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Par

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Essays on Sovereign Bond Markets

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Résumé en Français

Résumé - Chapitre 1

Certains investisseurs détiennent des informations que le marché n'a pas. Parmi les investisseurs les mieux informés, il y a les vendeurs à découvert: Les vendeurs à découvert gagnent des rendements anormaux (Cohen, Diether et Malloy (2007), Boehmer, Jones et Zhang (2008)), détectent les fraudes financières (Karpoff et Lou (2010)), votent mieux (Christoffersen, Geczy, Musto et Reed (2007)) et améliorent l'incorporation de l'information (Boehmer et Wu (2013)). La littérature sur l'information supérieure des vendeurs à découvert a presque été exclusivement axée sur le marché action. En particulier, aucun article n'a examiné si les vendeurs à découvert d'obligations souveraines disposent d'informations supérieures. Pourtant, une branche de la littérature sur les obligations souveraines souligne l'existence d'informations supérieures: Brandt et Kavajecz (2004) constatent que le *trading* sur le marché des obligations d'État est informé, tandis que Green (2004) constate que l'asymétrie d'information augmente après la publication de nouvelles macroéconomiques.

Dans cet article, je propose d'étendre au contexte des enchères d'obligations souveraines l'étude de l'information supérieure des vendeurs à découvert. J'étudie si les vendeurs à découvert sont mieux informés sur les enchères souveraines que le marché. J'identifie les changements de demande de vente à découvert par un changement simultané du volume et du coût de vente à découverte via les transactions repo ayant comme collatéral des obligations sur le point d'être émises. En utilisant les obligations italiennes sur la période 2005-2012, je trouve une forte augmentation moyenne de la demande de vente à découvert avant les enchères: Le volume de repo et la *specialness* (c.-à-d. le coût de vente à découvert) augmentent de 30% et 13 points de base, respectivement, à la veille du jour de l'enchère par rapport à quatre jours avant. Deuxièmement, je ne trouve pas qu'une augmentation de la demande de vente à découvert avant une vente aux enchères prédit une augmentation du rendement le jour de l'enchère. Par conséquent, les vendeurs à découvert ne prévoient pas les résultats de l'enchère. Troisièmement, les obligations

pour lesquelles la demande de vente à découvert a augmenté le jour de l'enchère ont plutôt tendance à avoir une rentabilité future plus faible que les autres obligations. Toutefois, la rentabilité obtenue en vendant à découvert le jour de l'enchère et en rachetant cinq jours après l'enchère n'est pas significativement différente de zéro. Par conséquent, il n'y a aucune preuve que les vendeurs à découvert interprètent mieux les résultats d'enchères que le marché. Dans l'ensemble, je ne trouve pas que les vendeurs à découvert aient des informations supérieures à propos des enchères d'obligations souveraines.

Le sujet de cet article est pertinent. Tout d'abord, la réponse à la question de recherche n'est pas évidente. Bien que les ventes à découvert soient utilisées par les *market-makers* dans la période des enchères (Keane (1996), Moulton (2004)), cela n'exclut pas l'existence d'information supérieure à propos des enchères compte tenu du fait que le *trading* d'obligations d'État est informé (Brandt et Kavajecz (2004)), en particulier autour des événements macroéconomiques (Green (2004)).

Deuxièmement, une question importante – mais complexe – concernant l'information supérieure des vendeurs est celle de la provenance de cette information: S'agit-il d'informations d'*insiders* ou bien d'une capacité supérieure d'analyse de la part des vendeurs à découvert. L'étude de la vente à découvert d'obligations d'État présente un avantage par rapport au marché action: Le délit d'initié est peu probable. Cela permet déterminer plus précisément la source de l'information.

Troisièmement, les ventes aux enchères sont des événements importants, récurrents, où est déterminé le coût de la dette des pays souverains. L'étude de l'information supérieure que posséderaient les vendeurs à découvert permet d'approfondir notre compréhension de la façon dont l'information est produites dans cette période cruciale pour les états. De plus, le marché principal pour emprunter des obligations souveraines – à savoir le marché repo – est un marché qui présente un volume de transactions moyen de plus de 180 milliards d'euros par jour en Europe. C'est un marché important pour le financement (Gordon et Metrick (2012)) et pour le prêt de titres (Duffie (1996)). Il existe une littérature en croissance mais encore peu développée sur ce marché. Par conséquent, l'étude de la vente à découvert d'obligations d'État participe à l'étude du marché repo.

Voici les trois points principaux de ma méthodologie. Tout d'abord, j'étudie si la vente à découvert prévoit les rendements futurs. Pour mesurer la vente à découvert, j'utilise un changement simultané de deux variables: Une variable de volume et une variable de prix. Plus précisément, je considère qu'une augmentation (diminution) simultanée du *short interest* et du coût de vente à découvert est indicatrice d'une augmentation (diminution) de la demande de vente à découvert. Je vérifie ensuite si le changement de demande de vente à découvert prédit les rendements futurs. Cette méthodologie permet d'éviter de capturer la vente à découvert imputée aux variations de l'offre de prêt d'actifs. En effet, si une augmentation du coût de la vente à découvert peut provenir d'une diminution de l'offre de prêt d'actifs, une augmentation simultanée du coût et du volume de vente à découvert provient nécessairement d'une augmentation de la demande de vente à découvert. Et comme l'ont trouvé Cohen, Diether et Malloy (2007), seules la variation de la demande prédit les rendements futurs.

Deuxièmement, pour mesurer le *short interest* et le coût de vente à découvert, j'utilise le marché de "repo spécial". La façon principale de vendre des obligations souveraines à découvert est d'effectuer une transaction sur ce marché. Le parti intéressé à l'emprunt d'un actif prête de l'argent à un taux appelé *special rate* qui est généralement inférieur à un taux en vigueur appelé *general collateral*: La différence entre ces deux taux s'appelle *specialness* et est utilisée comme mesure du coût de vente à découvert. En échange, le prêteur d'argent reçoit l'actif en collatéral. Étant donné que la grande majorité des opérations de repo ont une durée d'un jour, j'utilise le volume journalier des transactions repo comme une mesure du *short interest* de l'obligation.

Troisièmement, je me concentre sur les réémissions. Les réémissions sont des ventes aux enchères qui augmentent le volume des obligations existantes, au lieu d'entraîner l'émission de nouvelles obligations. Les obligations réémises se négocient donc sur des marchés liquides avant leur réémission.

Cet article s'adresse à trois volets de la littérature. Tout d'abord, il s'adresse à la littérature de la vente à découvert. L'écrasante majorité de cette littérature se concentre sur le marché action. Le consensus est que les ventes à découvert prédisent des rendements négatifs anormaux et que les investisseurs sont informés (voir par

exemple Jones et Lamont (2002), Desai, Ramesh, Thiagarajan et Balachandran (2002), Boehmer, Jones et Zhang (2008)).

Cohen, Diether et Malloy (2007) est l'article sur les ventes à découvert d'actions le plus proche du mien. Ils constatent qu'une augmentation de la demande de vente à découvert d'une action prédit des rendements anormaux négatifs. Comme Cohen, Diether et Malloy (2007), je distingue les augmentations de vente à découvert dues aux augmentations de la demande et celles dues aux augmentations de l'offre de prêt d'actif. Cependant, contrairement à Cohen, Diether et Malloy (2007), j'étudie les obligations souveraines et non les actions. Aussi, contrairement à eux, je ne trouve pas que l'augmentation de la demande de vente à découvert prédise la rentabilité future.

Il existe une petite sous-branche de la littérature de vente à découvert autre que sur le marché action. Asquith, Au, Covert et Pathak (2013) constatent que les vendeurs à découvert des obligations d'entreprises ne sont pas informés. Comme Asquith, Au, Covert et Pathak (2013), j'étudie la vente à découvert d'obligations et je demande si les vendeurs à découvert sont informés. Comme eux, je trouve qu'ils ne sont pas informés. Cependant, j'étudie les obligations souveraines alors qu'ils étudient les obligations d'entreprises. Banerjee et Graveline (2013) constatent que les vendeurs à découvert des bonds du trésor Américain paient une prime de liquidité pour emprunter des actifs liquides. Comme Banerjee et Graveline (2013), j'étudie la vente à découvert des obligations d'État. Cependant, contrairement à eux, je demande si les vendeurs à découvert possèdent de l'information supérieure.

Deuxièmement, cet article se rapporte à une petite littérature qui étudie l'information sur les marchés obligataires souverains. Brandt et Kavajecz (2004) constatent que le flux d'ordre d'obligations d'État est informé. Green (2004) constate que le *trading* sur le marché du Trésor devient plus informé après la publication de nouvelles macroéconomiques. Il constate également qu'il n'y a pas d'asymétrie d'information avant la publication d'informations macroéconomiques. Comme Brandt et Kavajecz (2004) et Green (2004), j'étudie l'information supérieure qui se trouverait sur le marché des obligations souveraines. Cependant, contrairement à eux, j'analyse les ventes à découvert et ne trouve aucune information supérieure.

Enfin, cet article se rapporte à la littérature sur le marché repo pendant la période des enchères. Keane (1996) et Moulton (2004) étudient la *specialness* autour des enchères. Comme Keane (1996) et Moulton (2004), je trouve que la *specialness* augmente avant les enchères. Contrairement à eux, j'observe également le volume des opérations de repo. Cela permet d'isoler les augmentations des ventes à découvert dues à la demande, et de ne pas inclure les augmentations des ventes à découvert due à l'offre de prêt d'actifs.

Résumé - Chapitre 2

La liquidité du marché repose sur des intermédiaires ("fournisseurs de liquidité") agissant comme un tampon entre les acheteurs et les vendeurs. Ces fournisseurs de liquidité peuvent acheter et vendre à la demande et de manière rentable en raison de leur présence continue sur le marché (Grossman et Miller (1988)). En particulier, les fournisseurs de liquidité jouent un rôle de premier plan dans les enchères où ils peuvent acheter de gros volumes d'actifs à rabais. Cependant, le bénéfice tiré de la participation aux enchères est incertain car dépend de la présence ou non de contreparties naturelles au jour de l'enchère: Une présence plus importante qu'attendue de contreparties naturelles peut considérablement réduire le besoin de liquidité. En effet, il y a des variations importantes quant à qui achète les bons du Trésor: Les contreparties naturelles - tels que les fonds d'investissement - peuvent acheter aux enchères de 0% à 46% d'une émission de bonds du Trésor Américain (Fleming (2007)). Dans cet article, je fais un lien entre les prix secondaires et cette incertitude sur la présence d'acheteurs naturels. Ce sujet est intéressant pour les émetteurs parce qu'ils utilisent les prix secondaires pour prendre des décisions d'émission et pour évaluer le résultat des enchères.

Plus précisément, je développe et teste une théorie expliquant pourquoi les prix des obligations diminuent progressivement quelques jours avant les enchères du Trésor, telles que rapportées par Lou, Yan et Zhang (2013) et étudiées dans Duffie (2010). Lou, Yan et Zhang (2013) constatent que, dans les quelques jours qui précèdent les ventes aux enchères des bonds du Trésor Américain, les prix secondaires des obligations similaires diminuent progressivement, atteignent un minimum le jour de l'enchère et augmentent graduellement. Ce schéma de prix se manifeste dans

différents contextes: Premièrement, il se produit dans les enchères des bonds du Trésor, y compris dans les cas où le phénomène *on/off-the-run* est absent (voir la section empirique de cet article); dans d'autres types d'enchères telles que les SEOs (Corwin (2003)) ou la fixation du cours de l'or (US District Court (2014)); et avant les ventes anticipés de contrats futurs (Bessembinder et al. (2016)).

Ce schéma de variation de prix est difficile à comprendre dans le sens où il implique que certains investisseurs sont prêts à acheter des obligations avant l'enchère à un prix qui, en moyenne, dépasse le prix espéré de l'enchère. Certes, les investisseurs qui ont besoin d'acheter l'obligation avant la vente aux enchères seraient prêts à payer une prime (égale à la moitié du bid-ask spread) plutôt que d'acheter le jour de l'enchère à un prix ex-ante incertain (Grossman et Miller (1988)). Mais, à l'inverse, les vendeurs seraient prêts à consentir un rabais pour vendre avant l'enchère. Par conséquent, le prix moyen avant l'enchère devrait être égal au prix espéré au jour de l'enchère. Au lieu de cela, le schéma de prix observé est tel que le prix avant l'enchère est supérieur aux prix au jour de l'enchère. Ainsi, les investisseurs qui ont besoin d'acheter l'obligation avant l'enchère paient une prime supérieure au rabais que consentent ceux qui ont besoin de vendre. Il existe donc une asymétrie que le modèle de cet article prédit et explique.

Dans le modèle, les investisseurs averses au risque anticipent une vente d'actifs dont l'ampleur – et donc le prix – sont incertains. Tout d'abord, je montre que les investisseurs font face à un compromis: Ils peuvent spéculer sur la différence entre le prix avant l'enchère et le prix espéré au jour de l'enchère, ou ils peuvent se couvrir (*hedging*) du risque de prix avec une position longue. Plus précisément, le besoin de *hedging* vient de l'incertitude quant au montant du rabais auquel l'investisseur achètera au vendeur: Pour *hedger* cette incertitude, on peut prendre une position longue qui s'apprécie lorsque le prix de vente est élevé et, par conséquent, lorsque le rabais est faible. Deuxièmement, je montre que le prix d'équilibre est supérieur au prix de vente espéré en raison du *hedging*. Troisièmement, à mesure que l'incertitude sur le prix de vente diminue, les positions spéculatives à découvert augmentent et le prix diminue.

