Information Spillovers and Sovereign Debt: Theory Meets the Eurozone Crisis[*]

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Abstract

We develop a theory of information spillovers in primary sovereign bond markets when a common pool of competitive investors may acquire information about default risk and later trade in secondary markets. Strategic complementarities in information acquisition lead to the co-existence of an *informed regime* and an *uninformed regime* with lower yields and volatility. Small shocks to default risk in one country may trigger information acquisition in multiple countries. This leads to retrenchment of capital flows and sharp yield increases in other risky countries, but "reverse spillovers" to safe countries. Competitive secondary markets strengthen these forces and amplify spillovers. These results are consistent with the behavior of primary and secondary market yields, market segmentation, and information acquisition during the Eurozone sovereign debt crisis.

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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. This leads to information rents for investors who know more about the common value of bonds than others. Information is particularly valuable during periods of heightened uncertainty (such as crises) in which default risk can vary substantially from auction to auction. In such circumstances investors may be more inclined to either acquire information or to withdraw from auctions in which other investors have an information advantage, moving funds to other countries or safer investment opportunities. We analyze equilibrium portfolio choice and information acquisition in discriminatory-price auctions using a multi-country model with stochastic government default risk and trading in both primary and 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.

The main application of our theory is the recent Eurozone sovereign debt crises, which generated a number of striking empirical regularities. 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 during the crisis while German yields fell. These pricing facts align with changes in portfolios: markets were well-integrated before the crisis, with many investors holding bonds in multiple countries, but quickly fragmented *during* and *after* the crisis. Italian and Portuguese bonds were predominantly held by domestic investors during and after the crisis, but German bonds were increasingly held by non-resident investors after the crisis. We measure the information content of auctions by asking whether realized auction prices reveal information that is persistently reflected in secondary market prices. We find evidence that auction prices contained information in periphery countries during the Eurozone crisis, but not before the crisis, and not in core countries.

We provide an account of these facts using a model with two countries (or regions) and a continuum of risk averse investors. In each country, a discriminatory-price multi-unit auction 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 face an exogenous revenue requirement, and bonds are risky because governments may default according to an exogenous stochastic process. No investor knows the true default risk in both countries, but they can learn it a cost in one or both countries. Information is valuable because informed investors can better target bids to fundamental bond values.

Since the bonds being auctioned are risky and bidders are risk averse, investors require compensation in form of risk premia, and risk premia naturally increase with a concentration in bond holdings. When all investors are uninformed, optimal bidding strategies lead to well-diversified portfolios that are symmetric across all agents. In the presence of informed investors, uninformed investors instead face a trade-off between capturing infra-marginal risk premia and overpaying in bad states of the world. In equilibrium, uninformed investors bid less in auctions with many informed bidders, and their reduced participation is reflected in lower prices because informed investors must bear more risk. This leads to knock-on effects on portfolios: informed investors disproportionately invest in countries in which they are informed, and uninformed investor either shift to risk-free assets or to countries in which they are not at an informational disadvantage.

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 establish the well-known result that higher default risk in one country leads to lower prices in all countries if preferences satisfy decreasing risk aversion. While this channel can help to rationalize yield correlations between Portugal and Italy during Eurozone crisis, it cannot speak to the observed portfolio reallocation across investors or the *decrease* in yields in Germany and other core countries.. We obtain asymmetric spillovers when one country is relatively risky and informed while the other is a "safe haven" with low default risk and no information. This allows us to speak to the divergent paths of Germany and the periphery during the crisis.

For risk-averse bidders, the ability to accurately forecast marginal prices is more valuable if prices are more variable across states of the world, if they hold a large share of their bonds in a particular country, or if they place particular weight on states with high marginal utility, such as a government default. All else equal, the value of information is thus increasing in debt levels, portfolio concentration, and the *level* and *variance* of default risk. Conversely, marginal prices are more variable when there are more informed investors who target their bids to the realized state of the world. Hence the value of information may increase in the share of informed investors who participate in the auction. However, information acquisition is a *strategic complement* only when the number of informed investors is low. If the share of informed investors is large, they compete away the information rents leading to a reduction in the value of information.

The resulting strategic interactions in information acquisition allow for multiple equilibria distinguished by their information regime. 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 expected price in the informed regime. This is for two reasons: the lack of winner' curse encourages participation, and, under convex marginal utility, the required risk premium is lower when bonds are priced according to an average default probability. 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. This allows us to speak to the sudden and large spikes during the Eurozone crisis. Importantly, these effects arise *only* because we explicitly model the primary market protocol; in Walrasian markets, information acquisition is a strategic substitute (see e.g Grossman and Stiglitz (1976)).

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 a single asset, investors have stronger incentives to acquire information about this asset. 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. This suggests a simple test of our theory: if some investors 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 and 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 here a different form of spillovers, which stem not from country fundamentals (the supply side) but rather from the investment decisions 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 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 provide evidence of this effect by measuring the primary-secondary market spread.

Our work provides a theoretical underpinning to 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 strong 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.

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.[1] 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 good quality. 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.[2]

Considering 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.

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

[1]The main challenge is solving an equilibrium that involves bidders with a double dimensional strategic problem: choosing 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).

[2]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.

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.[3]

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 restricted in the units they can buy. We study flexible bidding strategies and cross-auction linkages.

The model in this paper complements Cole, Neuhann, and Ordoñez (2020), which studies a single-country model with a fixed information environment and provides evidence for asymmetric information about default risk in Mexican sovereign bond auctions.[4] In this paper, we allow for endogenous information acquisition and use a multi-country model with cross-auction linkages. 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. While Cole, Neuhann, and Ordoñez (2020) exploit detailed bidding information in Mexico to assess the extent and nature of asymmetric information among investors, here we exploit primary and secondary market prices in Portugal, Italy and Germany to assess spillovers and segmentation effects during the Eurozone crisis.

The paper proceeds as follows. 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 6 studies the role of secondary markets on bond yields, information acquisition, and spillovers. Section 7 applies these results to the experiences of Portugal, Italy and Germany during the Eurozone crisis. Section 8 concludes.

[3] Kastl (2011) extended Wilson model, which is based on continuous and differentiable functions, to more realistic discrete-step functions, showing that in such case only upper and lower bounds on private valuations can be identified, which he does by exploiting the previously discussed resampling method on Czech bills auctions.

[4] Cole, Neuhann, and Ordoñez (2021) uses additional data from Mexico to show that asymmetric information may support bond prices in particularly bad times.

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 $\vec{\delta} = [\delta_1, \delta_2]$.

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 θ_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 θ_j is independently distributed across countries and we define $\vec{\theta} \equiv [\theta_1, \theta_2]$. Fluctuations in θ reflect variation in *private* information, while changes in $[\kappa_j(g), \kappa_j(b)]$ or their probabilities, reflect variation in *public* information. 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 structure. 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 θ_1 and/or θ_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 $C(a_1,a_2) \geq 0$ and is 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 θ_{-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.

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 θ_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. [5] 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

[5] 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.

bidding function $B_j(\theta_j) \equiv B'(P(\theta_j)$ that maps θ_j into quantities associated with the marginal price in θ_j. This makes plain that 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 bids* $\mathcal{E}_j^i(\theta_j)$ which collect all bids by an investor of type i that are executed in country j when the state is θ_j. Since each bid is associated with a state-specific marginal price, the elements of these sets are states of the world. For 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 θ_j, respectively. Because only informed investors can submit state-contingent bids, we have

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

Thus investor i's total expenditure on bonds in country j and state θ_j is

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

The market-clearing condition in country j and state θ_j is

$$\sum_i n^i X_j^i(\theta_j) = D_j. \tag{1}$$

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

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

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 also do not reveal information.)

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

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

The final number of bonds held by the investor for each j and θ_j is

$$\widehat{\mathcal{B}}^i_j(\theta_j) = \mathcal{B}^i_j(\theta_j) + \widehat{B}^i_j(\theta_j)$$

while total holdings of the risk-free asset at secondary market close are given by

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

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 θ_j,

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

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*

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

The first pair of constraints ensures that bids are non-negative at auction and that there is 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 $P_j : \{b, g\} \to [0, 1]$ and $\widehat{P}_j : \{b, g\} \to [0, 1]$ 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 numerical examples 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 6.

3 Auction Equilibrium

We begin by discussing optimal bidding strategies when there are no secondary markets. 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.[6] 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 sets 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.

Optimal bidding strategies 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. It is helpful to summarize investor i's expected marginal utility for bids in country j given state θ_j

[6] 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.

and default decision δ_j by

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

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

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

Given Inada conditions, borrowing constraints do not bind for any investor. The non-negativity constraint on bids may bind for some investors in some states of the world. In any equilibrium, the marginal rate of substitution must therefore be equal to bond yields only for the *marginal* investor. 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. In contrast, the winner's curse may lead uninformed investors to stop bidding at high prices.

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 θ_j, and uninformed investors are marginal in every state. That is,

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

(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

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

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

Optimal portfolios give rise to standard asset pricing relationships: marginal investors price bonds such that bond yields are equal to state-contingent marginal rates of substitution. 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, while uninformed investors instead may cease to bid at the high price in order to escape the winner's curse. However, uninformed investors are always at an interior optimum for bids at the low price because low bids are not subject to the winner's curse.

The following analytical example illustrates the way prices are determined by considering the special case where investors hold no bonds in Country 2. Asymmetric 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 such bids are accepted in all states, thereby altering marginal incentives to bid at the low price even when such bids are effectively state-contingent.

Example 1. *Let $D_2 = 0$. For informed investors, the relevant MRS in state θ_1 is*

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

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

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

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

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

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

4 Within-Country Effects of Asymmetric Information

We now characterize how asymmetric information affects 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 that 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 the behavior of prices as a function of the share of informed investors.

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 $n_1 \to 0$.*
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 $\lim_{n_1 \to 0} P_1(b) < \bar{P}_1$.*

Comparative statics of the high price are straightforward. Since informed investors do not face the winner's curse, they always spend more at high prices. Hence the high price monotonically increases in the share of informed investors. The comparative statics of the low marginal price with respect to n_1 are driven by two competing 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. Conversely, informed investors spend less in the bad state which 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.

