this section, we provide further background on the European Sovereign Debt Crisis, which lasted several years and involved most Eurozone countries. Its start can be dated to late 2009, when some European countries reported surprisingly high deficit-to-GDP ratios following the global financial crisis of 2008, with Greece being the most dramatic case. Lane identifies three sub-periods of the crisis. In the first phase, Greek yields diverged from the rest of the Eurozone in early 2010, and Greece required official assistance in May 2010. Next, Irish and Portuguese yields decoupled from the remaining countries in 2010 and the first half of 2011. Ireland required a bailout in November 2010 followed by Portugal in May 2011. These events were closely followed by rising yields in Spain and Italy in early 2011. Interestingly, yields of "core" countries such as Germany and France remained low throughout. During the second and third phases of the crisis, Lane also documents that markets became fragmented, in the sense that investors pulled back from foreign countries.

Portugal was among the hardest-hit countries. Moody's downgraded its sovereign bond rating in the summer of 2010, and it obtained a bailout for 78 billion euros from the ECB and the IMF almost a year later. The experience of Italy was quite different. In contrast to Greece, Ireland, Portugal and Spain, Italy was able to keep its 2009 budget deficit in check. It was, however, a very indebted country, second only to Greece in Europe, which raised concerns about its sustainability. Even though Italian bonds were not downgraded based on Italy's fundamentals, there was an increase in oversight by credit rating agencies. As a result, on August of 2011 the ECB announced the possibility of buying Italian bonds to lower borrowing costs. Italian debt ended up downgraded by Standard and Poor's of September 2011, more than a year after Portugal. Germany followed a very different path. German bonds and its fundamentals were never in doubt, not by investors nor credit rating agencies. Indeed, Germany's borrowing costs declined while most other countries' were increasing. As a result Germany took a leading role in managing the crisis.

In sum, Portugal was a country with fundamental solvency problems that were quickly recognized by credit rating agencies, while Germany did not have fundamental problems. Italy was an intermediate case. It did not pose clear fundamental problems: banks were sound, there was no speculation in a housing bubble, the annual budget deficit was low and, while indebtedness was large, and more than half the debt was owned by Italians, making it less vulnerable to foreign investors. Still, Italy raised suspicion given its high overall debt levels, which induced investors to better assess its economic and political prospects. The New York Times reported "As Greece teeters on the brink of a default, the game has changed: Investors are taking aim at any country suffering from a combination of high debt, slow growth and political dysfunction and Italy has it all, in spades."<sup>12</sup> Through the lens of our model, it is thus a case study for information spillovers.

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<sup>12</sup>"Debt Contagion Threatens Italy" New York Times, July 11, 2011.

In the main text, we showed yields for one-year bonds. We now also show them for six-month bonds in Figure 12. While Portuguese yields departed from Italy and Germany in 2009, Italian yields departed from those in Germany, slightly at the beginning of 2010 and then more dramatically when Portugal lost access to markets in April 2011. At that point Italy's borrowing costs increased dramatically, moving in opposite direction than those in Germany. While this pattern is very clear for the one-year maturity, it is also present in the half-year maturity, albeit with higher volatility.