Pour tester les implications du modèle, j'utilise les enchères du Trésor italien de 2000 à 2015. Comme prédit par le modèle, je montre que les rendements des obligations

augmentent de 1,2 points de base de plus que les autres jours au moment où le Trésor se réunit avec les *primary dealers* et lorsque le Trésor annonce la taille de l'enchère. Enfin, la stratégie empirique de cet article permet d'exclure d'autres explications telles que le phénomène *on / off-the-run*.

Comprendre la baisse graduelle des prix avant les enchères du Trésor est importante pour plusieurs raisons. Premièrement, les prix avant les enchères servent de benchmarks pour le prix des enchères et peuvent être utilisés dans les décisions d'émission (Faulkender (2005)). En outre, si la baisse du prix est due à du *front-running* (Brunnermeier et Pedersen (2005)), il pourrait être préférable pour l'émetteur de révéler peu d'information sur la taille de l'enchère plutôt que de l'annoncer, comme c'est le cas en pratique (Sundaresan (1994)). Deuxièmement, alors que la littérature a étudié les prix après une large vente (Grossman et Miller (1988)), le prix avant la vente a été peu étudié. De plus, les théories existantes des prix post-vente ne s'appliquent pas aux prix avant la vente. Par exemple, Grossman et Miller (1988) supposent que les fournisseurs de liquidité sont autant susceptibles d'acheter que de vendre, ce qui ne s'applique pas aux émissions.

Les principales caractéristiques du modèle sont les suivantes. Il existe trois périodes ($t = 1, 2, 3$), un actif risqué (par exemple, une obligation du Trésor), un actif sans risque, des *liquidity traders* infiniment averses au risque et des fournisseurs de liquidités du type CARA. À $t = 3$, les actifs arrivent à échéance. À $t = 2$, les *liquidity traders* vendent une quantité d'actifs risqués, Z . À $t = 1$, les fournisseurs de liquidités échangent des actifs tout en étant incertain de la taille de la vente Z , laquelle est supposée avoir une moyenne positive. La quantité Z peut être interprétée comme l'offre nette: La différence entre la taille de l'enchère et la quantité achetée par les acheteurs naturels. En effet, bien que les émetteurs divulguent généralement à l'avance les tailles d'émission, l'offre nette est incertaine car dépend de la présence ou non d'acheteurs naturels au jour de l'enchère.

Le résultat central du modèle est que la demande des fournisseurs de liquidité a deux composantes: Une demande de *hedging* et une demande spéculative. La demande de *hedging* implique de prendre une position longue dans l'actif pour couvrir l'incertitude sur l'offre nette, Z . La demande spéculative consiste à spéculer

sur la différence entre le prix à $t = 1$ et le prix attendu à $t = 2$. De plus, je montre que la demande spéculative diminue lorsque l'incertitude sur Z est plus grande.

En effet, la vente constitue une opportunité d'investissement alors que l'offre nette, Z , est une variable d'état qui détermine la rentabilité de l'opportunité. Par conséquent, les fournisseurs de liquidités averses au risque chercheront à couvrir ces changements d'opportunités d'investissement (Merton (1973)) avec un investissement qui est corrélé négativement à la variable d'état Z . Autrement dit, les investisseurs voudraient diversifier le risque de Z : Donc leur valorisation d'un actif dépend du "beta" de cet actif vis-à-vis de Z . À cet égard, une position longue dans l'actif risqué est précieuse car la rentabilité de cet investissement est élevée lorsque Z est faible. Outre le *hedging*, les fournisseurs de liquidité ont une demande spéculative: Ils peuvent augmenter leur richesse finale espérée en vendant (achetant) l'actif à $t = 1$ et en achetant (vendant) à $t = 2$ si le prix à $t = 1$ est supérieur (en dessous) du prix espéré à $t = 2$.

Je dérive alors le prix à $t = 1$ et montre qu'il dépasse le prix attendu à $t = 2$ en raison de l'existence de la demande de *hedging*. En particulier, sans demande de *hedging* (ou, de manière équivalente, lorsque tous les investisseurs ont un horizon court), le prix serait inférieur au prix de vente espéré: En effet, les investisseurs exigeraient un rabais pour détenir l'actif à $t = 1$ en raison de l'incertitude quant à l'offre nette. En outre, je montre que la différence entre le prix à $t = 1$ et le prix attendu à $t = 2$ augmente avec l'incertitude quant à l'offre nette, Z : Ceci vient du fait que la spéculation est moins intense lorsque l'incertitude sur le prix à $t = 2$ est plus grande. Par conséquent, comme l'incertitude sur Z diminue, la spéculation augmente et le prix diminue.

Enfin, j'étudie comment l'hétérogénéité des investisseurs affecte le *trading*. Tout d'abord, je considère le cas où les fournisseurs de liquidités ont une aversion de risque hétérogène. Deuxièmement, j'introduis des investisseurs à horizon court. En particulier, je montre que les investisseurs à horizon court vendent à découvert l'actif et que les ventes à découvert diminuent avec l'incertitude quant à l'offre nette, Z .

Le modèle a une nouvelle implication: Lors de l'arrivée d'une information "manquante" sur l'offre nette, le prix devrait réagir davantage dans les cas d'information négative que dans les cas d'information positive.

Plus précisément, je définis comme "manquante" toute information qui permet de mieux estimer l'offre nette. Tout d'abord, et évidemment, le prix devrait refléter la nature de l'information: Il diminue (augmente) dans le cas d'une offre nette plus important (plus petite) qu'espérée. Deuxièmement, il existe une composante supplémentaire du mouvement des prix, laquelle est toujours négative: En effet, l'arrivée de l'information réduit l'incertitude et intensifie la convergence du prix d'avant l'enchère vers le prix espéré d'enchère. Pour résumer, une information négative (positive) entraînera une baisse (augmentation) de prix pour refléter la nature de l'information et une baisse de prix simultanée pour refléter la spéculation plus élevée en raison d'une incertitude plus faible. Par conséquent, le prix bougera plus dans le cas où l'information est négative que dans le cas où elle est positive.

Je teste ensuite un corollaire de mon implication: Lorsque l'échantillon contient autant d'informations négative que positive, l'arrivée d'une information manquante sur l'offre nette entraîne en moyenne une baisse de prix. L'échantillon se compose de 800 enchères de bons du Trésor italien de 2000 à 2015. Pour tester le corollaire, j'utilise deux événements qui ont lieu avant l'enchère: D'abord, la réunion entre le Trésor italien et les principaux *primary dealers*; deuxièmement, l'annonce de la taille de l'émission. La réunion des *primary dealers* et l'annonce de la taille représentent des informations manquantes sur l'offre nette, Z. Par conséquent, leur arrivée réduit l'incertitude sur Z. Notons que la stratégie empirique de ce papier permet d'observer le prix secondaire des obligations avant leur vente aux enchères. En effet, j'étudie les réémissions: Ce sont des ventes aux enchères qui augmentent le volume d'obligations existantes.

Comme prédit par le modèle, je trouve que le rendement du bond ré-ouvert augmente en moyenne – de 1,2 points de base supplémentaire – lors des deux jours d'information comparé aux jours sans information. Enfin, je suis en mesure d'exclure le phénomène *on/off-the-run* (Krishnamurthy (2002)) car il n'y a aucun changement de *on/off-the-run* lors de réémissions.

La contribution principale de cet article est de proposer et tester un nouveau mécanisme pour expliquer les changements de prix autour des enchères du Trésor, comme indiqué dans Lou et. al. (2013), Duffie (2010) et Beetsma et. al. (2016). Il est important de noter que la contribution théorique de l'article s'étend à une littérature plus large: Celle qui étudie les prix des actifs autour d'événements anticipés. En effet, le mécanisme théorique de cet article peut expliquer pourquoi les prix diminuent avant des ventes prévisibles telles que les SEOs (Corwin (2003), Meidan (2005)), le *rebalancing* des contrats futurs (Bessembinder et al. (2016)) et le fixing du marché de l'or (Abrantes-Metz et Metz (2014)). En particulier, mon modèle montre que la baisse de prix n'est pas nécessairement symptomatique de front-running (Brunnermeier et Pedersen (2005)) ou d'autres manipulations de prix (Abrantes-Metz et Metz (2014)).

Mon modèle est lié à trois articles: Bessembinder et. al. (2016), Vayanos et Wang (2012) et Duffie (2010). Bessembinder et. al. (2016) étudient les prix avant un *trade* anticipé de contrats futurs par un ETF. Dans leur modèle, la diminution du prix se produit à cause du front-running. À l'inverse, dans mon modèle, les investisseurs ne sont pas stratégiques: Ils ne tiennent pas compte de leur propre impact sur les prix. En outre, Bessembinder et. al. (2016) ne suppose aucune incertitude tandis que, dans mon modèle, le prix de l'enchère est incertain.

Vayanos et Wang (2012) étudient comment l'incertitude sur les dotations en deuxième période affecte les prix dans la première période. De même, j'étudie comment l'incertitude quant à l'offre nette d'enchère (modélisée comme une dotation) affecte les prix de la première période. Cependant, dans leur modèle, l'incertitude concerne les dotations d'investisseurs qui *tradent* à la fois dans la première et la deuxième période; tandis que, dans mon modèle, l'incertitude concerne les traders qui arrivent sur le marché au cours de la deuxième période. De plus, dans mon modèle, la dotation moyenne est positive. Enfin, je montre que le prix de la première période est supérieur au prix espéré de la deuxième période, tandis que Vayanos et Wang (2012) montrent le contraire.

Duffie (2010) et mon article utilisent une approche de gestion de portefeuille pour étudier la variation des prix autour d'événements anticipés. Dans Duffie (2010), la variation des prix est générée par le fait que certains traders ne peuvent pas trader

de manière continue. Au contraire, je ne fais pas l'hypothèse que certains investisseurs ne peuvent pas échanger à la date de la vente: Je génère la différence de prix en supposant que les fournisseurs de liquidité ne prévoient qu'imparfaitement l'offre nette.

Résumé - Chapitre 3

Certains titres peuvent être plus facilement utilisés comme garantie pour obtenir un financement bon marché que d'autres: Ceux-ci ont une forte valeur de collatéral. Par exemple, avant une vente aux enchères, des obligations semblables à celles mises aux enchères sont soumises à une forte demande sur le marché repo: Les investisseurs sont prêts à prêter de l'argent à un taux faible pour pouvoir emprunter ces obligations, ce qui permet aux propriétaires de ces obligations d'obtenir un financement bon marché pendant cette période (Keane (1996), Moulton (2004)). De même, certaines classes d'actifs offrent une valeur de collatéral plus élevée que d'autres (Bartolini et al. (2011)).

Toute chose étant égale par ailleurs, un actif à valeur de collatéral élevée devrait être plus cher qu'un actif à valeur de collatéral faible. Dans le cas contraire, les *arbitrageurs* peuvent intervenir: Ils achètent l'actif à forte valeur de collatéral et vendent l'autre, jusqu'à ce que la valeur de collatéral soit reflétée dans les prix. À cet égard, Duffie (1996) développe une relation de non-arbitrage: Une obligation avec un faible taux repo est plus chère qu'une obligation identique à taux repo élevé. La différence de prix est égale aux intérêts économisés en utilisant comme collatéral l'obligation à faible taux repo au lieu d'utiliser celle à taux repo élevé.

Dans cet article, j'étudie la mesure dans laquelle les prix reflètent la valeur de collatéral pendant une crise. La réponse n'est pas évidente. D'une part, si le taux repo n'est reflété dans les prix que grâce à l'activité d'arbitrage, il est peu probable qu'elle soit reflétée dans les prix en cas de crise. En effet, la crise est connue pour être un période où l'arbitrage est plus difficile, potentiellement en raison des contraintes de financement (Gromb et Vayanos (2010)): Dans le cas où les prix et la valeur de collatéral ne sont pas alignés, les *arbitrageurs* ne sont pas en mesure de corriger la distorsion. D'un autre côté, les investisseurs ont généralement des

contraintes de cash pendant une crise. Par conséquent, en période de crise, ils sont susceptibles de favoriser les titres qui fournissent une meilleure garantie pour financer leurs investissements ou pour obtenir de l'argent bon marché en cas de choc de liquidité. Par ce biais, la valeur de collatéral a de fortes chances d'être reflétée dans les prix et l'écart de prix entre les titres de haute et faible qualité de collatéral est susceptible d'augmenter en cas de crise (Garleanu et Pedersen (2011)).

Dans cet article, j'utilise 54 paires d'obligations souveraines identiques au cours de la période 2005-12 (même émetteur, taux de coupons et échéance restante). Tout d'abord, je trouve que la relation de non-arbitrage de Duffie (1996) performe moins bien au cours de la crise des *subprimes* qu'en dehors de la crise: Pendant la crise, la différence de prix entre deux obligations s'écarte plus de la différence de coût de financement qu'avant la crise. Deuxièmement, cependant, je trouve qu'une obligation à faible taux repo a 17.95% plus de chance d'être la plus chère pendant la crise, comparé à 9.00% avant la crise. Ainsi, il existe des limites d'arbitrage qui empêchent la valeur de collatéral d'être pleinement reflétée dans les prix, en particulier pendant la crise. Pourtant, une partie de la valeur de collatéral est reflétée dans les prix parce que les prix et les taux repo présentent un co-mouvement plus important pendant la crise: Une obligation chère (bon marché) a également un taux repo faible (élevé).