Taken together, prices react more strongly to movements in default risk when there are more informed investors. This creates a susceptibility of prices to news that is absent in the uninformed regime. Moreover, state-contingent marginal prices do not converge to each other even when the share of informed investors is low. This is because all uninformed bids at the high price are accepted even when the state is low; thus market clearing only forces convergence of the high price to the uninformed price.

This has two important implications. The first is that a change in the information regime exposes the government to more downside risk. The other is that an informed investor's opportunities to exploit private information depend on whether there are other informed investors. When no investors is informed, prices are not state-contingent and the main advantage of being informed is the ability to adjust quantities. When some investors are informed, equilibrium prices are low in the bad state, which allows the investor to participate capture a risk premium at low prices while also avoiding the winner's curse. Thus, the presence of informed investors can create "better deals" that raise the value of being informed. We later show that this effect can lead to multiple equilibria.

Figure 1 illustrates these mechanisms using our numerical example. We hold prices and bids in Country 2 fixed at the level that would obtain in an equilibrium where there are no informed investors. We plot marginal prices and the *expected average price* $\mathbb{E}[P_1]$. In the good state, all accepted bids are executed at $P_1(g)$. In the bad state, some uninformed bids are executed at $P_1(g)$ and the remainder at $P_1(b)$,

$$\mathbb{E}[P_1] \equiv f_1(g)P_1(g) + f_1(b)\left(\frac{(1-n_1)B_1^U(g)P_1(g) + \big((1-n)B_1^U(b) + n_1 B_1^I(b)\big)\, P_1(b)}{(1-n)\left(B_1^U(g) + B_1^U(b)\right) + n_1 B_1^I(b)}\right)$$

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. In the given example, $P_1(b)$ is strictly decreasing and ex-

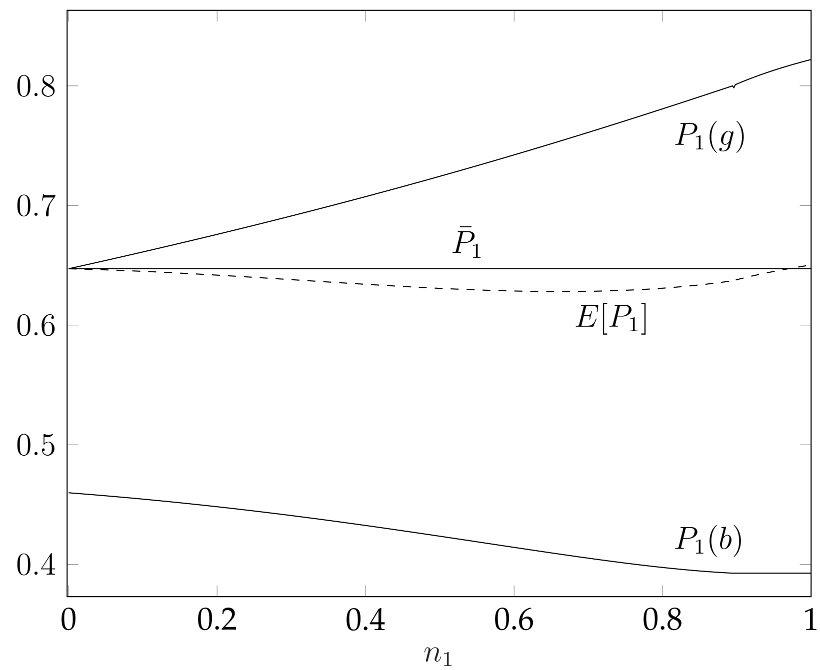


Figure 1: Prices in Country 1 as a function of n_1 given a fixed bond portfolio in Country 2.

pected 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. Moreover, price differences between states are sufficiently large such that uninformed investors withdraw from bidding at the high price very quickly. Our example provides further intuition.

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

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

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

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

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

We now study how the share of informed investors is determined. Since all investors are uninformed in Country 2, 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, ΔV^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 than when there is a small strictly positive share of investors than when all investors are uninformed. This is because of the sharp difference in the low marginal price that is induced by a switch to the informed regime.[7] This allows for the co-existence of the informed and uninformed regime for appropriate 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 $n_1 \in$*

[7] In Cole, Neuhann, and Ordoñez (2020) 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.

$(0, \bar{n}_1]$ *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.

Our example allows us compute the value of information in closed form and provides intuition into how 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* $\bar{\kappa}_1 W/(1-\bar{P}_1)$ *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*

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

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

Next consider the limit of the informed regime as $n_1 \to 0$. *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 uniformed regime. This is not true for informed investors, who may submit bids at two distinct marginal prices. The resulting consumption profile in state* θ_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*

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

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

The example highlights that fundamental volatility raises the value of information. This is because fundamental volatility creates volatility in optimal state-contingent bidding strategies. Since only informed investors can submit state-contingent bids, this raises the benefit of being informed. Below we use this observation to argue that (small) fundamental shocks can trigger switches in the information regime.

Figure 2 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, and parameters are as in Definition 4. The value of information jumps at $n_1 = 0$ as the information regime switches from uninformed to informed. Within the informed regime, it is 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.

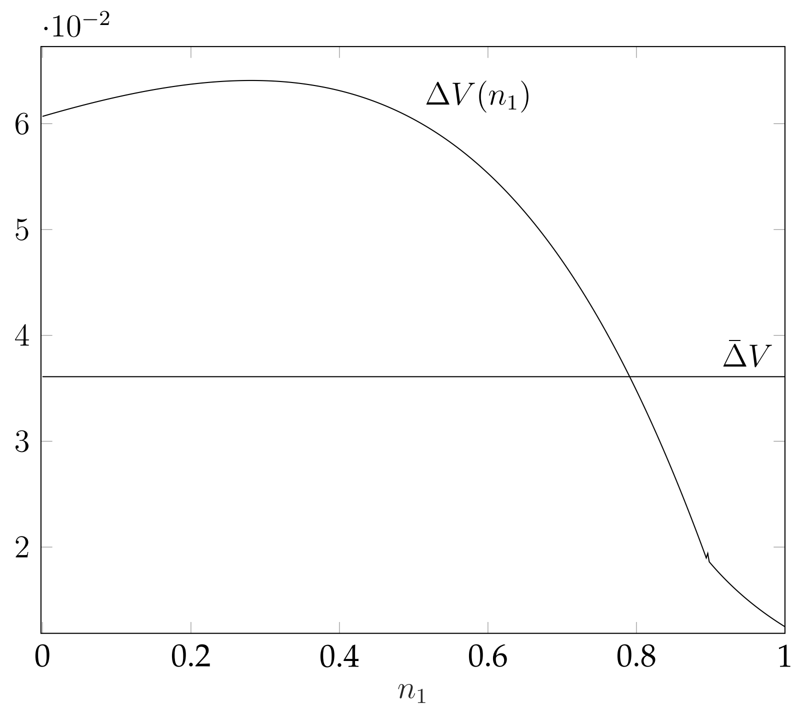


Figure 2: The value of information in Country 1 as a function of n_1.

Figure 3 plots the value of information in the uninformed regime and in the informed regime in the limit $n_1 \to 0$ as a function of the bad-state default probability $\kappa_1(b)$. An increase in $\kappa_1(b)$ raises default risk and increases the variance of default risk across states. 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. The regions in which an informed equilibrium exists thus expands as default risk rises. Hence shocks to fundamental risk can lead to more information acquisition.

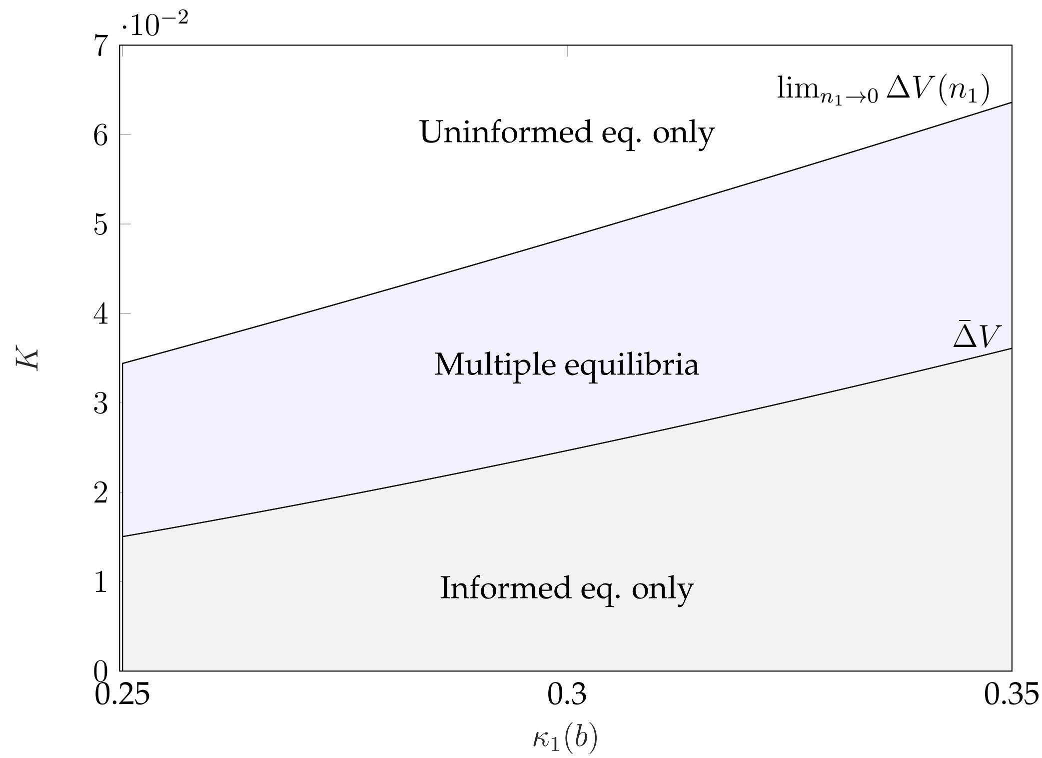


Figure 3: Information regimes in Country 1 given $\kappa_1(b)$.

5 Cross-Country Spillovers: Prices versus Portfolios

We now characterize the scope for spillovers in our model. We first study the scope for spillovers when there is no 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. However, all investors choose the same portfolios in all countries, and the direction of the spillover is negative no matter the fundamentals in either country. That is, there is insulation of portfolio composition from price changes, and there can be no "reverse" spillovers such as those observed between the core and periphery during the Eurozone. In the following sections, we show that information spillovers can generate such effects.