Figure 12: Real Annualized Yields

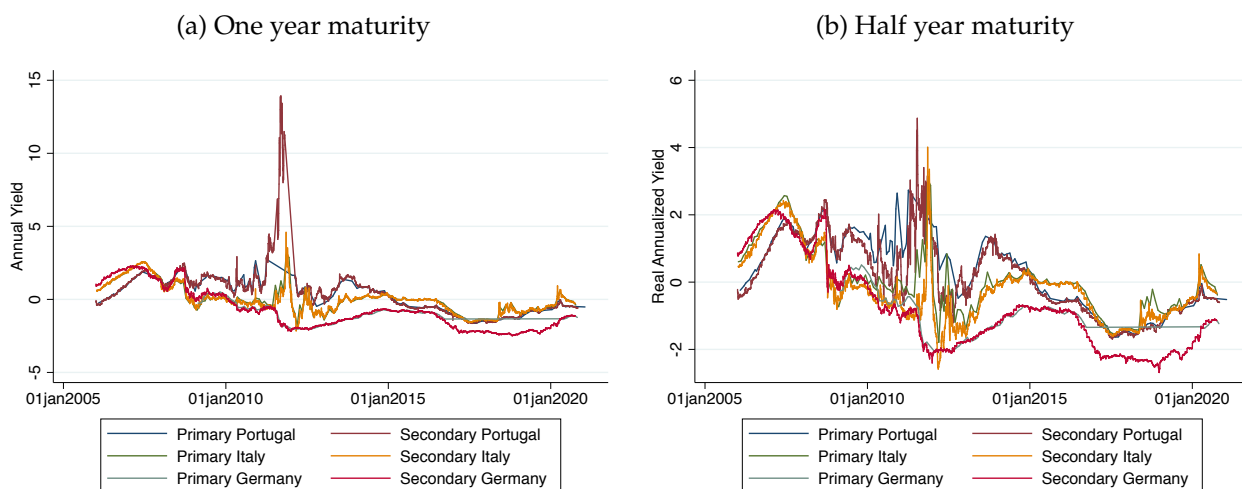
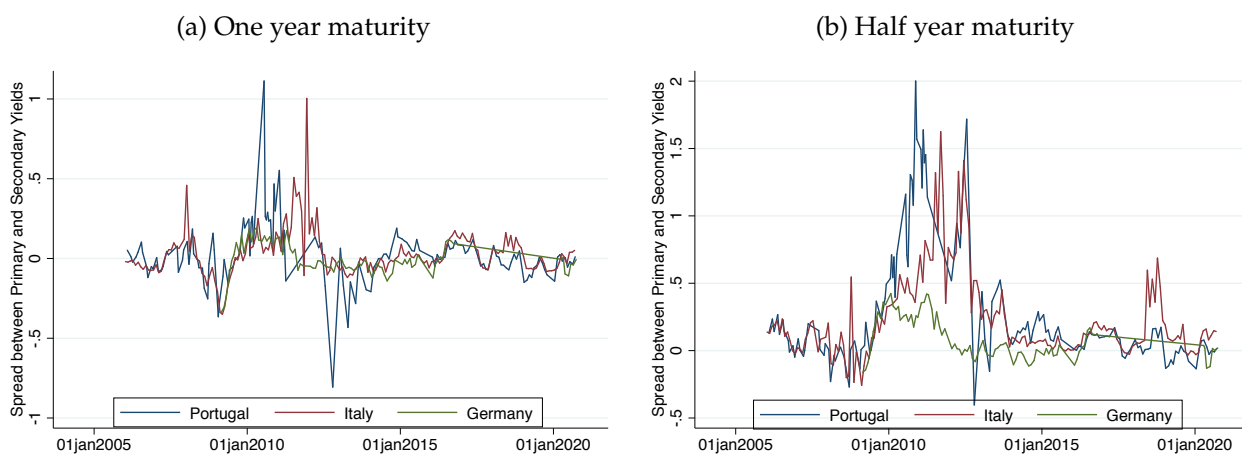


Figure 13 shows the spread between primary and secondary yields for each country and each maturity.

Figure 13: Spreads between primary and secondary yields



## C Details on Primary Market Institutions and Data

Here we present the details and sources of the primary markets data we use in our analysis. We also discuss the institutional details of primary markets in the three countries that we focus on in the main text. To provide a sense of the available data on primary markets, we first provide a brief description of the variables that we have collected and used:

- Auction Date: Date on which the auction is held.
- Maturity Date: Date on which the face value of the bond is paid to the investor.
- Effective Maturity: This variable highlights the distinction between new bond issuance (a new brand instrument is auctioned) and re-openings (a bond previously issued is auctioned). For example, a 9-month bond could be “re-opened” 6 month later. This implies the new issued bond will mature in 3 months, and both bonds will mature the same day. The effective date for the new issued bond will equal 3 months.
- Segment Maturity: In the previous example, this refers to the date of the original issuance. This implies that the segment maturity will equal 9 months for the re-opened 3 month bond. The Segment maturity and the Effective Maturity will be same only for issuances of brand new bonds.
- Issuance Amount: Measured in euros. Total value of bonds auctioned.
- Bidded Amount: Measured in euros. Total value of bids by market participants in the auction. This variable potentially could be larger than the Issuance Amount, in which case the auctioneer creates a rule to allocate the auctioned resources.
- Alloted Amount: Measured in euros. Total value of the bonds effectively sold after the bid process is concluded. Normally if the Bidded Amount is larger than the Issuance Amount, the Alloted amount will equal the Issuance Amount. Otherwise it will equal the Bidded Amount.
- Weighted Average Price/Yield: A weighted average of all alloted (accepted) bids.
- Maximum Average Yield: It is the yield associated with the lowest accepted price .
- Minimum Average Yield: It is the yield associated with the highest accepted price.