Les deux mécanismes potentiels de ce co-mouvement – que je développe dans la dernière partie de l'article mais qui ne font pas l'objet d'une analyse approfondie – sont le *market-making* et les chocs de liquidité. Plus précisément, une obligation qui coûte cher a un taux repo faible pendant la crise car les *market-makers* ont des inventaires plus petits et doivent emprunter les obligations pour faire face à la demande. En conséquence, je trouve que le déséquilibre entre les ordres d'achat et les ordres de vente a augmenté au cours de la crise: Cela est cohérent avec la possibilité que les *market-makers* doivent compter sur le marché repo. De même, pendant la crise, une obligation qui est bon marché a un taux repo élevé car les investisseurs font face à de soudains chocs de liquidité: Alors que certains investisseurs vendent leurs titres obligataires, d'autres utilisent les obligations comme garantie pour emprunter de l'argent sur le marché repo.

Il est important d'étudier le lien entre les taux repo et les prix des obligations souveraines pendant la crise. Tout d'abord, cela permet d'approfondir notre

compréhension de la façon dont les limites d'arbitrage affectent les prix. En particulier, alors que la littérature étudie comment ces frictions ont un impact sur les actions ou les obligations (Garleanu et Pedersen (2011)), on n'a pas encore étudié leurs impact sur les taux repo. Deuxièmement, le marché repo est un grand marché avec un volume de transactions quotidien de 184 milliards d'euros pour les obligations européennes. Cependant, les déterminants des taux repo n'ont pas été exhaustivement étudiés dans la littérature.

Le setting est le suivant. Soit A et B deux obligations strictement identiques. Duffie (1996) développe la relation de non-arbitrage suivante entre les prix (P_A et P_B) et les taux repo (r_A et r_B):

$$P_B = \frac{P_A(1 + r_b)}{1 + r_a}$$

Dans cet article, je forme des paires de bond A et B identiques (même émetteur, même taux de coupon, même date d'échéance). J'étudie d'abord si la relation de Duffie (1996) tient plus pendant la crise des *subprime* qu'avant la crise. Je teste ensuite si l'obligation avec le taux repo le plus faible est la plus susceptible d'être celle dont le prix est le plus élevé; en particulier pendant la crise.

Plus précisément, chaque paire est composée d'une obligation zéro-coupon de 12 mois et d'une obligation zéro-coupon de 3 mois. Les deux obligations ont été émises par le gouvernement italien et arrivent à maturité en même temps. La seule différence est que la première a été émise 9 mois avant la deuxième et a généralement un volume d'émission plus important. Par conséquent, bien que les deux obligations aient des *bid-ask spread* similaires, je contrôle pour les différences potentielles de liquidité entre les deux obligations d'une même paire.

Mon article contribue à la littérature qui étudie le lien entre les prix secondaires et les taux repo (Duffie (1996), Jordan et Jordan (1997), Bartolini et al. (2010), D'Amico, Fan et Kitsul (2015), Corradin et Maddaloni (2017)). En particulier, je contribue à la littérature qui étudie la relation de non-arbitrage de Duffie (1996).

La contribution principale de cet article réside en sa capacité à observer directement la différence de taux repo de deux obligations identiques. A l'inverse, d'autres articles comparent le taux repo d'une obligation à une estimation du taux repo d'un portefeuille synthétique.

D'Amico, Fan et Kitsul (2015) trouvent que les taux repo sont sensibles aux chocs d'offre d'obligations. Ils constatent également que le choc sur le taux repo est répercuté sur le prix des obligations via le mécanisme développé dans Duffie (1996). Mon article et le leur sont différents. Tout d'abord, je compare la relation pendant et avant une période de crise, ce que D'Amico, Fan et Kitsul (2015) ne font pas. Deuxièmement, les deux articles diffèrent dans leur stratégie d'identification. D'Amico, Fan et Kitsul (2015) s'appuient sur la comparaison d'obligations qui ont reçu un choc d'offre exogène et des obligations qui n'ont pas reçu ce choc: Ils demandent si le prix des obligations qui ont connu une diminution d'offre a augmenté davantage (via la variation du taux repo). Au contraire, je compare des obligations identiques (même émetteur, échéance et taux de coupons) qui devraient donc avoir le même prix. Ces obligations identiques diffèrent dans leurs taux repo pour des raisons que je présume indépendantes de la valeur fondamentale des actifs. Je demande si l'obligation avec le taux repo le plus bas est la plus chère.

Jordan et Jordan (1997) testent une reformulation de la relation de non-arbitrage de Duffie (1996) et trouvent que les obligations qui sont *spéciales* –c.à.d. qui présentent un taux repo moins élevé que le taux en vigueur – sont plus chères que des obligations identiques. Contrairement à Jordan et Jordan (1997), j'étudie si la relation est meilleure ou pire pendant une période de crise. En outre, les deux articles diffèrent en terme de technique d'estimation. Pour chaque obligation de leur échantillon, Jordan et Jordan (1997) estiment le prix du marché d'une obligation ayant les mêmes caractéristiques mais ayant un taux repo plus élevé. Pour ce faire, chaque obligation dans leur échantillon est comparée à une obligation synthétique dont le prix provient du prix d'un portefeuille variable dans le temps. Au lieu de cela, je forme des paires d'obligations: Chaque obligation est comparée à une autre obligation qui a le même émetteur, le même taux de coupon et la même date d'échéance. Les paires sont donc stables dans le temps: Une paire est composée des deux mêmes obligations, depuis l'émission jusqu'à l'échéance.

References

- Abrantes-Metz, R., and Albert D., 2014. Are gold prices being fixed? Cited in Southern District of New York Case Number 1:14-md-02548, <http://www.bergermontague.com/media/434667/gold-complaint.pdf>.
- Asquith, P., Au, A.S., Covert, T. and Pathak, P.A., 2013. The market for borrowing corporate bonds. *Journal of Financial Economics*, 107(1), pp.155-182.
- Banerjee, S. and Graveline, J.J., 2013. The Cost of Short-Selling Liquid Securities. *The Journal of Finance*, 68(2), pp.637-664.
- Bartolini, L., Hilton, S., Sundaresan, S. and Tonetti, C., 2011. Collateral values by asset class: Evidence from primary securities dealers. *Review of Financial Studies*, 24(1), pp.248-278.
- Beetsma, R., Giuliadori, M., De Jong, F. and Widijanto, D., 2016. Price effects of sovereign debt auctions in the Euro-zone: the role of the crisis. *Journal of Financial Intermediation*, 25, pp.30-53.
- Bessembinder, H., Carrion, A., Tuttle, L. and Venkataraman, K., 2016. Liquidity, resiliency and market quality around predictable trades: Theory and evidence. *Journal of Financial Economics*, 121(1), pp.142-166.
- Boehmer, E., Jones, C.M. and Zhang, X., 2008. Which shorts are informed?. *The Journal of Finance*, 63(2), pp.491-527.
- Boehmer, E. and Wu, J.J., 2013. Short selling and the price discovery process. *Review of Financial Studies*, 26(2), pp.287-322.
- Brandt, M.W. and Kavajecz, K.A., 2004. Price discovery in the US Treasury market: The impact of orderflow and liquidity on the yield curve. *The Journal of Finance*, 59(6), pp.2623-2654.
- Brunnermeier, M.K. and Pedersen, L.H., 2005. Predatory trading. *The Journal of Finance*, 60(4), pp.1825-1863.
- Christoffersen, S.E., Geczy, C.C., Musto, D.K. and Reed, A.V., 2007. Vote trading and information aggregation. *The Journal of Finance*, 62(6), pp.2897-2929.

Cohen, L., Diether, K.B. and Malloy, C.J., 2007. Supply and demand shifts in the shorting market. *The Journal of Finance*, 62(5), pp.2061-2096.

Corradin, S. and Maddaloni, A., 2017. The importance of being special: repo markets during the crisis. Unpublished working paper. European Central Bank, Frankfurt, Germany.

Corwin, S.A., 2003. The determinants of underpricing for seasoned equity offers. *The Journal of Finance*, 58(5), pp.2249-2279.

D'Amico, S., Fan, R. and Kitsul, Y., 2015. The scarcity value of Treasury collateral: Repo market effects of security-specific supply and demand factors.

Desai, H., Ramesh, K., Thiagarajan, S.R. and Balachandran, B.V., 2002. An investigation of the informational role of short interest in the Nasdaq market. *The Journal of Finance*, 57(5), pp.2263-2287.

Duffie, D., 1996. Special repo rates. *The Journal of Finance*, 51(2), pp.493-526.

Duffie, D., 2010. Presidential Address: Asset Price Dynamics with Slow?Moving Capital. *The Journal of finance*, 65(4), pp.1237-1267.

Faulkender, M., 2005. Hedging or market timing? Selecting the interest rate exposure of corporate debt. *The Journal of Finance*, 60(2), pp.931-962.

Fleming, M.J., 2002. Are larger treasury issues more liquid? Evidence from bill reopenings. *Journal of Money, Credit and Banking*, pp.707-735.

Garleanu, N. and Pedersen, L.H., 2011. Margin-based asset pricing and deviations from the law of one price. *Review of Financial Studies*, 24(6), pp.1980-2022.

Gorton, G. and Metrick, A., 2012. Securitized banking and the run on repo. *Journal of Financial economics*, 104(3), pp.425-451.

Green, T.C., 2004. Economic news and the impact of trading on bond prices. *The Journal of Finance*, 59(3), pp.1201-1233.

- Gromb, D. and Vayanos, D., 2010. Limits of arbitrage. *Annu. Rev. Financ. Econ.*, 2(1), pp.251-275.
- Grossman, S.J. and Miller, M.H., 1988. Liquidity and market structure. *the Journal of Finance*, 43(3), pp.617-633.
- Jones, C.M. and Lamont, O.A., 2002. Short-sale constraints and stock returns. *Journal of Financial Economics*, 66(2), pp.207-239.
- Jordan, B.D. and Jordan, S.D., 1997. Special repo rates: An empirical analysis. *The Journal of Finance*, 52(5), pp.2051-2072.
- Karpoff, J.M. and Lou, X., 2010. Short sellers and financial misconduct. *The Journal of Finance*, 65(5), pp.1879-1913.
- Keane, F., 1996. Repo rate patterns for new Treasury notes. *Federal Reserve Bank of New York Current Issues in Economics and Finance*, 2(10).
- Krishnamurthy, A., 2002. The bond/old-bond spread. *Journal of financial Economics*, 66(2), pp.463-506.
- Lou, D., Yan, H. and Zhang, J., 2013. Anticipated and repeated shocks in liquid markets. *Review of Financial Studies*, p.hht034.
- Meidan, D., 2005. A re-examination of price pressure around seasoned equity offerings.
- Merton, R.C., 1973. An intertemporal capital asset pricing model. *Econometrica: Journal of the Econometric Society*, pp.867-887.
- Moulton, P.C., 2004. Relative repo specialness in US Treasuries. *The Journal of Fixed Income*, 14(1), pp.40-47.
- Sundaresan, S., 1994. An empirical analysis of US Treasury auctions: Implications for auction and term structure theories. *The Journal of Fixed Income*, 4(2), pp.35-50.
- U.S. District Court, 2014. Southern District of New York Case Number 1:14-md-02548

Vayanos, D. and Wang, J., 2012. Liquidity and asset returns under asymmetric information and imperfect competition. *Review of Financial Studies*, 25(5), pp.1339-1365.

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Introduction

Sovereign states borrow to finance their deficits. The main way for them to borrow cash is to issue debt instruments that I generically refer to as "government bonds". These bonds can be bought, sold or short-sold on the spot, in the future or even before they exist. They can also be borrowed, hedged, swapped, stripped and used as collateral to borrow cash or other securities. For any of these investment strategies, there is a market.

This thesis is about sovereign bond markets. Specifically, I study three types of markets: The primary, the secondary and the repo markets. They all have a different role in the economy. The primary market is where investors directly lend to the state –through an auction mechanism– and thus receive a sovereign bond. The secondary market is where changes in ownership of these bonds take place: Those who lent to the State on the primary market can sell their holdings to those who did not. Finally, the repo market is where investors borrow cash against their bonds. This is also where an investor can borrow someone else's bond in order to sell it to a third person: This practice is called *short-selling*.

In each of the three chapters of this thesis, I jointly study two or more of these markets. In the first chapter, I jointly study the three markets together. I ask if investors who short-sell in the days around primary auctions –by borrowing bonds on the repo market and selling them on the secondary market– are informed about the outcomes of these auctions. We know that short-sellers of stocks earn future abnormal returns (Cohen, Diether, and Malloy (2007); Boehmer, Jones and Zhang (2008)), detect financial misrepresentation (Karpoff, and Lou (2010)), vote better (Christoffersen, Geczy, Musto and Reed (2007)) and enhance price discovery (Boehmer and Wu (2013)). But what about short-sellers of sovereign bonds? While short-selling is used by market-makers around auctions (Keane (1996), Moulton (2004)) and may therefore be uninformed, the existence of superior information of short-sellers cannot be ex-ante disregarded given that the trading of government bond is informed (Brandt and Kavajecz (2004)), especially around macroeconomic events (Green (2004)).