5.1 Spillovers with symmetric information

Under symmetric information, all investors are marginal and we can simplify notation by dropping superscripts indicating investors types. The *net marginal benefit* of investing in country j is

$$F_j = \frac{1 - P_j}{P_j} - M_j, \tag{3}$$

The first term in F_j is the yield, the second is the relevant marginal rate of substitution. Equilibrium is such that $F_j = 0$ for all j, and $M_j = m_j(1)\kappa_j / m_j(0)(1 - \kappa_j)$.

Definition 5 (Default risk contagion)**.** *There is default risk contagion if the net benefit of investing in j decreases when country $-j$'s default risk increases, $\partial F_j / \partial \kappa_{-j} < 0$.*

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.*

An increase in default risk places more weight on states with low consumption. Under DARA, this leads to an increase in average risk aversion and a higher required risk premium. This logic operates for any possible fundamentals. Absent asymmetric information, the model can thus just not generate the divergent paths of the core and periphery without relying on multiple shocks to fundamentals in both regions. Moreover, all investors hold the same portfolios. Hence the model cannot speak to the divergent paths of foreign investors holdings either.

Remark 1. *Without asymmetric information, the role of the auction protocol is essentially irrelevant for prices: there is a single marginal price across all states of the world. Given symmetric information, our model thus behaves similar to existing frameworks in which there is a global pool of investors trading in competitive markets. The results in this section highlight why such models cannot speak to the observed facts on portfolio segmentation among investors.*

5.2 Spillovers through Asymmetric Information

We now show that variation in the share of informed investors in one country affects prices and portfolios in both countries. 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 assume that the utility function satisfies constant relative risk aversion (CRRA) with risk-aversion coefficient γ, 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 spend more in Country 2. We then show that this leads to higher incentives to acquire information in Country 2 as well.

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 θ_j at price $P_j(\theta_j)$ given default decision δ_j is $R_j(\theta_j, \delta_j) = \frac{1-\delta_j - P_j(\theta_j)}{P_j(\theta_j)}$. We define $\widehat{R}^i_j(\theta_j) \equiv \mathbb{E}[R_j(\theta_j, \delta_j)|\mathcal{F}^i]$ and $\widehat{\sigma}^i_j(\theta_j) \equiv \sqrt{\mathbb{V}^i[R_j(\theta_j, \delta_j)}$ 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

$$S^i_j(\theta_j) = \frac{\widehat{R}^i_j(\theta_j)}{\widehat{\sigma}^i_j(\theta_j)}.$$

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 to default risk below 50% because the variance is otherwise decreasing in κ_j.)

Lemma 1. *Let $\bar{\kappa}_1 < \frac{1}{2}$. For $\theta_1 = g$, $S^I_1(\theta_1) > S^U_1(\theta_1)$ and $\frac{\partial(S^I_1(\theta_1) - S^U_1(\theta_1))}{\partial P_1(g)} < 0$.*

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

$$\omega^i_j(\theta_j) \equiv \frac{\gamma P_j(\theta_j) B^i_j(\theta_j)}{W}.$$

To simplify notation, let $s^i_j(\theta_j) \equiv \frac{S^i_j(\theta_j)^2}{1+S^i_j(\theta_j)^2}$ denote a scaled version of the state-contingent Sharpe ratio and $s^i_j \equiv \sum_{\theta_j} f_j(\theta_j) s^i_j(\theta_j)$ 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. The next result formally characterizes optimal portfolios.

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

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

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. This is the high price increases in Country 1, which creates a bigger gap in the Sharpe ratios perceived by informed relative to uninformed investors. Since information acquisition is a strategic complement, there may thus be sudden and sharp increases in the extent of market segmentation.

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.

Since default risk is independent, segmentation leads to inefficient diversification. Figure 6 shows that this leads to lower prices (higher risk premia) in both countries. Despite that no investor acquires information in Country 2, that country's bond price is lower than in the uninformed regime.

Portfolio concentration raises the incentives to acquire information. To show this effect, we begin with our baseline model where there are n_1 informed investors in Country 1 and no informed investors in Country 2. We then compute incentives to become informed in Country 2. Given that there is asymmetric information in Country 1, we compute this value both for an investor who is informed in Country 1 (denoted by $\hat{\Delta}V^{\{1,1\}}(n_1)$) and one who is uninformed in Country 1 (denoted by

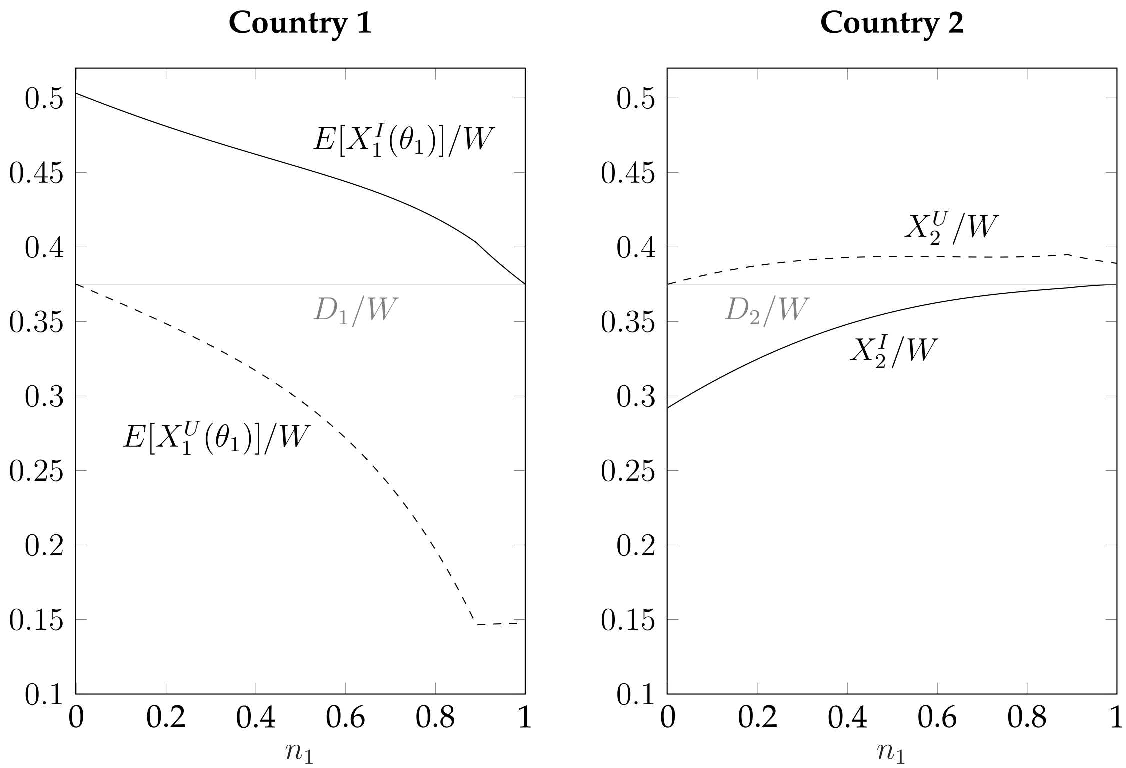


Figure 4: Effects of n_1 on portfolio shares across countries and investors.

Figure 5: Portfolio shares are defined as the ratio of expenditures in each country over wealth W. Since Country 1 portfolios are stochastic, we plot the cross-state average. 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($n_1 = 1$).

$\hat{\Delta} V^{\{0,1\}}(n_1)$). Figure 7 plots these two functions in black. The gray lines show the value of information in Country 1 that are familiar from Figure 2.

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 a second country is smaller than the incentive to become informed in a first country. The intuition is that a country without informed investors becomes a "safe haven" where uninformed investors do not face 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, they have a stronger incentives to acquire information in the "safe haven". The existence of informed investors thus begets further information acquisition, creating a novel channel of contagion through spillovers in the informational regime. We show

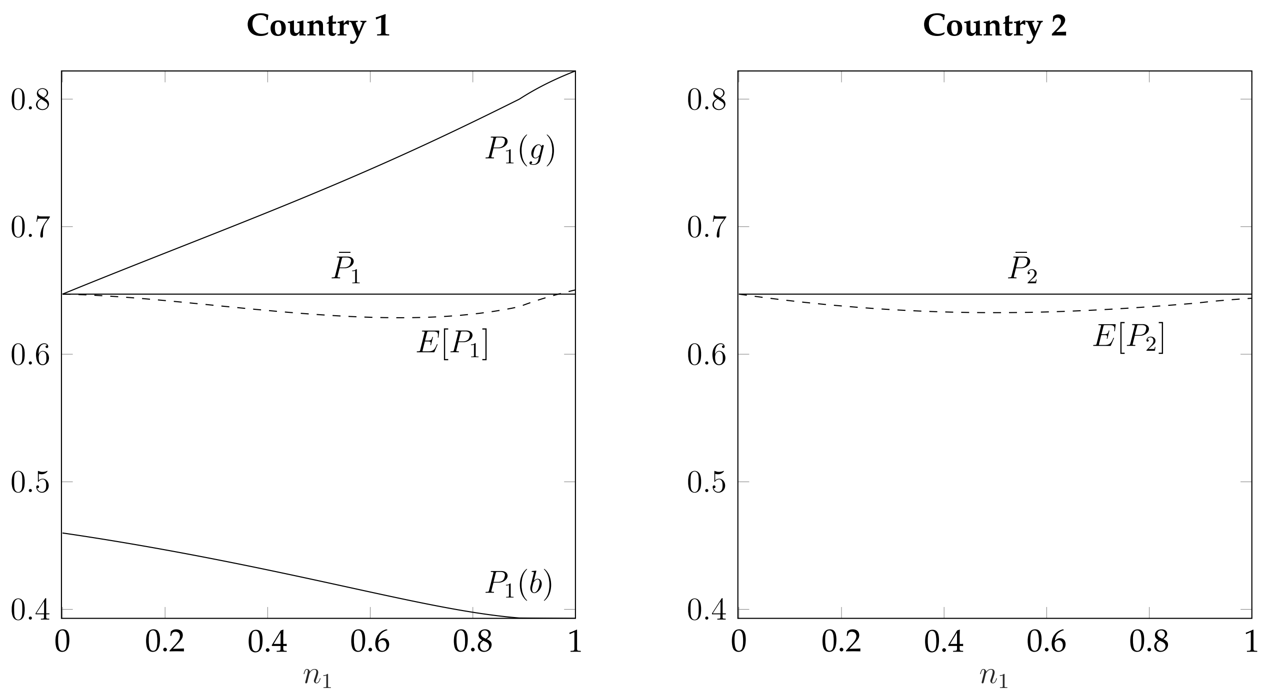


Figure 6: Prices in informed equilibrium as a function of n_1.

that this effect can help rationalize key facts from the Eurozone crisis.