In the paper we focus on discount Treasury Bills for Germany, Italy and Portugal. The specific names for the instrument in each country are:

1. **Germany:** Unverzinsliche Schatzanweisungen (Bubills).
2. **Italy:** Buoni Ordinari del Tesoro (BOTs).
3. **Portugal:** Bilhetes do Tesouro (BTs)

Table 8 lists all the relevant variables and their availability for each particular instrument.

Table 8: Primary Market Variables Availability by Country

Variable List - Auction			
Variables / Country	Germany (Bubills)	Italy (BOTs)	Portugal (BTs)
Data Availability	2005-2020	2000-2021	2006-2021
Auction Date	✓	✓	✓
Maturity Date	✓	✓	✓
Effective Maturity	✓	✓	✓
Segment Maturity	✓	✓	✓
Issuance Amount (€)	✓	✓	<i>Incomplete</i>
Bidded Amount (€)	✓	✓	✗
Alloted Amount (€)	✓	✓	✓
Weighted Average Price	✓	✓	✓
Weighted Average Yield	✓	✓	✓
Maximum Average Yield	✓	✓	✓
Minimum Average Yield	✗	✓	✓
Competitive Bids (€)	✓	✗	✓
Non-Competitive Bids (€)	✓	✗	✗
Competitive Allotment (€)	✗	✗	✓
Non-Competitive Allotment (€)	✗	✗	✓

Now we provide specific details about the auction protocol in each country. We provide the main source of information below, which we complement with more general details about participants in European auctions from the “European Primary Dealers Handbook”, published by the Association for Financial Markets in Europe’s (AFME): <https://www.afme.eu>.

## C.1 Germany

Data for Germany was taken from the Federal Republic of Germany's Finance Agency (Bundesrepublik Deutschland Finanzagentur GmbH), which is the central service provider for the Federal Republic of Germany's borrowing and debt management. They provide historical about auction results,<sup>13</sup> and information about the operation and institutional details of auctions.<sup>14</sup> We have complemented some of the information with data from the Bundesbank.<sup>15</sup>

**Description of the Primary Market:** Federal bonds (Bunds), five-year Federal notes (Bobls), Federal Treasury notes (Schätze) and Treasury discount paper (Bubills) are issued through a tender procedure. They differ in their maturity, and interest, among other details. Importantly, the German government issues and taps securities for *all their long-and short-term borrowing via multi-price auctions*. For easy of comparison with other countries, in this paper we focus on short-term treasury discount paper, Bubills. These bonds (normally) have maturities of 6 and 12 months. The auctions for Bubills take place on Mondays with value date on the following Wednesday.

**Participants:** Only members of the Bund Issues Auction Group (Bietergruppe Bundesemissionen) may participate in the auctions directly. Membership is approved by the German Finance Agency on behalf of the German Government. The Auction Group is comprised of credit institutions, securities trading banks and securities trading firms. At the end of each year, the German Finance Agency publishes a ranking list of bidders' maturity-weighted shares in the allotted issue amounts. Members are expected to have a certain minimum placing power, i.e. at least 0.05% of the total maturity-weighted amounts allotted in the auctions in a calendar year<sup>16</sup>. Those member institutions that fail to reach the required minimum share of the total amount allotted are excluded from the Auction Group.