In the second chapter of the thesis, I study the secondary market in the days around primary auctions. I develop and test a theory explaining why bond prices decrease gradually ahead of government bond auctions as reported by Lou, Yan and Zhang (2013) and studied in Duffie (2010). Lou, Yan and Zhang (2013) find that, in the few days leading up to U.S treasury auctions, the secondary prices of current issues decrease gradually, reach a minimum on auction day and then

increase gradually. This price pattern is a puzzle in that it implies that some investors are willing to buy bonds before the auction at a price which, on average, exceeds the auction price. There is therefore an asymmetry between buyers and sellers ahead of government bond auctions which this chapter's model predicts and explains.

Finally, in the third chapter of the thesis, I study the secondary and the repo markets. I ask if –during a crisis– the secondary market price of a bond takes into account how cheaply one can borrow cash by using that bond as collateral on the repo market. The answer is not obvious. On the one hand, arbitrageurs are known to be constrained during a crisis (Gromb and Vayanos (2010)): In case the secondary price fails to be in line with the cost of borrowing cash on the repo market, arbitrageurs are unlikely to correct the distortion. On the other hand, investors are typically cash-constrained during a crisis and are likely to choose their bond holdings depending on the ability to borrow cheap cash against these holdings (Garleanu and Pedersen (2011)).

I now let you browse through my findings.

References

- Boehmer, E., Jones, C.M. and Zhang, X., 2008. Which shorts are informed?. *The Journal of Finance*, 63(2), pp.491-527.
- Boehmer, E. and Wu, J.J., 2013. Short selling and the price discovery process. *Review of Financial Studies*, 26(2), pp.287-322.
- Christoffersen, S.E., Geczy, C.C., Musto, D.K. and Reed, A.V., 2007. Vote trading and information aggregation. *The Journal of Finance*, 62(6), pp.2897-2929.
- Cohen, L., Diether, K.B. and Malloy, C.J., 2007. Supply and demand shifts in the shorting market. *The Journal of Finance*, 62(5), pp.2061-2096.
- Duffie, D., 2010. Presidential Address: Asset Price Dynamics with Slow?Moving Capital. *The Journal of finance*, 65(4), pp.1237-1267.
- Gromb, D. and Vayanos, D., 2010. Limits of arbitrage. *Annu. Rev. Financ. Econ.*, 2(1), pp.251-275.

Garleanu, N. and Pedersen, L.H., 2011. Margin-based asset pricing and deviations from the law of one price. *Review of Financial Studies*, 24(6), pp.1980-2022.

Karpoff, J.M. and Lou, X., 2010. Short sellers and financial misconduct. *The Journal of Finance*, 65(5), pp.1879-1913.

Keane, F., 1996. Repo rate patterns for new Treasury notes. *Federal Reserve Bank of New York Current Issues in Economics and Finance*, 2(10).

Lou, D., Yan, H. and Zhang, J., 2013. Anticipated and repeated shocks in liquid markets. *Review of Financial Studies*, p.hht034.

Moulton, P.C., 2004. Relative repo specialness in US Treasuries. *The Journal of Fixed Income*, 14(1), pp.40-47.

Chapter 1

Are Short-Sellers of Sovereign Bonds Informed About Auctions?

I ask if short-sellers are superiorly informed about sovereign auctions. I identify shifts in short-selling demand as a simultaneous change in both the volume and the specialness of repo transactions collateralized by soon-to-be-issued bonds. I find a large average increase in demand for short-selling prior to auctions: Repo volume and specialness increase by 30% and 13 bps respectively on the eve of the auction day compared to four days before. Yet, I do not find that the demand for short-selling a bond –prior to the bond’s auction or on auction day– predicts a subsequent increase in the bond’s yield. Overall, in spite of an active short-selling activity around auctions, there is no evidence that short-sellers predict or interpret auction outcomes better than the market.

1.1 Introduction

Some investors hold information that the market does not hold. Among these superiorly informed investors are short-sellers: Short-sellers earn future abnormal returns (Cohen, Diether, and Malloy (2007); Boehmer, Jones and Zhang (2008)), detect financial misrepresentation (Karpoff, and Lou (2010)), vote better (Christoffersen, Geczy, Musto and Reed (2007)) and enhance price discovery (Boehmer and Wu (2013)). The literature on short-sellers’ superior information has almost exclusively been focused on equity. In particular, no paper has looked at whether short-sellers of sovereign bonds hold superior information. Yet, a branch of the sovereign bond literature points at the existence of superior information in the sovereign bond market: Brandt and Kavajecz (2004) find that the order flow in the government bond market is informed, while Green (2004) finds that the informativeness of trading in the Treasury market increases after the release of macroeconomic news.

In this paper, I propose to extend the study of short-sellers’ superior information to the context of sovereign bond auctions. I ask if short-sellers are superiorly informed about sovereign auctions.

I identify shifts in the demand for short-selling as a simultaneous change in both the volume and the specialness (i.e. short-selling cost) of repo transactions collateralized by soon-to-be-auctioned bonds. Using Italian bonds over 2005-12, I find a large average increase in the demand for short-selling prior to auctions: Repo volume and specialness increase by 30% and 13 bps respectively on the eve of the auction day compared to four days before. Second, however, I do not find that an increase in the demand for short-selling prior to an auction predicts a yield increase on auction day. Hence, short-sellers are not able to predict auction outcomes. Third, I find some indications that bonds for which the short-selling demand increased on auction day subsequently perform worse than other bonds. However, the return made from shorting on auction day and buying back five days after the auction is not significantly different from zero. Therefore, there is no evidence that short-sellers interpret auction outcomes better than the market. Overall, I do not find that short-sellers have superior information around auctions.

This paper's topic is relevant. First, the answer to the research question is not obvious. While short-selling is used for market-making purposes around auctions (Keane (1996), Moulton (2004)) and may therefore be uninformed, the existence of superior information of short-sellers cannot be ex-ante disregarded given that government bond market trading is informed (Brandt and Kavajecz (2004)), especially around macroeconomic events (Green (2004)).

Second, auctions are large repeated events where the cost of debt for sovereign nations is determined. Studying the potential superior information of short-sellers allows to deepen our understanding of how information is produced around that crucial time.

Finally, the main market for short-selling sovereign bond –the repo market– is a large market which features an average trading volume of over 180 Billion euros daily in Europe. It is an important market for financing (Gordon and Metrick (2012)) and security lending (Duffie (1996)). There exists a growing but still small literature on that market. Hence, studying government bond short-selling participates to the study of the repo market.

I now discuss the three main points of my methodology, which I present in more details in the next section. First, I study if short-selling predicts returns. To measure short-selling, I use simultaneous changes in two variables: A volume and a price variable. More precisely, I consider that a simultaneous increase (decrease) in the short-interest and the cost of short-selling indicates a positive (negative) shift in the demand for short-selling. I then test whether shifts in the demand for short-selling predict future returns. This methodology allows to avoid capturing short-selling imputed to changes in the supply of lendable assets: While an increase in the cost of short-selling

may come from a decrease in the “supply” of short-selling, a simultaneous increase in the cost and the volume of short-selling has to come from an increase in the demand for short-selling. As found by Cohen, Diether and Malloy (2007), only shifts in the demand predict future returns.

Second, to measure short-interest and short-selling cost, I use the *special repo market*. The main way to short-sell sovereign bonds is to enter into *special repo agreements*. The party interested in borrowing the security lends money to the security lender at a rate called *special repo rate* which is typically lower than a prevailing rate called *General Collateral rate*: The difference between these two rates is called *Specialness* and is used as a measure of short-selling cost. In exchange, the cash lender receives the bond as collateral. Since that the vast majority of repo transactions have a one-day duration, I use the daily volume of transactions collateralized by the to-be-issued bond as a measure of the bond’s short interest.

Third, I focus on re-openings. Re-openings are auctions that increase the outstanding volume of existing bonds, instead of resulting in the issuance of new bonds. The reopened bonds are therefore trading in large and liquid markets prior to their reopening.

This paper relates to three strands of literature. First, this paper relates to the short-selling literature. The largest part of the literature focuses on equity. The consensus is that short-selling predicts future negative returns and that investors are informed (see e.g. Jones, and Lamont (2002); Desai, Ramesh, Thiagarajan and Balachandran (2002); Boehmer, Jones, and Zhang (2008)).

The equity short-selling paper closest to mine is Cohen, Diether and Malloy (2007). They find that an increase in the demand for short-selling a stock predicts future negative abnormal returns. Like Cohen, Diether and Malloy (2007), I isolate increases in short-selling due to the demand for short-selling from increases in short-selling due to the supply of lendable assets. However, unlike Cohen, Diether and Malloy (2007), I study sovereign bonds and not stocks. Also, unlike them, I do not find that increases in the demand for short-selling predict returns.

There exists a small sub-branch of the short-selling literature which studies non-equity short-selling. Asquith, Au, Covert, and Pathak (2013) find that short-sellers of corporate bonds are uninformed. Like Asquith, Au, Covert, and Pathak (2013), I study short-selling of bonds and ask if bond short-sellers are informed. Like them, I find that they are not informed. However, I study sovereign bonds while they study corporate bonds. Banerjee and Graveline (2013) find that short-sellers of US government bonds pay a liquidity premium for borrowing liquid assets. Like Banerjee and Graveline (2013), I study short-selling of government bonds. However, unlike them, I ask if short-sellers hold superior information.

Second, this paper relates to a small literature in information on government bond markets. Brandt and Kavajecz (2004) find that the order flow in the government bond market is informed. Green (2004) finds that trading in the Treasury market becomes more informed after the release of macroeconomic news. He also finds that there is no asymmetric information before the release of macroeconomic news. Like Brandt and Kavajecz (2004) and Green (2004), I study the potential superior information that traders of government bonds may hold. However, unlike them, I analyze short-selling and I do not find any superior information.

Finally, this paper relates to the literature on repo around auctions. Keane (1996) and Moulton (2004) study specialness around auctions. Like Keane (1996) and Moulton (2004), I find that the specialness increases around auctions. Unlike them, I also observe the volume of repo transactions. This allows to isolate increases in short-selling due to the demand for short-selling from increases in short-selling due to the supply of lendable assets.

The paper proceeds as follows. Section 2 presents the institutional details. Section 3 presents the methodology and the data. Section 4 presents the empirical analysis. Section 5 concludes.

1.2 Institutional details

1.2.1 How to short government bonds?

There are two ways to short government bond. The main way is to enter into *special repo agreements*, also known as *reverse repo agreements*. The party interested in borrowing the security lends money to the security lender at a rate called *special repo rate* which is typically lower than a prevailing rate (the *general collateral rate*). In exchange, the cash lender gets the bond as collateral. She can then sell it on the secondary market. Since that most repo contracts have a one-day duration, the short-seller has to renew her contract until she decides to close her short position.

The other way to short government bonds is identical to the way investors usually short stocks: A would-be short-seller contacts a custodian bank via her broker and negotiate the terms of the security loan, such as the type of collateral that the security borrower has to post, the fee, the length of the loan etc.

1.2.2 Why do investors short government bonds around auctions?

Short-selling of government bonds is used during the auction cycle to facilitate the distribution of newly issued bonds: Before auctions, primary dealers can sell in advance their to-be-acquired

participation (Lou, Yan and Zhang (2013)) and, after auctions, auction participants can borrow securities in case they were not awarded enough shares at the auction (Jordan and Jordan (1997)). This can explain why short-selling government bonds around auctions is costly (Keane (1996), Moulton (2004)). In contrast, while equity investors may seek to short-sell newly issued stocks (Duffie, Garleanu and Pedersen (2002)), there is no institutional role of short-selling around equity issuance.

1.2.3 Other motivations of borrowing sovereign bond

First, given that bond prices are mainly influenced by interest rates, short-selling government bonds may be used as a way to hedge against interest-rate risks¹. Since that the price of virtually any security is influenced by interest rates, a vast variety of portfolios can be hedged by short-selling government bonds. In contrary, short-selling a particular stock would only be useful to hedge portfolios that contain this stock or, to a lesser extent, the stock's industry. As a result, short-selling is more used for hedging purposes on the government bond market than on the equity markets.

Second, arbitrage pricing may also have an impact on bond short-selling. First, as bonds are priced by arbitrage, there exists close substitutes to a particular bond, which means that a short-seller has a variety of bonds to choose from. In contrary, since that the price of a stock depends on the stock's idiosyncratic component, a short-seller with negative information about the cash-flow of a particular firm is unlikely to short-sell the stock of another firm. Second, because of arbitrage pricing, short-lived arbitrage opportunities arise on the government bond market. Hedge funds probably use short-selling to force the convergence between the price of two close substitutes (on/off-the-run phenomenon in Krishnamurthy (2002)). This could lead to profits that appear to be abnormal, even in absence of superior information. On the contrary, abnormal profit from betting on a stock against another stock is likely to be attributed to superior information.

¹There exists nonetheless popular hedging instruments such as futures (Hilliard (1984)), options (Longstaff (1995)) and interest-rate swaps (Bicksler and chen (1986))

1.3 Methodology and data

1.3.1 Data used in the literature

There are four types of data sets used in the equity short-selling literature. First, part of the literature uses Over-The-Counter (OTC) security lending transaction data (e.g. Cohen et. al. (2007)). This data is often proprietary and include rebate rates (i.e. the interest earned on cash collateral provided by the security borrower) and security borrowing volumes at the transaction-level (See e.g. D’Avolio (2002), Geczy, Musto and Reed (2002) and Cohen, Diether and Malloy (2007)). This is the most popular type of datasets used in this literature.