6 Effects of Secondary Markets

Most sovereign bonds can be readily traded in secondary markets once the auction closes. Since auction prices and allocations are disclosed at the end of the auction, all private information impounded into bids is revealed prior to 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.

In our setting, 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 remain unchanged relative to the pure auction without an aftermarket.

More interesting is the case with asymmetric information. Here, the ability to retrade bonds affords opportunities to flexibly exploit an information advantage at the auction. This is because informed investors are willing to buy more "underpriced"

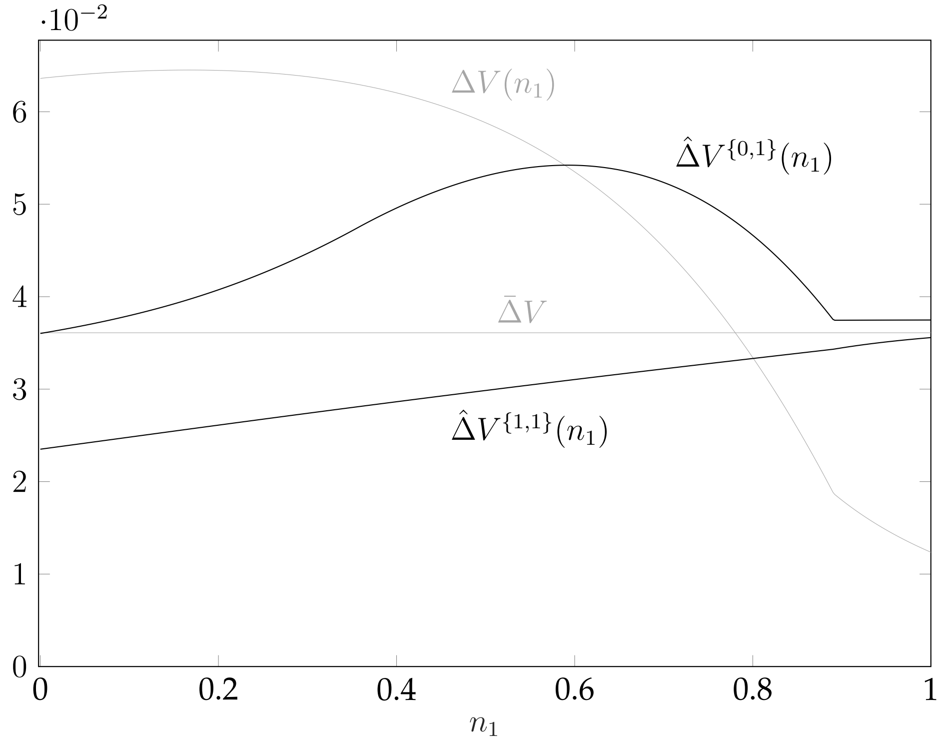


Figure 7: Value of Information as a function of n_1.

bonds at auction if they don't have to hold the default risk to maturity. The natural counterparties to these transactions are uninformed investors, who are willing to pay a markup in the secondary market to avoid the winner's curse at auction. This allows for pure arbitrage profits that raise the value of information.

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 and the multi-unit protocol, which allows bidders to adjust the intensive margin. However, arbitrage profits obtain only if there are not too many informed investors. 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.

Proposition 6. *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 low at the auction and selling high in the secondary market. That is, $P_j(g) <$

$\hat{P}_j(g)$ *if and only if* $n_j < \hat{n}_j$. *This arbitrage persists in the limit with no informed investors,* $\lim_{n_1 \to 0} P_j(g) < \lim_{n_1 \to 0} \hat{P}_j(\theta_j)$.

(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) The value of information is zero if and only if $n_1 \geq \hat{n}_1 = \frac{D_1}{W - D_2} \in (0, 1)$. *Hence any equilibrium with endogenous information acquisition satisfies* $n_1 < \hat{n}_1$. *Moreover, in the limit as* $n_1 \to 0$, *the value of information is strictly higher with secondary markets than without. Hence the threshold cost of information above which an informed equilibrium exists is strictly lower with secondary markets than without.*

When information is costly, any equilibrium in which information is acquired thus necessarily entails cross-market arbitrage. This leads to the following useful empirical implication, which we use extensively in our application to the Eurozone.

Corollary 1. *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 8 illustrates the equilibrium with secondary markets. The most striking observation is that prices in primary markets 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.

The figure shows that secondary markets amplify 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 Country 1 than they would without secondary market.

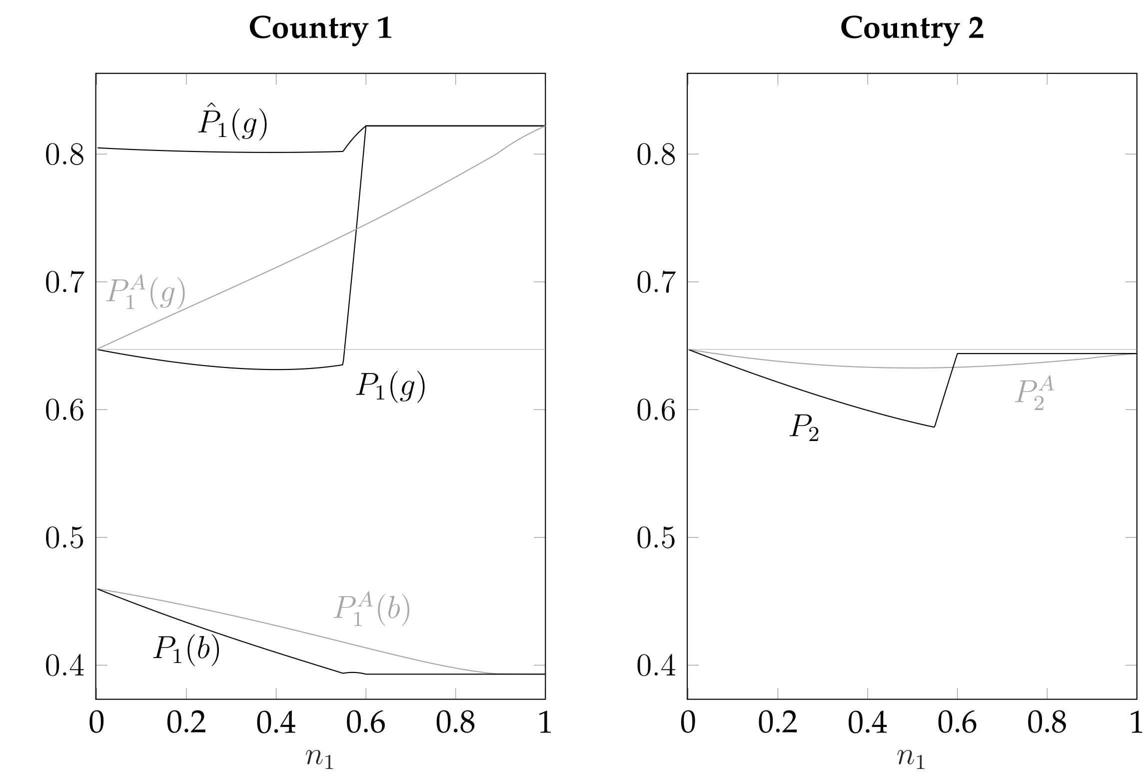


Figure 8: Effects of n_1 on prices and the value of information.

Figure 9: The left panel shows prices in Country 1, the right panel shows prices in Country 2. We show both the prices at the auction ($\hat{P}_1(\theta)$) and in the secondary markets ($P_1(\theta)$) for Country 1, and how they vary with n_1. We also show the corresponding prices in the model without secondary markets ($P_1^A(\theta)$) in grey, along with a horizontal line showing the uninformed equilibrium prices for comparison purposes. In Country 2, everyone is uninformed, so there is a single price schedule in which primary and secondary market prices coincide.

7 Information Spillovers in the European Debt Crisis

We argue that our theory of information spillovers offer a natural account for a number of key empirical regularities from 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[8] 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. The key empirical regularities we are interested in are the following.

[8]Long-maturity debt may be somewhat insulated from crisis events.

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 Italy and Portugal 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 Italy and Portugal but not in Germany.*

The first two facts are shown in Figure 10, the third is shown in Figure 11. To establish Fact 4, we regress the unexpected log change of secondary prices ($\Delta \log \text{Sec}_{i,t}$) on the unexpected log change of primary prices ($\Delta \log \text{Prim}_{i,t}$) for country i in auction day t, where we measure unexpected changes as the realized prices minus the prices predicted from regressions that include observable past prices. Table 7 shows our estimates. 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 10: Yields and cross-market spreads.