**Bidding Details:** Bids for Federal bonds, five-year Federal notes and Federal Treasury notes and Treasury discount paper must be for a par value of no less than €1 million or an integral multiple thereof and should state the price, as a percentage of the par value, at which the bidders are prepared to purchase. It is possible to make non-competitive bids and to submit several bids at different prices. In accordance to the multiple-price auction, bids which are above the lowest price accepted by the Federal Government will be allotted in full. Bids which are below the lowest accepted price will not be considered. Non-competitive bids are allotted at the weighted av-

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<sup>13</sup><https://www.deutsche-finanzagentur.de/en/institutional-investors/primary-market/auction-results/>

<sup>14</sup><https://www.deutsche-finanzagentur.de/en/institutional-investors/primary-market/auction-results/>

<sup>15</sup><https://www.bundesbank.de/resource/blob/706804/599ea32756aa5d2d8c9493b8a028e886/mL/2007-07-public-sector-debt-data.pdf>

<sup>16</sup>6-month Bubills are weighted with a factor of 0.5, while 12-month Bubills are weighted with a factor of 1. Schätze, Bobls, ten-year Bunds and 30-year Bunds are weighted with the factors 4, 8, 15 and 25 respectively.



erage price of the competitive bids accepted. Bidders are informed of the allotment immediately.

**Bund Bidding System (BBS):** The Deutsche Bundesbank provides the BBS (Bund Bidding System) as an electronic primary market platform. The allotted amounts are published in the Bund Bidding System (BBS) for the members of the Bund Issues Auction Group *on the day of the auction immediately after the allotment decision has been made*. The securities allotted are settled on the value date specified in the invitation to bid.

## C.2 Italy

Data for Italy was taken from the Ministry of the Economy and Finance (Ministero dell'Economia e delle Finanze). The Ministry provides historical information about auction results,<sup>17</sup> and information about the operation and institutional details of auctions.<sup>18 19</sup>

**Description of the Primary Market:** The Ministry of the Economy and Finance sets out the issue of five categories of Government bonds available for both private and institutional investors on the domestic market: Treasury Bills (BOTs); Zero Coupon Bonds (CTZs); Treasury Certificates (CCTeus); Treasury Bonds (BTPs); Treasury Bonds Indexed to Eurozone Inflation (BTP€is); Treasury Bonds Indexed to Italian Inflation (BTPItalia). They differ in their maturity, interest, and importantly in the auction type.

The Italian Treasury makes use of two kinds of auction protocols for these instruments:

1. Multi-price auction on a yield basis are used for BOTs, with standard maturities of 3, 6, and 12 months.
2. Single-price auction, where the auction price and the quantity issued are determined discretionally by the Treasury within a pre-announced interval of amounts in issuance, are used for all medium-long terms bonds (zero-coupon, nominal fixed and floating rate, and inflation indexed bonds).

**Participants** Only Primary Dealers can participate in auctions. They also have exclusive access to reserved reopenings of Government bond auctions and exclusive participation in syndicated and US dollar issuances. These Dealers are called

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<sup>17</sup>[http://www.dt.mef.gov.it/en/debito\\_pubblico/emissioni\\_titoli\\_di\\_stato\\_interni/risultati\\_aste/](http://www.dt.mef.gov.it/en/debito_pubblico/emissioni_titoli_di_stato_interni/risultati_aste/)

<sup>18</sup>[http://www.dt.mef.gov.it//export/sites/sitodt/modules/documenti\\_en/debito\\_pubblico/specialisti\\_titoli\\_di\\_stato/Specialists\\_evaluation\\_criteria\\_-\\_year\\_2019.pdf](http://www.dt.mef.gov.it//export/sites/sitodt/modules/documenti_en/debito_pubblico/specialisti_titoli_di_stato/Specialists_evaluation_criteria_-_year_2019.pdf)

<sup>19</sup>[http://www.dt.mef.gov.it/en/debito\\_pubblico/titoli\\_di\\_stato/quali\\_sono\\_titoli/bot/](http://www.dt.mef.gov.it/en/debito_pubblico/titoli_di_stato/quali_sono_titoli/bot/)

“Specialists” and must reside in the European Union, be a bank or an investment company, and operate on regulated markets and/or on wholesale multilateral trading systems whose registered office is in the EU. According to the Italian regulation, Primary Dealers should participate in the Government securities auctions with continuity and efficiency, and contribute to the efficiency of the secondary market. A necessary condition to maintain the qualification of a Specialist is the allocation at auction, on an annual basis, of a primary market quota equal to, at least, 3% of the total annual issuance through auctions by the Treasury<sup>20</sup>. Another index called the “Continuity of participation in auctions” parameter is an indicator that penalize those Specialists that more frequently did not achieve the minimum level of participation.