Another part of the literature uses monthly short-interest data provided once a month by the NYSE and other exchanges (e.g. Boehmer et. al. (2010) and Rapach et. al. (2016)). Short-interest is defined as the number of short positions that are not yet closed.

Finally, a third part of the literature uses short-selling transaction data (e.g. Boehmer et. al. (2008) and Kelly and Tetlock (2016)). This is trading data that allows to distinguish between long sales and short sales.

In the non-equity short-selling literature, most papers use OTC security lending transaction data (see e.g. Asquith et. al. (2013)) while there exists papers which use special repo data. For example, Banerjee and Graveline (2013) use special repo data to compare the cost of shorting a liquid security to the cost of shorting a less liquid security.

There are four types of short-selling proxies used in the literature, depending on the type of data used. As a proxy for the demand for short-selling, Cohen, Diether and Malloy (2007) use an indicator of whether, during a certain month and for a certain security, the cost of borrowing the security and the onloan percentage have both increased. The borrowing cost is computed as the risk-free rate minus the rebate rate, while the onloan percentage is the number of shares that are currently lent divided by the number of outstanding shares.

Rapach et. al. (2016) use as short-selling proxy the “short-interest” expressed in percentage of the total number of outstanding shares. Boehmer et. al. (2010) use either the same measure as Rapach et. al. or use the unstandardized short-interest. Note that the standardized short-interest and onloan percentage should be related: If the data provider of security lending transactions is comprehensive, then the two measures would be equal.

As a proxy for short-selling intensity, Kelley and Tetlock (2016) use short-sale volume scaled by trading volume. Boehmer et. al. (2008) use three different measures: the number of short-sale trades, the short-sale volume or the short-sale volume scaled by total trading volume.

Finally, Banerjee and Graveline (2013) construct a proxy of the cost for short-selling a liquid security compared to a less liquid security. They use the difference of the repo rate when using as collateral an off-the-run Treasury minus the repo rate when using as collateral the corresponding on-the-run Treasury. This difference is called “specialness”.

A literature review can be found in the Appendix.

1.3.2 Methodology

In this paper, I ask if short-sellers have superior information about future changes in price. To that end, I study if an increase in the demand for short-selling predicts future returns. My methodology is in the spirit of Cohen, Diether and Malloy (2007). I define an increase in the demand for short-selling a given bond as a simultaneous increase in 1) The volume, and 2) The specialness of repo transactions that use that bond as collateral.

I test the null hypothesis that β is equal to zero in the following simplified version of my specification:

$$\begin{aligned} &Yield_{AuctionDay,i} - Yield_{AuctionDay-1,i} \\ &= \alpha + \beta IncreaseDemand_{AuctionDay-5,AuctionDay-1,i} + Duration_{AuctionDay-1,i} \\ &\quad + Controls_{AuctionDay-1,i} + OriginalMaturity_{FE} + Year_{FE} + \epsilon_t \quad (1.1) \end{aligned}$$

where i is an auction, $IncreaseDemand_{AuctionDay-5,AuctionDay-1,i}$ is an indicator equal to 1 if there has been an increase over $(auction-5days, auction-1day)$ in the demand for short-selling the bond auctioned at auction i , and 0 otherwise. $Yield_{t,i}$ is the yield at date t of the bond auctioned at auction i ; $Duration_{t,i}$ is the bond’s duration on date t ; $Controls_i$ are fixed and time-varying controls at the bond level; $OriginalMaturity_{FE}$ are fixed effect at the level of the bond’s original maturity; $Year_{FE}$ are time-fixed effect at the year-level.

Before explaining why using repo transactions is adapted to this paper’s research question, I discuss the following three points about the specification. First, the left-hand side variable is the *unadjusted* change in yield, not the *abnormal* change in yield. However, on the right side, I

control for known predictors of bond returns. More precisely, I take care of interest-rate risk when controlling for duration. I also take care of default risk by comparing bonds of same issuer, and by adding year fixed-effects. Finally, I take care of liquidity risk by controlling for the bond's original maturity and time-to-maturity. Overall, the *normal* return that a bond should get –according to a model based on duration and default risks a la Fama and French (1993) and liquidity risk– is captured by the controls, not by the variable of interest *IncreaseDemand*.

Second, note that I focus on *re-opening*. Re-openings are auctions that increase the outstanding volume of existing bonds, instead of resulting in the issuance of new bonds. The reopened bonds are therefore trading in large and liquid markets prior to their reopening: The data for these bonds before the auction is available and reliable.

Finally, note that I also test if an increase in short-selling demand on auction day predicts post-auction returns. In that case, the specification is very similar to the specification above, except that the left hand-side variable is the change in yield in the five days following the auction, while the variable of interest measures the change in short-selling demand on auction day compared to one day before the auction.

I now discuss why using the volume and the specialness of special repo transactions is adapted to this paper's research question. In the equity short-selling literature, there exists data on short-interest or on-loan percentage. However, short interest data does not exist for sovereign bonds, while on-loan percentage exists only for OTC markets which represent a small fraction of the short-selling volume. I therefore use a proxy for short interest: The trading volume of special repo contracts.

What is the link between special repo trading and short-interest? Suppose a short seller who wants to increase her short position of bond B at date t compared to date $t-1$. She will go to the special repo market, get bond B, short it and provide cash at a low rate to the security provider. Since that the duration of a contract is typically one day, she will have to renew the contract until the date when she closes her short position –say date T . Hence, all else equal, the trading volume of special repo contracts between $t-1$ and t will increase, and so will the short interest for bond B. Similarly, the trading volume of special repo contracts of bond B between $T-1$ and T will decrease, and so will the short interest for bond B.

I now discuss two caveats of my short-selling proxy. First, an increase in the trading volume of special repo does not necessarily means an increase in the “number” of shorted bonds. Indeed, suppose that an investor do intra-day repo trading by entering a long repo contract for €10 million

of bond B at 9:30am, and then entering a short repo contract at 4:30pm for €10 million. Then my measure will show 20 million euros of repo transactions for bond B but, at best, only 10 million euros have effectively been sold short. In this paper, I operate under the assumption that there is no intra-day repo trading or that intra-day repo trading is homogenous across issues and time periods and is independent from returns.

Second, short-sellers may not short-sell on the day they borrow the security. Indeed, the most popular repo contract delivers the security two days after the trade, while bond purchases on the secondary typically settle three day after the trade. So, technically, a short-seller would be able to sell short on a given day and enter a repo contract on the next day. More generally, short-sellers may have a forward contract with a client with an ad-hoc delivery date. For simplicity, in this paper, I consider that investors simultaneously sell on the bond market and borrow the security on the repo market.

1.3.3 Data and Sample selection

My main dataset is the following. The yield data comes from Datastream (RY datatype). Other bond trading data comes from the MTS platform, which is a large platform of bond trading. The repo volumes and specialness data comes MTS repo, which is one of the three largest repo platforms in Europe. The repo rates can be thought as similar to the data in Banerjee and Graveline (2013). The dataset also includes data on auction results of Italian government bond from 2005 to 2012.

The sample consists in auctions of Italian bonds over January 2005 - October 2012. Following is how the sample is selected. I start with all Italian bonds quoted on the MTS platform that have been issued over 2005-2012. I keep only reopenings. I keep bonds with an original maturity of two years or more. Finally, I remove inflation bonds from the sample.

In the Appendix, I present and use an alternative dataset. It is composed of Over-The-Counter (OTC) security lending transactions, similarly to most datasets used in the equity short-selling literature (See e.g. D'Avolio (2002), Geczy, Musto and Reed (2002) and Cohen, Diether and Malloy (2007)). The data is provided by Markit and covers the 2006-2012 period. This dataset is meant to be an alternative to my Repo dataset.

Table 1.1 presents some summary statistics. In particular, the average reissued amount ranges from €1,798 MM (for 30 year bonds) to €2,694 MM (for 5 year bonds). These amounts are not large compared to US auctions, but this is due to the fact that US bonds are typically issued once or twice while Italian issues are reopened several times until maturity. The average repo volume in

a (-6,+6) window around reopenings ranges from 23% of the average reissued amount (2 and 3 year bonds) to 38% (10 year bonds). Hence, a substantial fraction of the auction size is borrowed. The average specialness ranges from 8.4 bps (2 year bonds) to 28 bps (10 year bonds): This means that the average rate on the cash lent by the security borrower is up to 0.28% lower than the prevailing rates. These specialness rates may not seem large in absolute term but they do when compared to the market returns of government bonds which are typically much lower than those of equity. Hence, specialness may represent a significant fraction of an investors' return. Finally, the total five-day borrowing cost spent for the whole repo market prior to each auction ranges from €7,900 (2 year bonds) to around €59,000 (10 year bonds). In all cases, the variance across auctions is equal to twice the mean. The maximum -€871,312- is reached for a 10 year bond auction in mid-october 2011, i.e. at the heights of the sovereign bond crisis. At this auction, the specialness was between 280 and 380 bps.

TABLE 1.1: Sample summary statistics. First panel: Auction data. Second panel: Repo market variables for reopened bonds over a (-6,+6) window around reopenings. Third panel: The average of short-selling cost spent on the entire repo market for borrowing the to-be-issued bond over a (-5,-1) around reopenings. The second panel reports the volume and specialness of special repo using the reopened security as collateral. The third panel reports summary statistics for a variable constructed as such: For each day over (-5,-1), I compute the product of the repo volume and the daily rate of specialness (=the average rate divided by 360) of repo transactions collateralized by the reopened bond; then I sum these five products. A special repo contract is a cash loan agreement where the ISIN of the bond serving as collateral is explicitly designated. Special repo contracts are often thought to be security lending agreements. Specialness is defined as the difference between the repo rate of a transaction collateralized by a generic collateral and the repo rate of a transaction collateralized by the auctioned bond. A reopening is a primary auction which results in the increase in the outstanding volume of a bond which was first issued in the past.

Data from the MTS Repo platform.

Issuer	Maturity	Obs.	Remaining maturity (Years)		Reissued amount (€MM)		Bid-cover ratio	
			Mean	Std.	Mean	Std.	Mean	Std.
Italy	2Y	66	1.98	0.12	2,346	443	1.77	0.27
Italy	3Y	63	2.95	0.21	2,810	545	1.57	0.24
Italy	5Y	66	4.89	0.36	2,694	728	1.58	0.26
Italy	10Y	93	9.42	1.41	2,502	839	1.55	0.26
Italy	15Y	44	13.18	2.47	1,790	649	1.66	0.30
Italy	30Y	28	29.04	2.99	1,798	518	1.54	0.21

Issuer	Maturity	Obs.	Special Repo Volume over (-6,+6) (€MM)				Specialness over (-6,+6) (bps)			
			Mean	Std.	Min	Max	Mean	Std.	Min	Max
Italy	2Y	858	557	441	0	3,685	8.44	17.91	-3.70	275.46
Italy	3Y	819	659	390	8	2,325	10.47	30.47	-3.19	412.82
Italy	5Y	858	750	518	27	3,537	14.15	37.06	-2.15	327.90
Italy	10Y	1,208	963	565	34	6,353	28.03	76.13	-5.87	1003.40
Italy	15Y	572	633	381	13	2,367	20.08	34.58	-1.63	293.23
Italy	30Y	364	539	349	25	2,261	11.48	25.36	-4.91	232.66

Issuer	Maturity	Total cost of five-day short-selling prior to auction (€)			
		Mean	Std.	Min	Max
Italy	2Y	7,979	13,022	119	58,185
Italy	3Y	16,546	36,420	420	222,134
Italy	5Y	21,845	41,027	258	180,467
Italy	10Y	59,187	127,132	1,068	871,312
Italy	15Y	35,232	57,760	379	265,051
Italy	30Y	19,318	39,158	444	176,246

1.4 Empirical analysis

First, I ask if there is short-selling around auctions. Second and third, I ask if short-sellers predict or interpret auction results better than the market. Finally, I discuss the results.

1.4.1 Preliminary analysis: Is there an average change in the demand for short-selling around auctions?

In this section, I perform a preliminary analysis. I ask if there is an average change in the demand for short-selling the auctioned bond. Although the informed short-seller might not be the average short-seller, this analysis serves as a motivation for studying short-selling in the particular context

of auctions. I find that the demand for short-selling the auctioned bond increases on average prior to the auction and decreases after the auction.

The first panel in Figure 1.1 shows the evolution around Italian auctions of the volume of repo transaction collateralized by the auctioned bond. Similarly, the second panel in Figure 1.1 shows the evolution of specialness around auctions, which is a measure of the discount agreed by cash lenders for receiving the auctioned bond as collateral compared to receiving a generic bond instead.

More precisely, the first (second) panel in Figure 1.1 reports the result of ten t-test specifications which test the null hypothesis that special repo volume or the specialness of the auctioned bond t days before the auction is equal to special repo volume or the specialness five days before the auction, where t belongs to $(-4,+5)$.