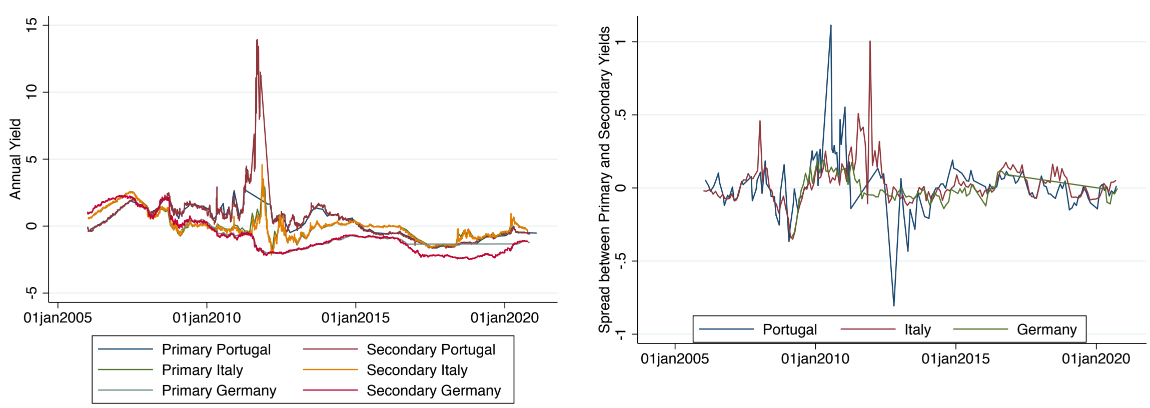
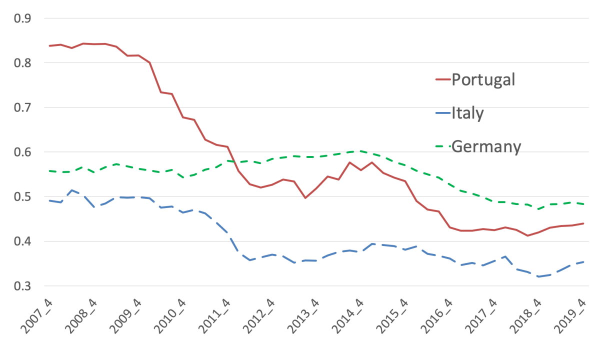


Figure 11: Segmentation.



To account for these facts, we study a repeated version of our model and modify it 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 1 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 $f(m) = 0.3$.

Table 1: Default Risk Across Public Regimes

	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%

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). For simplicity, we model these frictions as a fixed probability ρ that a given investor can access the secondary market.

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.

Table 2: Common parameters used in both event studies.

Parameter	Interpretation	Value
D	Country debt levels	300
W	Investor wealth	1000
γ	Coefficient of relative risk aversion	1
ρ	Secondary market liquidity	0.75

7.1 Event Studies

7.1.1 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 3 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 milder: it enters the alarming regime in the second phase, and remains there.

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

Table 3: 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 4: 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.

Table 4: Optimal information acquisition in the within-periphery simulation.

	Phase 1	Phase 2	Phase 3
Portuguese	Uninformed.	Uninformed	**Informed in Portugal**
Italian	Uninformed	Uninformed	**Informed in Italy**
Foreign	Uninformed	Uninformed	Uninformed

Figure 12 shows simulated yields and portfolios for all possible realizations of the underlying quality shock θ, where vertical lines indicate the three phases. We now show that transitions across these three phases can rationalize the key facts.

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 the 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 sudden shock to information acquisition in *both countries*. 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 predictability 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 with respect to the data.

7.1.2 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

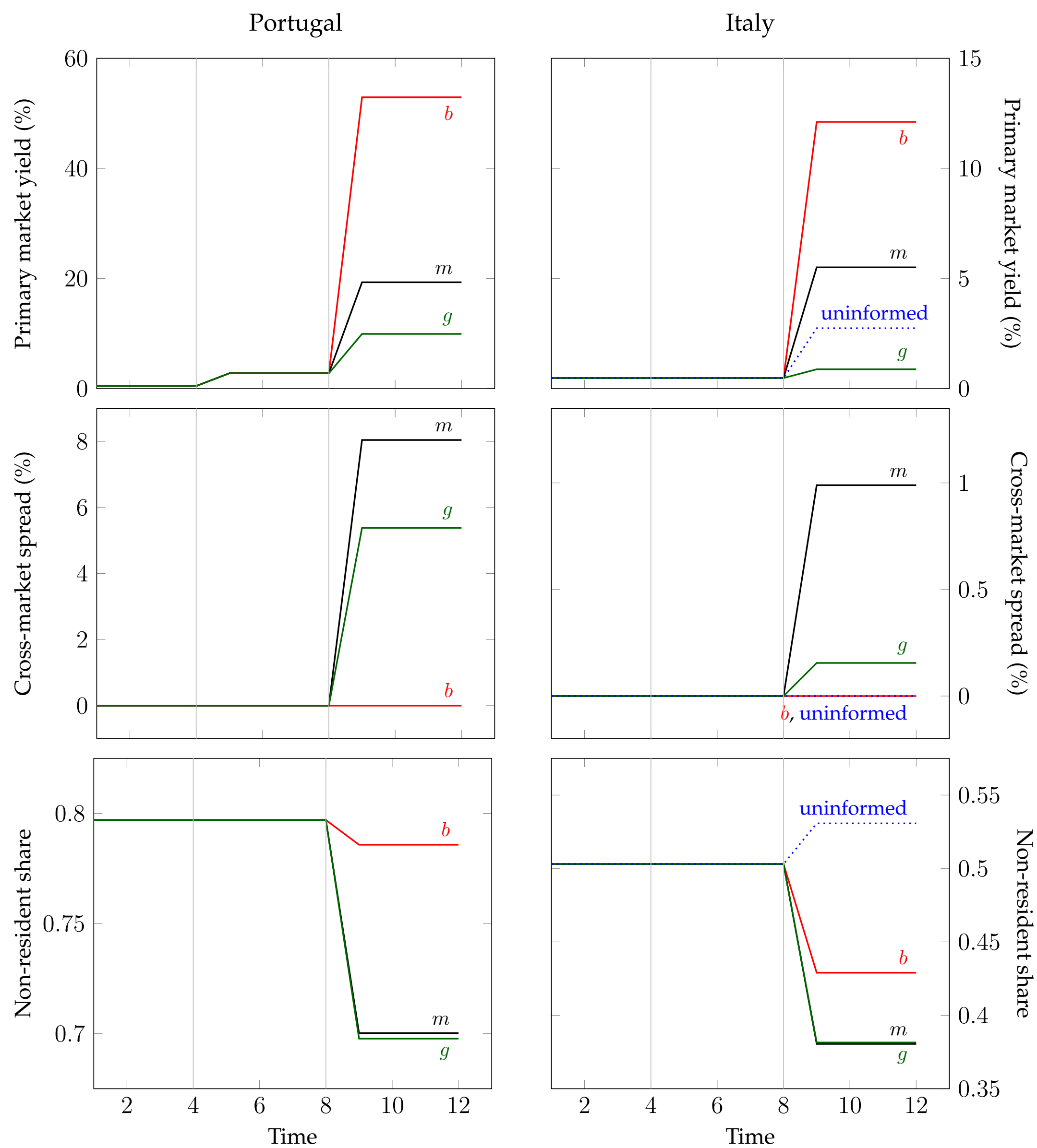


Figure 12: Portugal-Italy event study: primary market yields, the primary-secondary market spread, and non-resident shares for all quality shocks.

three phases: the tranquil period prior to the crisis, the initial shock to the periphery, and the full crisis.

Table 5 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 5: 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 to match non-resident shares in the tranquil period prior to the crisis.[9] 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 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 6.

Table 6: Optimal information acquisition in the core-periphery simulation.

Investor type	Phase 1	Phase 2	Phase 3
Periphery	Uninformed.	Uninformed	**Informed in Periphery**
German	Uninformed	Uninformed	Uninformed
Foreign	Uninformed	Uninformed	Uninformed

Figure 13 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 acqusition. 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 mar-

[9]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.

ket 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, average yields and yield volatility would have risen and the non-resident share would have *fallen*.

8 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 allows for endogenous asymmetric information about fundamental default risk. Second, we focus on primary 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.

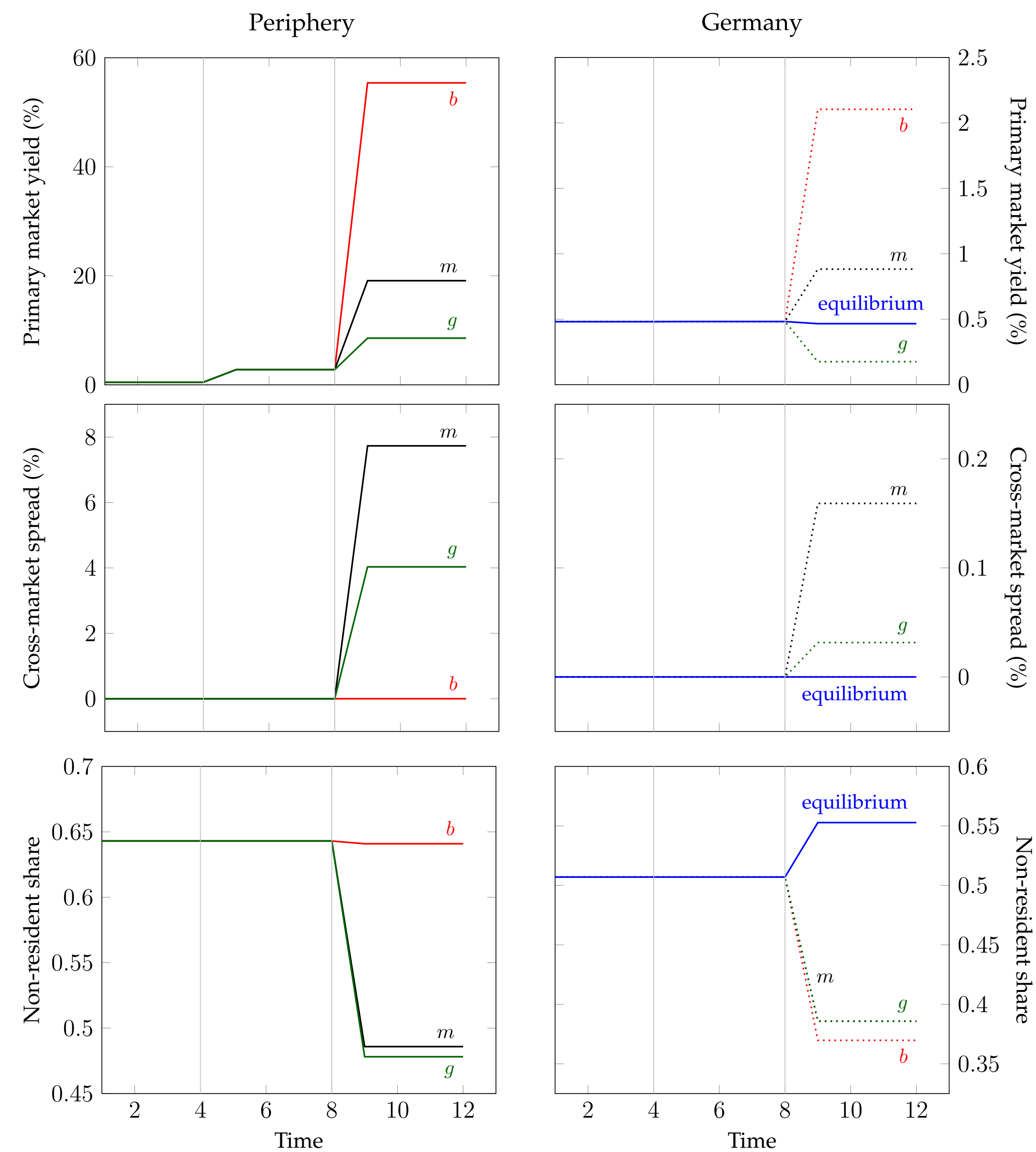


Figure 13: Periphery-Germany event study: primary market yields, the primary-secondary market spread, and non-resident shares for all quality shocks.