**Bidding Details** Authorized dealers can place up to five bids, using the National Interbank Network. until 11a.m of the auction day. Presently, the settlement date for all Government bonds is two business days following the auction date (T+2). For BOTs this usually coincides with the maturity of corresponding bonds, so as to facilitate reinvestment. In Italy, unlike in many other countries, dealers place their bids in yields, not prices. Their yields must differ by at least one thousandth of one percent, and must be of at least €1.5 million and at most the entire quantity offered by the Treasury at the auction. The minimum denomination for investors is €1,000. If bids at the final awarded yield cannot be completely satisfied, they are divided proportionally, rounding off when needed.<sup>21</sup>

### C.3 Portugal

Data for Portugal was taken from the Portuguese Treasury and Debt Management Agency (IGCP - Agência de Gestão da Tesouraria e da Dívida Pública). The Agency provides historical information about auctions results,<sup>22</sup> and information about the operation and institutional details of auctions.<sup>23</sup>

**Description of the Primary Market:** The IGCP issues various kind of debt instruments: Fixed rate Bonds (OT), Treasury Bills (BT), Floating Rate Bonds (OTRV), Saving Certificates (CA) and Treasury Certificates (CT), among others. The Obrigações do Tesouro (OT) are the main instrument used by the Republic of Portugal to satisfy its borrowing requirements. OTs are medium- and long-term book-entry securities issued by syndication, auction or by tap. These instruments are released every quarter, and auctioned through single/uniform auction protocols. In this paper we focus on Treasury Bill (BT) instruments, which are short-term securities with a face value of

<sup>20</sup>Values of 0.5, 1, and 2 are assigned to BOTs for 3, 6, and 12 months, respectively. Greater coefficients are obtained from longer maturity instruments like the BTPs of 20, 30, and 50 years which give scores of 13, 15, and 20, respectively.

<sup>21</sup>To avoid that the weighted average yield is negatively influenced by bids made at yields that are not in line with the market, a minimum acceptable (or safeguard) yield is calculated.

<sup>22</sup><https://www.igcp.pt/en/1-4-399/auctions/bt-auctions/>

<sup>23</sup>[https://www.igcp.pt/fotos/editor2/2015/Legislacao/Instrucao\\_BT\\_1\\_2015\\_UK.pdf](https://www.igcp.pt/fotos/editor2/2015/Legislacao/Instrucao_BT_1_2015_UK.pdf)

one euro and are issued with maturities of 3, 6, and 12 months. Importantly, *the IGCP uses the multi-price auction method for BTs.*

**Participants:** Participation in BT auctions is confined to institutions that have been granted the status of Treasury Bill Specialist (EBT)<sup>24</sup>. These Primary Dealers are entitled to exclusive access to the facilities created by the IGCP to support the market, such as the BT repo window of last resort, among others. Treasury Bill Specialists are bound to actively participate in BT auctions, by bidding regularly under normal market conditions and by subscribing to a share no lower than 2% of the amount placed in the competitive phase of auctions. They should also participate actively in the secondary market of Treasury Bills (BT), by maintaining a share of no less than 2% of the turnover of this market segment. Primary Dealers are ranked based on the EBT Performance Appraisal Index, which is constructed considering their participation in both primary and secondary markets.

**Bidding Details:** BT auctions can be held on the 1st or (usually) 3rd Wednesday of each month. The specific details for each auction are announced directly to the Treasury Bill Specialists (EBT) and to the market, up to three days before the auction date. Settlement takes place two working days after the auction date (T+2). BT auctions are supported by an electronic system: the Bloomberg Auction System (BAS) and follow a multi-price auction model.