Figure 1.1 reports α_{-4} , $\alpha_{-3} \dots \alpha_{+5}$ estimated in the following ten t-tests:

$$X_{i,-4} - X_{i,-5} = \alpha_{-4} + \epsilon_{i,-5} \quad (1.2)$$

$$X_{i,-3} - X_{i,-5} = \alpha_{-3} + \epsilon_{i,-4} \quad (1.3)$$

$$\dots \quad (1.4)$$

$$X_{i,+5} - X_{i,-5} = \alpha_{+5} + \epsilon_{i,+5} \quad (1.5)$$

where i is an Italian reopening; $-4, -3, \dots, +5$ is the time-to/from-auction of bond i ; $X_{i,t} - X_{i,t'}$ is either the log difference of the volume or the difference in specialness between t and t' of the repo transactions collateralized by the bond auctioned at auction i . Standard errors are clustered at the day-level and the bond's original maturity level.

The first panel in Figure 1.1 shows that the volume of special repo transactions collateralized by the auctioned bond is highest on auction day and decreases afterwards. The second panel in Figure 1.1 shows that the specialness of repo transactions collateralized by the auctioned bond increases prior to the auction, is highest one day prior to auction day and decreases afterwards.

Hence, prior to the auction there is an increase in the two variables: An increase in the volume of cash lent using the auctioned bond as collateral, and an increase in the discount agreed by cash lenders for receiving the bond as collateral instead of receiving a generic collateral. Specifically, repo volume and specialness increase by 30% and 13 bps respectively on the eve of the auction day compared to four days before. In the spirit of Cohen, Diether and Malloy (2007), this indicates the existence a positive shift in the demand for lending cash against the auctioned bond prior to the auction; i.e. there is a positive shift in the demand for short-selling the auctioned bond.

Similarly, there is a negative shift in the demand for short-selling the bond after the auction: Indeed, there is a decrease both in the volume of cash lent using the auctioned bond as collateral, and in the discount agreed by cash lenders for receiving the bond as collateral instead of receiving a generic collateral.

Finally, on auction day, the direction of the shift is ambiguous. Indeed, there is an increase in the volume of cash lent using the auctioned bond as collateral. However, the discounts agreed by cash lenders are smaller. Therefore, there is no obvious shift in demand for short-selling. Rather, the increase in volume and decrease in specialness indicates an increase in the demand for borrowing cash against the auctioned bond as collateral: This is compatible with a demand by auction participants to finance their purchase on the repo market.

Note that the pattern in the first panel of Figure 1.1 is new to the literature since that repo papers do not study repo volumes due to a lack of US data. However, the pattern in the second panel in Figure 1.1 is similar to the specialness pattern reported in Keane (1996) and Moulton (2004).

In graph XX in the appendix, I confirm these patterns using data of Over-The-Counter (OTC) security lending. The onloan percentage and the lending fee are seen to increase from $t=-5$ to $t=+1$ and to decrease afterwards.

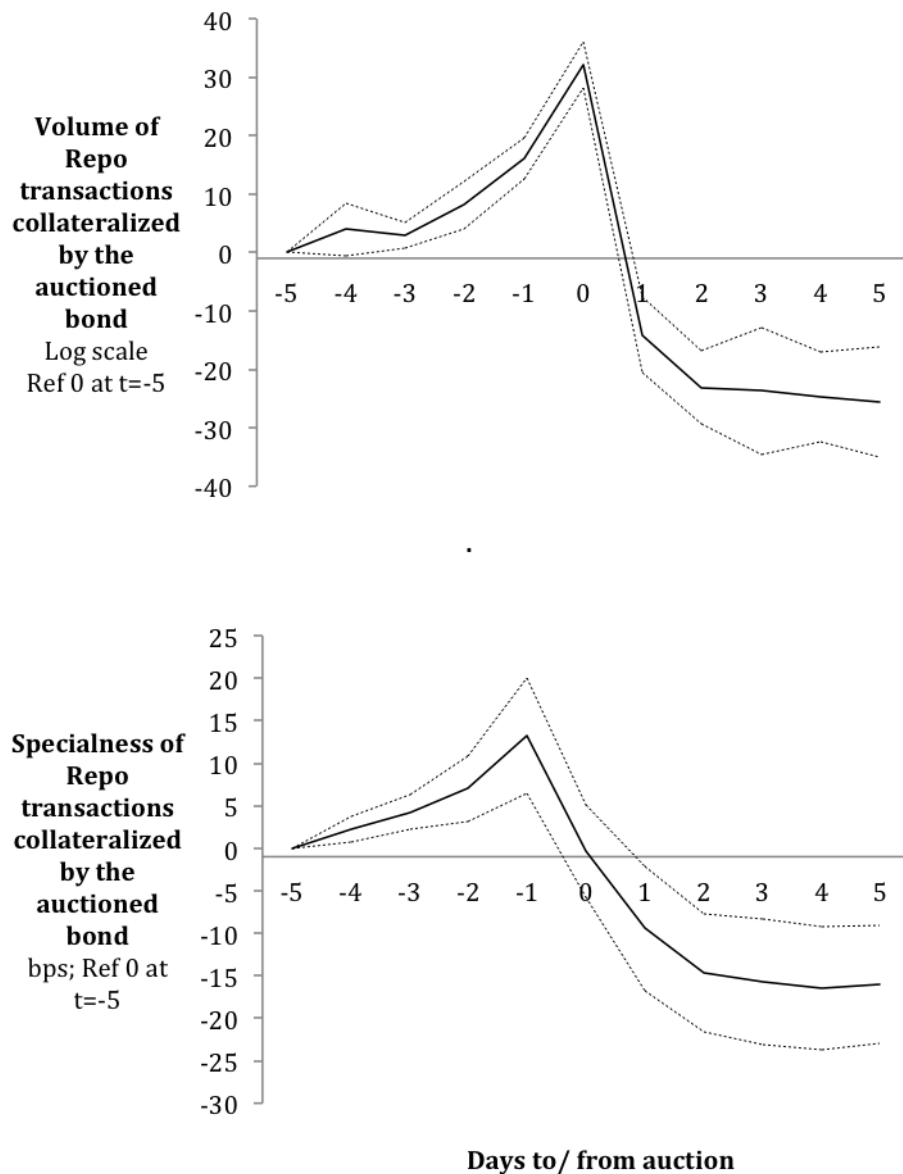


FIGURE 1.1: Reports the result of ten t-test specifications which test the null hypothesis that the volume (in the first panel) or the specialness (in the second panel) of repo transactions collateralized by the auctioned bond t days after the auction is equal to the volume (in first panel) or the specialness (in the second panel) 5 days before the auction, where t belongs to $(-5,+5)$. I use 360 Italian reopenings over 2005-12. A reopening is a primary auction that results in the increase in outstanding volume of a bond that was first issued in the past. The solid line is the point estimate. The two other lines corresponds to the 90% interval confidence. The repo data come from MTS repo. Standard errors are clustered at the maturity and daily levels

1.4.2 Do short-sellers predict auction results better than the market?

In the previous section, I studied average patterns. I found that there is an average increase (decrease) in the demand for short-selling before (after) the auction. In this section, I ask if short-sellers forecast auction results better than the market. To that end, I study if an increase in the

demand for short-selling between $t=-5$ and $t=-1$ can predict returns between $t=-1$ and $t=0$. I do not find that short-sellers are able to forecast auction results better than the market.

First, I create a dummy variable called *IncreaseDemand* which takes the value 1 for auctions for which both specialness and repo volume increased between $t=-5$ and $t=-1$; 0 otherwise.

Figure 1.2 shows how yields evolve over a $(-5,+5)$ time window around the auctions for which *IncreaseDemand* = 1 and around the auctions for which *IncreaseDemand* = 0. Of particular interest to the research question is whether the yield between $t=-1$ and $t=0$ evolved more for the auctions for which *IncreaseDemand* = 1 than for the other group.

Figure 1.2 shows that the yield between $t=-1$ and $t=0$ increases similarly for the two groups of auctions. This goes against the presence of superior information. However, Figure 1.2 also shows that the two groups of auctions are not fully comparable: The yield of the auctions for which *IncreaseDemand* = 1 increases more prior to the auction than that of the other group. Overall, further analysis is required. This can be done through regression analysis.

I now use regression analysis to study more carefully the link between short-selling volumes and returns. I test the null hypothesis that β is equal to zero in the following specification:

$$\begin{aligned}
& Yield_{AuctionDay,i} - Yield_{AuctionDay-1,i} \\
&= \alpha + \beta IncreaseDemand_{AuctionDay-5,AuctionDay-1,i} + Duration_{AuctionDay-1,i} \\
&+ Controls_{AuctionDay-1,i} + BondTradingVol_{AuctionDay-1,i} + \sum_{a=2}^5 \gamma_a \Delta Yield_{t-a,t-a+1} \\
&\quad + OriginalMaturity_{FE} + Year_{FE} + Weekday_{FE} + \epsilon_{AuctionDay-1} \quad (1.6)
\end{aligned}$$

where i is an auction, $IncreaseDemand_{AuctionDay-5,AuctionDay-1,i}$ is an indicator equal to 1 if there is an increase between $t=-5$ and $t=-1$ in both the specialness and volume of repo transactions collateralized by the bond auctioned at auction i ; 0 otherwise. $Yield_{t,i}$ is the yield at date t of the bond auctioned at auction i ; $Duration$ is the bond's duration $Controls$ are controls at the bond level; $BondTradingVol$ is the volume of bond trading at $t=-1$; $OriginalMaturity_{FE}$, $Year_{FE}$ and $Weekday_{FE}$ are fixed effect at the level of the bond's original maturity, the year-level and at the day-of-the-week level, respectively. Standard errors are clustered at the month-level.

Table 1.2 shows the results. The first column uses a basic specification with no control. In

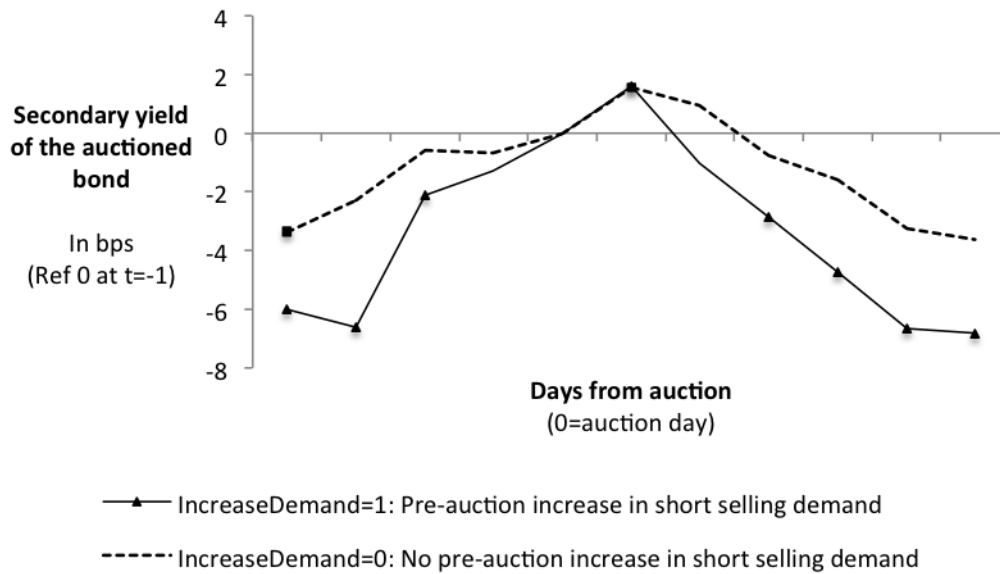


FIGURE 1.2: Reports the result of ten t-test specifications which test the null hypothesis that the secondary yield of the auctioned security t days before the auction is equal to the secondary yield one day before the auction day, where t belongs to $(-5,+5)$. I use 360 Italian reopenings in 2005-2012. Markers denote coefficients that are statistically different from 0. I separate between two groups of auctions: Auctions where the demand for short-selling demand increased over $(-5,-1)$, and a second group where the demand for short-selling did not increase. I define an increase in short-selling demand as an increase in volume and specialness of repo transactions collateralized by the auctioned bond. Specialness is defined as the difference between the repo rate of a transaction collateralized by a generic collateral and the repo rate of a transaction collateralized by the auctioned bond. Secondary yield data from Datas-tream (RY datatype). Repo data from the MTS Repo platform. Standard errors are clustered at the maturity and daily levels

the first column, I find that the coefficient of interest is not significantly different from zero: A simultaneous increase in repo volume and specialness prior to the auction does not predict the return on auction day.

The other columns confirm the absence of significance for the coefficient of interest. Specifically, in the second column, I add control at the bond-level (duration, coupon rate, tranche and remaining maturity). I also add fixed effects (year, original maturity and weekday). Finally, I cluster standard errors at the month-level.

In the third column, I control for current and past returns (up to one week) in order to control for public information in the spirit of Cohen, Diether and Malloy (2007). This allows to make sure that short-sellers do not simply use easily-available price information to forecast price reversal. Because what may matter is the short-selling volume as a proportion of the trading volume, I also control for the trading volume in the spirit of Christophe, Ferri and Angel (2004). The coefficient of interest is still insignificantly different from zero.

Overall, the demand for short-selling before the auction does not predict the change in price on auction day. Hence, there is no evidence that short-sellers predict auction results better than the market. Appendix Table A.2 confirm these results using OTC lending data.