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 Tables

Table 7: Elasticity of secondary market prices to information released at auction.

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

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

B Appendix: Proofs

B.1 Proof of Proposition 1

Investors' risk-aversion implies that we must have $P_j(\theta_j) < 1 - \kappa_j(\theta_j)$ 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 (excess return over storage), and each country's default decision is uncorrelated with that of the other country. Given a twice continuously differentiable utility function, a risk-averse investor must purchase a strictly positive quantity of any perfectly divisible risky gamble if it offers a strictly positive expected return. When there are no informed investors, uninformed investors face such a gamble and thus their first-order condition for optimal bids must hold with equality. When there are informed investors, informed investors also face such a gamble in every state, and thus their first-order condition holds with equality. Lemma **??** shows that the presence of informed investors leads to price dispersion. As a result, uninformed investors' bids at $P_j(g)$ are also accepted if $\theta_j = b$, and the expected default probability on a bond acquired at $P_j(g)$ is $\bar{\kappa}_1$. If $P_j(g) < 1 - \bar{\kappa}_1$, uninformed investors face a gamble with negative expected returns and the short-sale constraint on bids at $P_j(g)$ binds. Hence uninformed investors are marginal if there are no informed investors, and otherwise informed investors are marginal investors in every state. The stated optimality conditions are the first-order conditions for optimality derived from differentiating the objective function with respect to bids. Given the convexity of constraints and the strict concavity of the objective function, first-order conditions are necessary and sufficient for portfolio optimality.

B.2 Proof of Proposition 2

First statement. Let B_2 denote investors' bids in Country 2 given marginal price P_2. Assume that uninformed investors submit bids in all states, so that all first-order conditions for optimal bids hold with equality. We will first show that informed investors spend less than uninformed investors in the bad state, $P_1(b)B_1^I(b) < P_1(g)B_1^U(g) + P_1(b)B_1^U(b)$. 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 $P_1(b)$ (as stated in Proposition 2) then imply that, for any $\tilde{W} \in \{W - P_2B_2, W + (1 - P_2B_2\}$, marginal utility after repayment satisfies

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

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

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

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

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

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

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

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 $P_1(b)$.

Second statement. The first part follows directly from the first statement. Since informed investors spend relatively more in the good state for any marginal price, and increase in their mass must lead to a price increase. (The analogous statement does not necessarily hold for the bad state because market-clearing condition in state $\theta_1 = b$ is a function of $P_1(g)$ also.) In the limit as $n_1 \to 0$, uninformed investors must clear the market, $\lim_{n1\to 0} P_1(g)B_1^U(g) = D_1$. Since all high-price bids are also accepted in the bad state, uninformed investor's first-order condition then implies the result.

Third statement. Since $P_1(b) < 1 - \kappa_1(b)$, all investors face a gamble with strictly positive expected returns at $P_1(b)$. Hence by Proposition 1 the first-order condition for bids at $P_1(b)$ binds with equality for all investors and $B_1^i(b) > 0$ for all i if $n_1 > 0$. Since $\lim_{n_1\to 0} P_1(g) = \bar{P}_1$ and $P_1(g) > P_1(b)$ for all $n_1 > 0$ by Lemma **??**, we have ruled out $\lim_{n_1\to 0} P_1(b) > \bar{P}_1$. Now suppose for a contradiction that $\lim_{n_1\to 0} P_1(b) = \bar{P}_1$. If $B_1^U(b) = 0$, uninformed investors' consumption is invariant to the state. By the first-order condition for bids at $P_1(g)$, these investors are indifferent on the margin between buying and selling a bond that defaults with probability $\bar{\kappa}_1$. Since $\lim_{n_1\to 0} P_1(b) = \bar{P}_1$, the continutity of marginal utility implies that there exists $\bar{n}_1 > 0$ sufficiently close to zero such that it is strictly optimal to submit negative bids at $P_1(b)$ because the associated bonds default with probability $\kappa_1(b) > \bar{\kappa}_1$. Contradiction.

Next, we show that $P_1(b) < \bar{P}_1$ for all $n_1 > 0$. Suppose for a contradition 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 $P_1(g) \geq P_1(b)$ by Lemma **??**. 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 $X_1^U(g) \leq X_1^U(g)$. Hence $n_1X_1^I(b) + (1-n_1)X_1^U(b) < D_1$, a contradiction with the market-clearing condition.

Q.E.D.

B.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 and its proof show that the informed equilibrium satisfies $\lim_{n_1 \to 0} P_1(g) = \bar{P}_1$, $\lim_{n_1 \to 0} P_1(b) < \bar{P}_1$, $\lim_{n_1 \to 0} P_1(b) < \bar{P}_1$, $\lim_{n_1 \to 0} B_1^U(g) = \bar{B}_1$ and $\lim_{n_1 \to 0} B_1^U(b) = 0$. Hence in the limit as $n_1 \to 0$, 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 $n_1 \to 0$. By the fact that $\lim_{n_1 \to 0} P_1(g) = \bar{P}_1$, 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 $P_1^0(b) \equiv \lim_{n_1 \to 0} P_1(b)$. 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 $\Delta \bar{V} < \lim_{n_1 \to 0} \Delta V(n_1)$, and we can find a cost of information such that it is strictly suboptimal 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.

B.4 Proof of Proposition 7

We first state a proposition on the general properties of cross-country spillovers.

Proposition 7 (Risk-based contagion)**.** *Assume there are no informed investors in either country. Then the following statements hold:*

(i) An increase in κ_1 simultaneously decreases prices in both countries if and only if

$$\left[\frac{\partial F_1}{\partial P_1}\frac{\partial F_2}{\partial P_2} - \frac{\partial F_1}{\partial P_2}\frac{\partial F_2}{\partial P_1}\right]\left[-\frac{\partial F_{-j}}{\partial P_{-j}}\frac{\partial F_j}{\partial \bar{\kappa}_1} + \frac{\partial F_j}{\partial P_{-j}}\frac{\partial F_{-j}}{\partial \bar{\kappa}_1}\right] < 0 \quad \textit{for all } j.$$

(ii) There is contagion through the default risk channel ($\partial F_j/\partial \kappa_{-j} < 0$) if and only if there is decreasing absolute risk aversion. There is no cross-country contagion ($\partial F_j/\partial \kappa_{-j} = \partial F_j/\partial P_{-j} = 0$) if and only if there is constant absolute risk aversion.

(iii) Under decreasing absolute risk aversion, a shock to $\bar{\kappa}_1$ that lowers P_1 also lowers P_2 if

$$\frac{\partial F_j}{\partial P_{-j}} > \frac{\frac{\partial F_{-j}}{\partial P_{-j}}\frac{\partial F_j}{\partial \bar{\kappa}_1}}{\frac{\partial F_{-j}}{\partial \bar{\kappa}_1}} \quad \textit{where} \quad \frac{\frac{\partial F_{-j}}{\partial P_{-j}}\frac{\partial F_j}{\partial \bar{\kappa}_1}}{\frac{\partial F_{-j}}{\partial \bar{\kappa}_1}} < 0.$$

The proposition first states a general necessary and sufficient condition for contagion. The first term on the left-hand side compares the magnitude of within-country price effects with cross-country price effects, while second term determines the magnitude of contagion due to default risk. The second statement in the proposition shows that the sign of the default risk contagion channel is determined by the properties of investors' absolute risk aversion: there is contagion through default risk if and only if there is decreasing absolute risk aversion (DARA). This is because an increase in default risk places more weight on states with low consumption. Under DARA, this leads to an increase in average risk aversion and a higher required risk premium. With constant absolute risk aversion (CARA) instead, a level change in consumption does not change the required risk premium and prices are perfectly insulated from fundamental shocks in the other country.

The sign of the pure price contagion channel is $\partial F_j/\partial P_{-j}$ is ambiguous under DARA. To account for this, the third statement provides a sufficient condition for simultaneous price decreases which ensures that any positive spillovers from pure price contagion do not not outweigh the negative spillovers from default risk contagion. (We provide sufficient conditions for negative price spillovers below.)

First Statement. Write the system of first-order conditions in vector form as

$$\begin{bmatrix} F_1 \\ F_2 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

Differentiating with respect to $\bar{\kappa}_1$ and applying the implicit function theorem gives

$$\begin{bmatrix} \frac{\partial F_1}{\partial P_1} & \frac{\partial F_1}{\partial P_2} \\ \frac{\partial F_2}{\partial P_1} & \frac{\partial F_2}{\partial P_2} \end{bmatrix} \begin{bmatrix} \frac{\partial P_1}{\partial \bar{\kappa}_1} \\ \frac{\partial P_2}{\partial \bar{\kappa}_1} \end{bmatrix} = \begin{bmatrix} -\frac{\partial F_1}{\partial \bar{\kappa}_1} \\ -\frac{\partial F_2}{\partial \bar{\kappa}_1} \end{bmatrix}$$

Define the determinant of the square matrix as

$$\det = \frac{\partial F_1}{\partial P_1}\frac{\partial F_2}{\partial P_2} - \frac{\partial F_1}{\partial P_2}\frac{\partial F_2}{\partial P_1}$$

Then

$$\begin{bmatrix} \frac{\partial P_1}{\partial \bar{\kappa}_1} \\ \frac{\partial P_2}{\partial \bar{\kappa}_1} \end{bmatrix} = \frac{1}{\det} \begin{bmatrix} \frac{\partial F_2}{\partial P_2} & -\frac{\partial F_1}{\partial P_2} \\ -\frac{\partial F_2}{\partial P_1} & \frac{\partial F_1}{\partial P_1} \end{bmatrix} \begin{bmatrix} -\frac{\partial F_1}{\partial \bar{\kappa}_1} \\ -\frac{\partial F_2}{\partial \bar{\kappa}_1} \end{bmatrix}$$

The first statement follows from this expression.