In the competitive phase, each participant may submit a maximum of five bids per line, in multiples of €1 million, the total of which cannot exceed the indicative amount of the auction, divided by the number of lines. Should the total amount of bids exceed the amount that the IGCP decided to place in the auction, the bids with a rate equal to the cut-off rate are allotted on a pro-rata basis (according to €1,000 lots). The IGCP may decide to place an amount up to one-third higher than that announced. The auction results are announced up to 15 minutes after that time, usually in the three-minute period following the deadline. The non-competitive phase amounts to a maximum of 40% of the amount allocated at the competitive auction. The competitive phase of auctions will end at 10.30a.m (11.30a.m CET) and the period for the submission of bids for the non-competitive phase will end at 10.30p.m (11.30p.m CET) of the following business day.

## D Details on Secondary Market Institutions and Data

The yields for the Treasury Bills of the three countries, traded daily on secondary markets, were obtained from Bloomberg. Table 9 shows the availability of the data by country and by instrument, and the corresponding Bloomberg tickers. As clear from the table, and for availability reasons, we will focus on 6-month and 12-month T-bills.

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<sup>24</sup>Notice that for Portugal, the list of the Primary Dealers for the Bond Market (OT) might differ from that of the Primary Dealers / Specialists in the Treasury Bills market (EBT).

Table 9: Secondary Market Variables Availability by Country

Variable List - Auction						
Instrument / Country	Germany (Bubill)		Italy (BOT)		Portugal (BT)	
	Ticker	Period	Ticker	Period	Ticker	Period
3-month T-bill	X	X	X	X	GTPTE3M Govt	2004-2021
6-month T-bill	GTDEM6M Govt	2002-2021	GTITL6M Govt	2006-2021	GTPTE6M Govt	2004-2021
12-month T-bill	GTDEM12M Govt	1997-2021	GTITL1Y Govt	2006-2021	GTPTE1Y Govt	2002-2021

In what follows we discuss the requirements for participation of Primary Dealers in secondary markets in each of the three countries we consider.

## D.1 Germany

Nominal and inflation-linked German government securities traded on German exchanges, numerous international electronic trading platforms and on the over-the-counter (OTC) markets. Unlike many other countries, the German Primary Dealers do not have strict market maker obligations, especially in the secondary market.<sup>25</sup> At the end of 2020, Bubills made up €113,5 bn of Federal securities outstanding in the secondary market (incl. inflation-linked securities). This corresponds to a share of about 8% of the volume of all outstanding Federal securities.

## D.2 Italy

The Treasury does not directly set specific quoting obligations for Primary Dealers (i.e., Specialists) on the market. According to the current Italian framework, the Treasury must evaluate the Specialists on quote-driven regulated markets, on a relative basis monitoring certain parameters such as the quotation quality index.<sup>26</sup> Other indices used to evaluate Specialists include cash traded volumes parameter, depth contribution indices, repo traded volumes, etc.

<sup>25</sup>In 2005, the German Finance Agency established a reporting system regarding the secondary market activities of the members of the Bund Issues Auction Group in marketable German Federal securities. The members of the Bund Issues Auction Group provide information on prices, trade volumes, and counterparty data to the Finance Agency.

<sup>26</sup>The quotation quality index (QQI) is an indicator based on high frequency snapshots, made on each market day for each Specialist. For each snapshot, the ranking of the Specialist is made with respect to the best ranked Specialist, both for the bid and ask sides for each traded instrument. The index rewards more those dealers that continuously show the best prices both for the bid and the ask sides. Lower QQI values, which indicate an average overall positioning closer to the best prices, denote a better performance. The daily rankings relative to each bond are then aggregated (simple average) by classes of bonds.

### D.3 Portugal

Primary Dealers commit to continuously quote firm prices for all the securities subject to quoting obligations for a minimum of EUR 5 million amounts both for bid and offer sides at least five hours per day. New BT lines are admitted to trading immediately after being issued for the first time and once the pricing is defined. An EBT has fulfilled its quoting obligation if it has established a compliance ratio of at least 80% for each entire calendar month.<sup>27</sup> If any of these conditions are not met, the EBT is non-compliant on that security. An EBT can achieve additional points on the market making activity if they quote more than the minimum amount required, quote longer than the minimum time required, and comply with the requirements in specially volatile days.

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<sup>27</sup>For an EBT to be compliant on any given security, it must provide quotes for a minimum of five hours a day in one of the designated platforms, and the bid offer spread of such quote cannot exceed in more than 50% the average of all quotes from all EBTs that quoted that security for at least five hours, on the same day.