In unreported tables, I perform some robustness tests. I find that the coefficient is still not significantly different from zero. Specifically, I first change the horizon: Instead of measuring the short-selling shift between $t=-5$ and $t=-1$, I alternatively use $t=-4$, $t=-3$ and $t=-2$ as starting point. Second, I compare 10-year bonds for which $IncreaseDemand = 1$ to 10-year bonds for which $IncreaseDemand = 0$. Third, I change the methodology for sorting auctions. For each maturity and each year, I select the auctions where the change between $t=-5$ and $t=-1$ in specialness is in the top five deciles, provided that the change is positive. Then, within these auctions, I select the auctions where the change in repo volume is in the top five deciles, provided that the change is positive. This group of auctions is the treated group. All the other auctions are included in the control group. The coefficient of interest is still insignificant.

TABLE 1.2: Link between (1) An increase in short-selling demand at $t=-1$ compared to $t=-5$, and (2) Yield change between $t=-1$ and $t=0$ for the auctioned bond, where $t=0$ is the auction day. I measure short-selling demand by changes in the volume and the specialness of repo transaction collateralized by the auctioned bond. Specialness is defined as the difference between the repo rate of a transaction collateralized by a generic collateral and the repo rate of a transaction collateralized by the auctioned bond. *IncreaseDemand* is an indicator equal to 1 if the increase in specialness and repo volume over $(-5,-1)$ are both positive; 0 otherwise. Italian sample over 2005-12. Secondary yield data from Datastream (RY datatype). Repo data from the MTS platform. t statistics in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

	Δ Yield	Δ Yield	Δ Yield
	(-1,0)	(-1,0)	(-1,0)
IncreaseDemand (Coef. of interest)	0.0204	0.357	0.933
	(0.02)	(0.41)	(0.93)
Log trading volume at -1			-1.414*
			(-1.91)
Δ Yield (-2,-1)			0.226*
			(1.78)
Δ Yield (-3,-2)			-0.251*
			(-1.92)
Δ Yield (-4,-3)			-0.0207
			(-0.18)
Δ Yield (-5,-4)			-0.0522
			(-0.42)
Δ Yield (-6,-5)			-0.103
			(-1.03)
Constant	1.571***		
	(2.80)		
Observations	360	360	355
Controls (duration, coupon rate, tranche, remaining maturity)	No	Yes	Yes
Fixed-effects (original maturity, year, weekday)	No	Yes	Yes
Month-level clustering	No	Yes	Yes

1.4.3 Do short-sellers interpret better auction results?

In the previous section, I found no evidence that short-sellers forecast auction results better than the market. In this section, I ask if short-sellers interpret better auction results. Specifically, I

study if short-sellers are quicker than the market in coming up with the “right” interpretation of auction results. To that end, I study if an increase in the demand for short-selling at $t=0$ compared to $t=-1$ can predict the return between $t=0$ and $t=+5$. I find results which tend to indicate that short-sellers do not interpret better auction results: Granted, in some specifications, I find that the return of heavily-shortened auctions are lower than that of lightly-shortened auctions; however, these returns are often insignificantly different from zero. Hence, a short-seller who shorts on auction day and buys back at $t=-5$ will make a zero profit, before accounting for borrowing fees.

Note that, given that the data is at the daily level, I only study potential situations where –by the end of the auction day– the market has failed in coming up with the right interpretation of auction results. In particular, I do not study situations where short-sellers are a few seconds or minutes quicker than the market in interpreting the auction results.

First, I create a dummy variable called “IncreaseDemand”. The dummy is defined differently than in the first section: It takes the value 1 for auctions for which specialness and repo volume increased between $t=-1$ and $t=0$; 0 otherwise.

Figure 1.3 shows how yields evolve over a $(-5,+5)$ time window around the auctions for which $IncreaseDemand = 1$ and around the auctions for which $IncreaseDemand = 0$. Of particular interest is whether the yield increased more between $t=0$ and $t=+5$ for the group of auctions for which $IncreaseDemand = 1$ than for the other group.

Figure 1.3 shows that the yield decreases similarly for the two groups of auctions. However, the two groups of auctions are not comparable because their yields evolved differently before the auction: The yield for $IncreaseDemand = 1$ did not significantly increase, while it significantly increased for $IncreaseDemand = 0$.

Then I turn to regressions. I use a specification which is close to that used in the previous section. More precisely, I test the null hypothesis that β is equal to zero in the following specification:

$$\begin{aligned}
& Yield_{AuctionDay+\delta,i} - Yield_{AuctionDay,i} \\
& = \alpha + \beta IncreaseDemand_{AuctionDay-1,AuctionDay,i} + Duration_{AuctionDay,i} \\
& + Controls_{AuctionDay,i} + \log(Volume_{Bid}) + \log(Volume_{Allotted}) + BondTradingVol_{AuctionDay,i} \\
& + \sum_{a=2}^5 \gamma_a \Delta Yield_{t-a,t-a+1} + OriginalMaturity_{FE} + Year_{FE} + Weekday_{FE} + \epsilon_{AuctionDay} \quad (1.7)
\end{aligned}$$

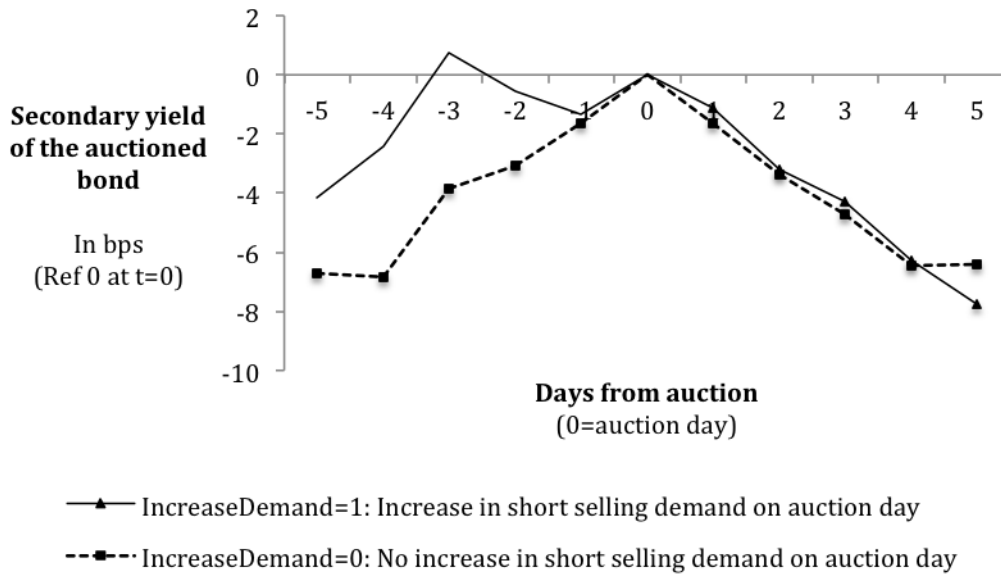


FIGURE 1.3: Reports the result of ten t-test specifications which test the null hypothesis that the secondary yield of the auctioned security t days before the auction is equal to the secondary yield on auction day, where t belongs to $(-5,+5)$. I use 360 Italian reopenings in 2005-2012. Markers denotes coefficients that are statistically different from 0. I separate between two groups of auctions: Auctions where the demand for short-selling demand increased on auction day compared to one day before, and a second group where the demand for short-selling did not increase. I define an increase in short-selling demand as an increase in volume and specialness of repo transactions collateralized by the auctioned bond. Specialness is defined as the difference between the repo rate of a transaction collateralized by a generic collateral and the repo rate of a transaction collateralized by the auctioned bond. Secondary yield data from Datastream (RY datatype). Repo data from the MTS Repo platform. Standard errors are clustered at the maturity and daily levels

where δ belongs to $(+1,+5)$, i is an auction, $IncreaseDemand_{AuctionDay-1,AuctionDay,i}$ is an indicator equal to 1 if there is an increase between $t=-1$ and $t=0$ in both the specialness and volume of repo transactions collateralized by the bond auctioned at auction i ; 0 otherwise. $Yield_{t,i}$ is the yield at date t of the bond auctioned at auction i ; $Duration$ is the bond's duration $Controls$ are controls at the bond level; $BondTradingVol$ is the volume of bond trading at $t=-1$; $Log(Volume_{Bid})$ and $Log(Volume_{Allotted})$ are the log of the volume bid and allotted at auction; $OriginalMaturity_{FE}$, $Year_{FE}$ and $Weekday_{FE}$ are fixed effect at the level of the bond's original maturity, the year-level and at the day-of-the-week level, respectively. Standard errors are clustered at the month-level.

Table 2.4 shows the results in specifications where the left-hand variable is the change in yield over $(0,+5)$. The first column uses a basic specification with no control. In the first column, I find that the coefficient of interest is insignificantly different from zero. In addition, the coefficient's sign is opposite to what would be expected in presence of superior information.

The other columns confirm that the coefficient of interest is not significantly different from zero. Specifically, in the second column, I add control at the bond-level (duration, coupon rate, tranche and remaining maturity). I also add fixed effects (year, original maturity and weekday) and I cluster standard errors at the month-level. In the third column, I control for current and past returns (up to one week). I also control for the current trading volume. Finally, I control for auction outcome information (the amount issued and the amount bid at auction).

Appendix Table A.3 confirm these results using OTC lending data.

Importantly, I find that the results in Table 2.4 are not robust to various specification changes. In particular, in Table 1.4, I report some robustness tests and find the coefficient of interest to be significantly positive.

Specifically, in the first column, I report a test where I keep only 10-year bonds. I find that the coefficient is (weakly) significantly different from zero and is positive. The coefficient is equal to 8.92, which means that an increase in short-selling demand between $t=-1$ and $t=0$ predicts that the change in yield between $t=0$ and $t=+5$ will be 8.92 bps higher than in absence of increase in short-selling demand (i.e. a 0.66% lower return, using an average duration of 7.5 years). In unreported statistics, I also find that the unconditional average yield change in the sample for which *IncreaseDemand* = 1 is positive and equal to 3.57 bps. This means that short-sellers are able to make a profit of 3.57 bps (0.27%) by shorting at $t=0$ and buying back at $t=+5$.

This result has to be considered with care, though. Indeed, the sample is very small: Only 11 auctions of 10-year bonds have seen both the repo volume and specialness increase at $t=0$. The normality condition for OLS might not be satisfied. In addition, when using 3-year bonds instead of 10-year bonds, I find that the coefficient is significantly positive but the average return for the treated sample is positive. Finally, the results are not robust to using 2-year or 5-year bonds instead of 10-year bonds.

In the second column, I change the methodology for sorting auctions. For each maturity and each year, I select the auctions where the change between $t=-1$ and $t=0$ in specialness is in the top five deciles, provided that the change is positive. Then, within these auctions, I select the auctions where the change in repo volume of is in the top five deciles, provided that the change is positive. This group of auctions form the treated group. All the other auctions are the control group. I find that the coefficient is statistically different from zero, is positive and equal to 8.98. This means that an increase in short-selling demand between $t=-1$ and $t=0$ predicts that the change in yield between $t=0$ and $t=+5$ will be 8.98 bps higher than in absence of increase in short-selling demand.

However, in unreported statistics, I find that the average yield change for the treated group is not statistically different from zero: This means that, even if the returns are less positive in the treated than in the control groups, short-sellers do not make a profit. Worse, transaction and security lending fees will make the returns negative for short-sellers.

In unreported tests, I replicate the test reported in the second column except that I introduce some specification changes. The result in the second column is robust to these changes. Specifically, I first sort first by volume then specialness to construct the dummy variable. Second I exclude 2011, which was the year of the sovereign bond crisis. Third, I measure yield changes between $t=0$ and $t=+4$ or $t+3$ instead of $t+5$.

Overall, this section's results are ambiguous. I find some indications that short-selling on auction day predicts post-auction returns. However, these results are dependent on the way the variable of interest is constructed. In addition, in most specifications, the average return in the heavily shorted group is not negative: This means that short-sellers do not make a profit. There is, therefore, no strong evidence that short-sellers interpret better auction results than the market.