Second Statement. We will first show that there is no contagion with CARA preferences. Without loss of generality, 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 resulting consumption profile depends only on the default decisions δ_1 and δ_2,

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

where $\delta_j = 1$ if j defaults and $\delta_j = 0$ otherwise. Expected marginal utility conditional on δ_j is

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

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

$$(1 - \bar{\kappa}_1)(1 - P_1)m_1(0) - \bar{\kappa_1} P_1 m_1(1) = 0 \tag{4}$$
$$(1 - \bar{\kappa}_2)(1 - P_2)m_2(0) - \bar{\kappa_2} P_2 m_2(1) = 0. \tag{5}$$

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

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

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 any variables indexed by $-j$.

Based on this new notation, $F_j = y_j - \frac{\kappa_j}{1-\bar{\kappa}_j} \widetilde{M}_j$. Hence

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

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 (as we discussed this is zero with CARA). Hence $\frac{\partial F_j}{\partial \bar{\kappa}_{-j}} < 0$. Differentiating $\widetilde{M}_j$ with respect to $\bar{\kappa}_{-j}$ yields

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

Observe that

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

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 Ω strictly decreasing in $\tilde{W}$ for any $B, \tilde{W} > 0$. This holds by definition of DARA since

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

Third Statement. By the second statement, we have that $\frac{\partial F_{-j}}{\partial P_{-j}}$, $\frac{\partial F_j}{\partial \bar{\kappa}_1}$, $\frac{\partial F_{-j}}{\partial \bar{\kappa}_1}$ are all strictly negative. Under the stated condition, we therefore have the that the second term of the condition in Statement (i) is strictly negative for each j. If prices are to decline in Country 1, we must have $\frac{\partial F_1}{\partial P_1}\frac{\partial F_2}{\partial P_2} - \frac{\partial F_1}{\partial P_2}\frac{\partial F_2}{\partial P_1} > 0$, and Country 2 prices also decline.

Q.E.D.

B.5 Proof of Corollary ??

There is pure price contagion if $\partial F_j / \partial P_{-j} > 0$. From the third statement of Proposition 7 this is the case if and only if,

$$\frac{\partial \widetilde{M}_j}{\partial B_{-j}} > 0 \Leftrightarrow \frac{-u''(w + B_{-j})}{u'(w + B_{-j})} < \frac{-u''(w + B_j + B_{-j})}{u'(w + B_j + B_{-j})} \left[\frac{1 - \bar{\kappa}_{-j} + \bar{\kappa}_{-j} \frac{u'(w)}{u'(w + B_{-j})}}{1 - \bar{\kappa}_{-j} + \bar{\kappa}_{-j} \frac{u'(w + B_j)}{u'(w + B_j + B_{-j})}} \right].$$

We can rewrite this condition as

$$\frac{-u''(w+B_{-j})}{u'(w+B_{-j})} < \frac{-u''(w+B_j+B_{-j})}{u'(w+B_j+B_{-j})}\left[\frac{\frac{(1-\bar{\kappa}_{-j})u'(w+B_{-j})+\bar{\kappa}_{-j}u'(w)}{u'(w+B_{-j})}}{\frac{(1-\bar{\kappa}_{-j})u'(w+B_j+B_{-j})+\bar{\kappa}_{-j}u'(w+B_j)}{u'(w+B_j+B_{-j})}}\right].$$

Cancelling $u'(w+B_j+B_{-j})$ in the denominator

$$\frac{-u''(w+B_{-j})}{u'(w+B_{-j})} < \frac{-u''(w+B_j+B_{-j})}{u'(w+B_j)}\left[\frac{(1-\bar{\kappa}_{-j})u'(w+B_{-j})+\bar{\kappa}_{-j}u'(w)}{(1-\bar{\kappa}_{-j})u'(w+B_j+B_{-j})+\bar{\kappa}_{-j}u'(w+B_j)}\right].$$

Cancelling $u'(w+B_j)$ in both sides and rearranging

$$\frac{-u''(w+B_{-j})}{(1-\bar{\kappa}_{-j})u'(w+B_{-j})+\bar{\kappa}_{-j}u'(w)} < \frac{-u''(w+B_j+B_{-j})}{(1-\bar{\kappa}_{-j})u'(w+B_j+B_{-j})+\bar{\kappa}_{-j}u'(w+B_j)}.$$

In the limit as $D_{-j} \to 0$, we have that $B_{-j} \to 0$ and the condition is not fulfilled by DARA. In the limit as $w \to 0$, the left hand side goes to 0 and the condition is fulfilled.

B.6 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.**

B.7 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

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

We compute a second-order Taylor approximation of the objective function around $B^i_j(\theta_j) = 0$ for all i, all j, and all θ_j. For informed investors, the associated first-order conditions with respect to $B^i_1(g)$, $B^i_1(b)$ and B^i_2 are, respectively,

$$
\begin{aligned}
0 =& f_1(g)(1-\kappa_1(g)-P_1(g))U'(W) \\
&+ f_1(g)\Big[\kappa_1(g)(-P_1(g))^2 + (1-\kappa_1(g))(1-P_1(g))^2\Big]U''(W)B^I_1(g) \\
&+ f_1(g)(1-\kappa_1(g)-P_1(g))(1-\bar{\kappa}_2-P_2)U''(W)B^I_2
\end{aligned}
\tag{6}
$$

$$
\begin{aligned}
0 =& f_1(b)(1-\kappa_1(b)-P_1(b))U'(W) \\
&+ f_1(b)\Big[\kappa_1(b)(-P_1(b))^2 + (1-\kappa_1(b))(1-P_1(b))^2\Big]U''(W)B^I_1(b) \\
&+ f_1(b)(1-\kappa_1(b)-P_1(b))(1-\bar{\kappa}_2-P_2)U''(W)B^I_2
\end{aligned}
\tag{7}
$$

$$
\begin{aligned}
0 =& (1-\bar{\kappa}_2-P_2)U'(W) \\
&+ \Big[\bar{\kappa}_2(-P_2)^2 + (1-\bar{\kappa}_2)(1-P_2)^2\Big]U''(W)B^I_2 \\
&+ f_1(g)(1-\bar{\kappa}_2-P_2)(1-\kappa_1(g)-P_1(g))U''(W)B^I_1(g) \\
&+ f_1(b)(1-\bar{\kappa}_2-P_2)(1-\kappa_1(b)-P_1(b))U''(W)B^I_1(b)
\end{aligned}
\tag{8}
$$

Define informed expected rates of return by $\tilde{r}^I_1(g) = \frac{1-\kappa_1(g)-P_1(g)}{P_1(g)}$, $\tilde{r}^I_1(b) = \frac{1-\kappa_1(b)-P_1(b)}{P_1(b)}$ and $\tilde{r}^I_2 = \frac{1-\bar{\kappa}_2-P_2}{P_2}$ and let $\sigma^I_1(g)$, $\sigma^I_1(b)$, and σ^I_2 denote the associated standard deviations. The first term of the RHS of (6) 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

$$
f_1(g)\Big[\kappa_1(g)(-P_1(g))^2+(1-\kappa_1(g))(1-P_1(g))^2\Big]U''(W)B^I_1(g) = f_1(g)\mathbb{E}\left[\left(r^I_1(g)\right)^2\right]P_1(g)^2U''(W)B^I_1(g)
$$

All other terms in equations (6)-(8) can be analogously rewritten. Let $U(c) = \frac{c^{1-\gamma}-1}{1-\gamma}$, and define the state-contingent portfolio weights $\omega^I_1(g) = \frac{P_1(g)B^I_1(g)}{W}$, $\omega^I_1(b) = \frac{P_1(b)B^I_1(b)}{W}$, and $\omega_2^I = \frac{P_2 B_2^I}{W}$. Since $Var(x) = \mathbb{E}[x^2] - (\mathbb{E}[x])^2$, the system of equations is

$$\tilde{r}_1^I(g) = \gamma\omega_1^I(g)\left(\left(\sigma_1^I(g)\right)^2 + \left(\tilde{r}_1^I(g)\right)^2\right) + \gamma\omega_2^I\left(\tilde{r}_1^I(g)\tilde{r}_2^I\right) \tag{9}$$

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

$$\tilde{r}_2^I = \gamma\omega_2^I\left(\left(\sigma_2^I\right)^2 + \left(\tilde{r}_2^I\right)^2\right) + f_1(g)\gamma\omega_1^I(g)\tilde{r}_1^I(g)\tilde{r}_2^I + f_1(b)\gamma\omega_1^I(b)\tilde{r}_1^I(b)\tilde{r}_2^I \tag{11}$$

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 σ_g, σ_b, and σ_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 volatities:

$$\omega_g = \left(\frac{R_g}{\sigma_g^2 + R_g^2}\right)(1 - \omega_2 R_2)$$

$$\omega_b = \left(\frac{R_b}{\sigma_b^2 + R_b^2}\right)(1 - \omega_2 R_2)$$

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

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

$$R_g\omega_g = s_g\left(1 - R_2\omega_2\right)$$

$$R_b\omega_b = s_b\left(1 - R_2\omega_2\right)$$

$$R_2\omega_2 = s_2\left(1 - f_1(g)R_g\omega_g - f_1(b)R_b\omega_b\right)$$

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

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

It follows that

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

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.

B.8 Proof of Proposition 6

First Statement. Let all investors be uninformed. Since all investors are symmetric, there is no arbitrage across markets. If they are no price differences across markets, all investors must hold the same portfolio ex-post. Since no information is revealed at any stage, any equilibrium must feature the same allocation as the auction equilibrium.

Second Statement. Consider the bad state. If $P_j(b) > \hat{P}_j(b)$, it is strictly optimal to submit zero bids at auction, which is a contradiction with auction market clearing. Next, suppose $P_j(b) < \hat{P}_j(b)$. Recall that all investors' bids at $P_j(b)$ are executed if and only if $\theta_1 = b$. Hence is strictly optimal for all investors to sell bonds in the secondary market. Hence the secondary market cannot clear. Now consider the good state. By auction market-clearing, we cannot have $P_j(g) > \hat{P}_j(g)$ because all investors would then strictly prefer to trade in the secondary market. Next, we show that we must have $P_j(g) < \hat{P}_j(g)$. Suppose not, $P_j(g) = \hat{P}_j(g)$. Then uninformed investors can trade under perfect information in the secondary market but receive the same price as in the auction. Hence the value of information is zero, and there is no incentive to become informed. $P_j(g) < \hat{P}_j(g)$ is sustainable in equilibrium because uninformed investors are adversely selected if buying at auction. Hence as long as $\hat{P}_j(g) - P_j(g)$ is sufficiently small, uninformed investors strictly prefer to buy in the secondary market.

Suppose $\theta_j = b$, both informed and uninformed investors would trade to arbitrage price differences (recall that uninformed bids at the low price are accepted if and only if $\theta_1 = b$). But if all investors take the same side of the arbitrage in the primary market, then the secondary market cannot clear. Now turn to the good state. If

$P_j(g) > q_j(g)$, then all investors find it strictly optimal to wait, and the primary market does not clear. Hence the informed cannot do better than the uninformed, and there are no incentives to acquire information. Hence, when there is information in the auction it must be that $P_j(g) < q_j(g)$.

Now, turning to bids, informed investors fully exploit the arbitrage opportunity using all wealth allocated to country j to buy bonds in the good state and by selling a fraction to uninformed investors in the secondary market. Uninformed investors cannot exploit the arbitrage in the same manner ecause they run the risk of overpaying in the bad state. To see why arbitrage can persist, note that the supply of assets in the secondary market is bounded above by $\sum_{i:a_j^i=1} \frac{n^i \tilde{W}}{P_j(g)}$, while the demand for bonds in the primary market is decreasing in the fraction of informed investors. All else equal, reducing the number of informed investors thus widens the gap between primary and secondary market prices in the high state.

Third statement. In the limit $n_1 \to 0$, almost all investors are ex-ante identical. By market-clearing, it follows trivially that auction prices must converge to the limiting prices of the auction-only equilibrium. Now consider the limit of secondary market prices. Since $\hat{P}_1(b) = P_1(b)$ for all $n_1 > 0$, we have $\lim_{n_1\to 0} \hat{P}_1(b) = \lim_{n_1\to 0} P_1^A(b)$. Next consider the high state. The case $\lim_{n_1\to 0} \hat{P}_1(g) < \lim_{n_1\to 0} P_1(g)$ can be immediately ruled out by the second statement. Suppose for a contradiction that $\lim_{n_1\to 0} \hat{P}_1(g) = \lim_{n_1\to 0} P_1(g)$. Since $\lim_{n_1\to 0} P_1(b) < \lim_{n_1\to 0} P_1(g)$, 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. **Q.E.D.**

Proposition 8 (Value of Information)**.** *When there are secondary markets after the auction:*

(i) As $n_1 \to 0$, the value of information is strictly higher than without secondary markets.

(ii) The range of information costs for which an informed equilibrium exists is strictly larger.

(iii) If and only if $n_1 \geq \hat{n}_1 \equiv \frac{D_1}{W-D_2}$, the value of information is zero, the equilibrium with secondary markets delivers the same allocations and prices as the full information auction equilibrium, and there is no cross-market arbitrage, $P_j(\theta_j) = \hat{P}_j(\theta_j)$ for all θ_j.

(iv) Any equilibrium with endogenous information acquisition satisfies $n_1 < \hat{n}_1$.

B.9 Proof of Proposition 8

First Statement. By Proposition 6, $\lim_{n_1\to 0} \hat{P}_j(\theta_j) = \lim_{n_1\to 0} P_j^A(\theta_j)$ and $\lim_{n_1\to 0} \hat{P}_1(g) > \lim_{n_1\to 0} P_1(g)$. By the Inada condition, it is always strictly optimal to invest a strictly positive amount of wealth into the risk-free asset in the auction equilibrium say $\tilde{W}$. The following is a feasible portfolio that generates strictly higher utitlity than the optimal auction-only portfolio: (i) buy the same portfolio at auction, (ii) in addition spend

$\tilde{W}$ on bonds in state g in Country 1, and (iii) sell the additional bonds purchased with $\tilde{W}$ in the secondary market at a strict profit. This portfolio has higher average returns and less volatility, and so it is strictly preferred. Since uninformed investors obtain the same utility as in the auction equilibrium in the limit $n_1 \to 0$, the result follows.

Second Statement. Follows immediately from the first statement.

Third Statement. There is enough informed capital to fully arbitrage prices if and only if $n \geq \hat{n}_1$. Let $\widehat{P}_1(g)d$, $\widehat{B}^I(g)$, 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 $\widehat{P}_2\widehat{B}_2^I$ in Country 2. By auction-clearing, $\widehat{P}_2\widehat{B}_2^I = D_2$. 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 $\widehat{P}_1$ if $\theta_1 = g$, we require that $n_1(W - D_2) \geq \widehat{P}_1 B_1^I(g) = D_1$, where the last equality follows from auction clearing. This holds iff $n_1 \geq \hat{n}_1$. Hence iff $n \geq \hat{n}_1$, we can construct an equilibrium in which informed investors buy the entire supply of bonds in the primary market when $\theta_1 = g$, and then sell some of these bonds to uninformed investors in the secondary market at the same price. This implies that uninformed investors can buy bonds as if they were informed and choose not to participate in primary markets. Hence the equilibrium must be such that all prices are identical to the fully informed equilibrium.

Fourth statement. By the third statement, uninformed investors choose the same ex-post portfolio as informed investors if and only if $n_1 \geq \hat{n}_1$. Hence the value of information is positive if and only if $n_1 < \hat{n}_1$.

C Further Background on the Eurozone Crisis

In this section, we provide futher 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."[10] Through the lens of our model, it is thus a case study for information spillovers.

In the main text, we showed yields for one-year bonds. We now also show them for six-month bonds in Figure 14. 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 15 shows the spread between primary and secondary yields for each country and each maturity.

D 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

[10] "Debt Contagion Threatens Italy" New York Times, July 11, 2011.

Figure 14: Real Annualized Yields

(a) One year maturity (b) Half year maturity

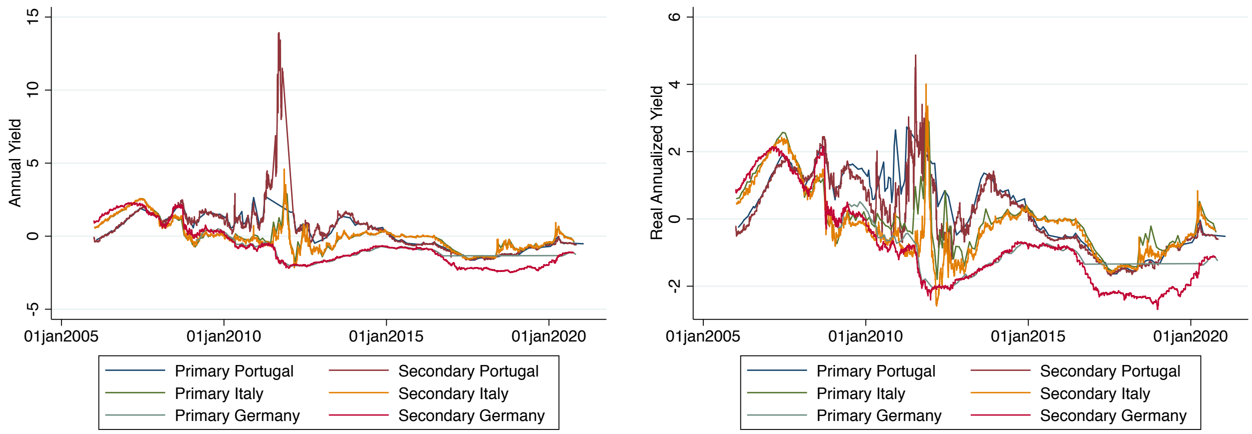

Figure 15: Spreads between primary and secondary yields

(a) One year maturity (b) Half year maturity

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 (€)	✓	✓	*Incomplete*
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.

D.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,[11] and information about the operation and institutional details of auctions.[12]. We have complemented some of the informa-

[11]https://www.deutsche-finanzagentur.de/en/institutional-investors/primary-market/auction-results/

[12]https://www.deutsche-finanzagentur.de/en/institutional-investors/primary-market/auction-results/

tion with data from the Bundensbank.[13]

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 [14]. 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 average 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.

[13] https://www.bundesbank.de/resource/blob/706804/599ea32756aa5d2d8c9493b8a028e886/mL/2007-07-public-sector-debt-data.pdf

[14] 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.

D.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,[15] and information about the operation and institutional details of auctions.[16] [17]

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 "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 [18]. Another index called the

[15] http://www.dt.mef.gov.it/en/debito_pubblico/emissioni_titoli_di_stato_interni/risultati_aste/

[16] http://www.dt.mef.gov.it//export/sites/sitodt/modules/documenti_en/debito_pubblico/specialisti_titoli_di_stato/Specialists_evaluation_criteria_-_year_2019.pdf

[17] http://www.dt.mef.gov.it/en/debito_pubblico/titoli_di_stato/quali_sono_titoli/bot/

[18] 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.

"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.[19]

D.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 infomration about auctions results,[20] and information about the operation and institutional details of auctions.[21]

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 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)[22]. 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

[19] 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.

[20] https://www.igcp.pt/en/1-4-399/auctions/bt-auctions/

[21] https://www.igcp.pt/fotos/editor2/2015/Legislacao/Instrucao_BT_1_2015_UK.pdf

[22] 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).

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.

E 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.

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	✗	✗	✗	✗	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.

E.1 Germany

Nominal and inflation-linked German government securities as well as bills are traded on German stock exchanges, numerous international electronic trading platforms and on the over-the-counter (OTC) market. Unlike many other countries, the German Primary Dealers do not have strict market maker obligations, especially in the secondary market.[23] 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.

E.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.[24] Other indices used to evaluate Specialists include cash traded volumes parameter, depth contribution indices, repo traded volumes, etc.

[23] 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.

[24] 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.

E.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.[25] 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.

[25]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.