TABLE 1.3: Link between (1) An increase in short-selling demand at $t=0$ compared to $t=-1$, and (2) Yield change between $t=0$ and $t=+5$ for the auctioned bond, where $t=0$ is the auction day. I measure short-selling demand by changes in the volume and the specialness of repo transaction collateralized by the auctioned bond. Specialness is defined as the difference between the repo rate of a transaction collateralized by a generic collateral and the repo rate of a transaction collateralized by the auctioned bond. *IncreaseDemand* is an indicator equal to 1 if both specialness and repo volume increased over $(-1,0)$; 0 otherwise. Italian sample over 2005-12. Secondary yield data from Datastream (RY datatype). Repo data from the MTS Repo platform. t statistics in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

	Δ Yield (0,+5)	Δ Yield (0,+5)	Δ Yield (0,+5)
IncreaseDemand (Coef. of interest)	-1.373 (-0.51)	3.476 (1.08)	2.819 (0.92)
Log trading volume at $t=0$			-3.748 (-1.14)
Δ Yield (-1,0)			0.0900 (0.25)
Δ Yield (-2,-1)			-0.278 (-0.59)
Δ Yield (-3,-2)			-0.115 (-0.31)
Δ Yield (-4,-3)			-0.232* (-1.87)
Δ Yield (-5,-4)			-0.275** (-2.36)
Δ Yield (-6,-5)			-0.132 (-0.41)
Amount offered at auction			-5.148 (-0.56)
Amount bid at auction			12.07 (1.02)
Constant	-6.398*** (-5.14)		
Observations	360	360	360
Controls (duration, coupon rate, tranche, remaining maturity)	No	Yes	Yes
Fixed-effects (original maturity, year, weekday)	No	Yes	Yes
Month-level clustering	No	Yes	Yes

TABLE 1.4: Robustness table. Link between (1) An increase in short-selling demand at $t=0$ compared to $t=-1$, and (2) Yield change between $t=0$ and $t=+5$ for the auctioned bond, where $t=0$ is the auction day. I measure short-selling demand by changes in the volume and the specialness of repo transaction collateralized by the auctioned bond. Specialness is defined as the difference between the repo rate of a transaction collateralized by a generic collateral and the repo rate of a transaction collateralized by the auctioned bond. *IncreaseDemand* is defined differently in column 1 and column 2. In column 1, *IncreaseDemand* is an indicator equal to 1 if both specialness and repo volume increased over $(-1,0)$; 0 otherwise. In column 2, *IncreaseDemand* is an indicator equal to 1 if the following two conditions are satisfied: 1) The change in specialness over $(-5,-1)$ is positive and belongs to the sample's top 50th, and 2) Within this subsample, the change in repo volume is positive and belongs to the top 50th; 0 otherwise. In the first column, I restrict the sample to 10-year bonds. Italian sample over 2005-12. Secondary yield data from Datastream (RY datatype). Repo data from the MTS Repo platform. t statistics in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

	Δ Yield (0,+5)	Δ Yield (0,+5)
	10Y only Double sorting	
IncreaseDemand (Coef. of interest)	8.922*	8.984**
	(1.74)	(2.45)
Log trading volume at $t=0$	1.220	-3.677
	(0.23)	(-1.09)
Δ Yield (-1,0)	0.481	0.110
	(0.99)	(0.31)
Δ Yield (-2,-1)	1.522*	-0.253
	(1.88)	(-0.56)
Δ Yield (-3,-2)	-1.144**	-0.127
	(-2.11)	(-0.34)
Δ Yield (-4,-3)	-0.522	-0.236*
	(-1.64)	(-1.92)
Δ Yield (-5,-4)	-0.453	-0.282**
	(-1.47)	(-2.43)
Δ Yield (-6,-5)	-0.597	-0.0746
	(-0.84)	(-0.22)
Observations	93	360
Controls (duration, coupon rate, tranche, auction results)	Yes	Yes
Fixed-effects (original maturity, year, weekday)	Yes	Yes
Month-level clustering	Yes	Yes

1.4.4 Discussion

In the previous sections, I did not find that short-sellers had superior information. Following are three potential reasons why.

First, informed short-sellers might have short-lived information. For example, they might receive information only a couple of minutes prior to the auction. My tests –which are based on the difference between the yield one day before the auction and the yield on auction day– will not capture such a situation. High frequency data is available and provided by MTS.

Second, the vast majority of short-selling may be linked to market-making. Hence, it might be difficult to isolate shifts in informed short-selling from shifts in market-making short-selling. One solution would be to develop a theory of market-making: This would allow to create a control variable for this type of short-selling.

Finally, informed investors may not use the repo market but Credit Default Swaps (CDS) or bond futures.

1.5 Conclusion

I ask if short-sellers are superiorly informed about sovereign auctions. I identify shifts in the demand for short-selling as a simultaneous change in both the volume and the specialness (i.e. short-selling cost) of repo transactions collateralized by soon-to-be-auctioned bonds. Using Italian bonds over 2005-12, I find a large average increase in the demand for short-selling prior to auctions: Repo volume and specialness increase by 30% and 13 bps respectively on the eve of the auction day compared to four days before. Second, however, I do not find that an increase in the demand for short-selling prior to an auction predicts a yield increase on auction day. Hence, short-sellers are not able to predict auction outcomes. Third, I find some indications that bonds for which the short-selling demand increased on auction day subsequently perform worse than other bonds. However, the return made from shorting on auction day and buying back five days after the auction is not significantly different from zero. Therefore, there is no evidence that short-sellers interpret auction outcomes better than the market. Overall, I do not find that short-sellers have superior information around auctions.

References

- Akbas, F., 2016. The calm before the storm. *The Journal of Finance*, 71(1), pp.225-266.
- Asquith, P., Au, A.S., Covert, T. and Pathak, P.A., 2013. The market for borrowing corporate bonds. *Journal of Financial Economics*, 107(1), pp.155-182.
- Asquith, P., Pathak, P.A. and Ritter, J.R., 2005. Short interest, institutional ownership, and stock returns. *Journal of Financial Economics*, 78(2), pp.243-276.
- Banerjee, S. and Graveline, J.J., 2013. The Cost of Short-Selling Liquid Securities. *The Journal of Finance*, 68(2), pp.637-664.
- Beber, A. and Pagano, M., 2013. Short-selling bans around the world: Evidence from the 2007-09 crisis. *The Journal of Finance*, 68(1), pp.343-381.
- Berkman, H., McKenzie, M.D. and Verwijmeren, P., 2016. Hole in the wall: Informed short selling ahead of private placements. *Review of Finance*, p.pnw176.
- Bicksler, J. and Chen, A.H., 1986. An economic analysis of interest rate swaps. *The Journal of Finance*, 41(3), pp.645-655.
- Boehmer, E., Huszar, Z.R. and Jordan, B.D., 2010. The good news in short interest. *Journal of Financial Economics*, 96(1), pp.80-97.
- Boehmer, E., Jones, C.M. and Zhang, X., 2008. Which shorts are informed?. *The Journal of Finance*, 63(2), pp.491-527.
- Boehmer, E. and Wu, J.J., 2013. Short selling and the price discovery process. *Review of Financial Studies*, 26(2), pp.287-322.
- Brandt, M.W. and Kavajecz, K.A., 2004. Price discovery in the US Treasury market: The impact of orderflow and liquidity on the yield curve. *The Journal of Finance*, 59(6), pp.2623-2654.
- Chen, H. and Singal, V., 2003. Role of speculative short sales in price formation: The case of the weekend effect. *The Journal of Finance*, 58(2), pp.685-706.

Christoffersen, S.E., Geczy, C.C., Musto, D.K. and Reed, A.V., 2007. Vote trading and information aggregation. *The Journal of Finance*, 62(6), pp.2897-2929.

Christophe, S.E., Ferri, M.G. and Angel, J.J., 2004. Short-selling prior to earnings announcements. *The Journal of Finance*, 59(4), pp.1845-1876.

Cohen, L., Diether, K.B. and Malloy, C.J., 2007. Supply and demand shifts in the shorting market. *The Journal of Finance*, 62(5), pp.2061-2096.

D'avolio, G., 2002. The market for borrowing stock. *Journal of financial economics*, 66(2), pp.271-306.

Dechow, P.M., Hutton, A.P., Meulbroek, L. and Sloan, R.G., 2001. Short-sellers, fundamental analysis, and stock returns. *Journal of Financial Economics*, 61(1), pp.77-106.

Desai, H., Ramesh, K., Thiagarajan, S.R. and Balachandran, B.V., 2002. An investigation of the informational role of short interest in the Nasdaq market. *The Journal of Finance*, 57(5), pp.2263-2287.

Duffie, D., 1996. Special repo rates. *The Journal of Finance*, 51(2), pp.493-526.

Duffie, D., Garleanu, N. and Pedersen, L.H., 2002. Securities lending, shorting, and pricing. *Journal of Financial Economics*, 66(2), pp.307-339.

Evans, R.B., Geczy, C.C., Musto, D.K. and Reed, A.V., 2009. Failure is an option: Impediments to short selling and options prices. *Review of Financial Studies*, 22(5), pp.1955-1980.

Fama, E.F. and French, K.R., 1993. Common risk factors in the returns on stocks and bonds. *Journal of financial economics*, 33(1), pp.3-56.

Geczy, C.C., Musto, D.K. and Reed, A.V., 2002. Stocks are special too: An analysis of the equity lending market. *Journal of Financial Economics*, 66(2), pp.241-269.

Gorton, G. and Metrick, A., 2012. Securitized banking and the run on repo. *Journal of Financial economics*, 104(3), pp.425-451.

- Green, T.C., 2004. Economic news and the impact of trading on bond prices. *The Journal of Finance*, 59(3), pp.1201-1233.
- Grullon, G., Michenaud, S. and Weston, J.P., 2015. The real effects of short-selling constraints. *Review of Financial Studies*, 28(6), pp.1737-1767.
- Hilliard, J.E., 1984. Hedging interest rate risk with futures portfolios under term structure effects. *The Journal of Finance*, 39(5), pp.1547-1569.
- Jones, C.M. and Lamont, O.A., 2002. Short-sale constraints and stock returns. *Journal of Financial Economics*, 66(2), pp.207-239.
- Jordan, B.D. and Jordan, S.D., 1997. Special repo rates: An empirical analysis. *The Journal of Finance*, 52(5), pp.2051-2072.
- Kaplan, S.N., Moskowitz, T.J. and Sensoy, B.A., 2013. The effects of stock lending on security prices: An experiment. *The Journal of Finance*, 68(5), pp.1891-1936.
- Karpoff, J.M. and Lou, X., 2010. Short sellers and financial misconduct. *The Journal of Finance*, 65(5), pp.1879-1913.
- Keane, F., 1996. Repo rate patterns for new Treasury notes. *Federal Reserve Bank of New York Current Issues in Economics and Finance*, 2(10).
- Kelley, E.K. and Tetlock, P.C., 2016. Retail short selling and stock prices. *Review of Financial Studies*, p.hhw089.
- Krishnamurthy, A., 2002. The bond/old-bond spread. *Journal of financial Economics*, 66(2), pp.463-506.
- Lamont, O.A. and Stein, J.C., 2004. Aggregate short interest and market valuations (No. w10218). National Bureau of Economic Research.
- Longstaff, F.A., 1995. Hedging interest rate risk with options on average interest rates. *The Journal of Fixed Income*, 4(4), pp.37-45.

Lou, D., Yan, H. and Zhang, J., 2013. Anticipated and repeated shocks in liquid markets. *Review of Financial Studies*, p.hht034.

Moulton, P.C., 2004. Relative repo specialness in US Treasuries. *The Journal of Fixed Income*, 14(1), pp.40-47.

Nagel, S., 2005. Short sales, institutional investors and the cross-section of stock returns. *Journal of Financial Economics*, 78(2), pp.277-309.

Rapach, D.E., Ringgenberg, M.C. and Zhou, G., 2016. Short interest and aggregate stock returns. *Journal of Financial Economics*, 121(1), pp.46-65.

Chapter 2

Trading Ahead of Treasury Auctions

I develop and test a model explaining the gradual price decrease observed in the days leading to large anticipated asset sales such as Treasury auctions. In the model, risk-averse investors anticipate an asset sale which magnitude, and hence price, are uncertain. I show that investors face a trade-off between hedging the price risk with a long position, and speculating on the difference between the pre-sale and the expected sale prices. Due to hedging, the equilibrium price is above the expected sale price. As the sale date approaches, uncertainty about the sale price decreases, short speculative positions increase and the price decreases. In line with the predictions, I find that the yield of Italian Treasuries increases by 1.2 bps after the release of auction price information, compared to non-information days.

2.1 Introduction

Market liquidity relies on intermediaries (“liquidity providers”) acting as a buffer between buyers and sellers. These liquidity providers can profitably trade on demand due to continued presence in the market (Grossman and Miller (1988)). In particular, liquidity providers play a prominent role in auctions where they may buy large volumes of assets at a discount. However, the profit derived from auction participation is uncertain because it depends on whether or not natural counterparties are present on auction day: A larger-than-expected presence of natural buyers may considerably reduce the need for liquidity provision. Indeed, there is significant variation as to who buys Treasury assets: Natural buyers –such as investment funds– may buy as much as 46% and as little as none of a given US Treasury issue at an auction (Fleming (2007)). In this paper, I relate secondary prices to this auction uncertainty. This topic is of interest for issuers because they use secondary prices to take issuance decisions and to benchmark auction outcomes.

Specifically, I develop and test a theory explaining why bond prices decrease gradually ahead of Treasury auctions as reported by Lou, Yan and Zhang (2013) and studied in Duffie (2010). Lou, Yan and Zhang (2013) find that, in the few days leading up to U.S treasury auctions, the secondary prices of current issues decrease gradually, reach a minimum on auction day and then increase gradually.

This price pattern arises in various contexts: First, it occurs in Treasury auctions, including in cases where the on/off-the-run phenomenon is absent (see this paper’s empirical section); in other types of auctions such as SEOs (Corwin (2003)) or gold fixing (US District Court (2014)); and ahead of predictable sales of future contracts (Bessembinder et. al. (2016)).

This price pattern is a puzzle in that it implies that some investors are willing to buy bonds before the auction at a price which, on average, exceeds the auction price. Admittedly, investors who *need* to buy the bond before the auction would be ready to do so at a premium (equal to the “half bid-ask spread”) rather than to wait and trade on auction day at an uncertain price (Grossman and Miller (1988)). But conversely, sellers would be ready to trade at a discount. As a result, the pre-auction mid price should equal the expected mid price on auction day. Instead, the observed price pattern is such that the former exceeds the latter. Hence, investors who need to buy the bond before the auction are paying a premium exceeding the discount paid by sellers. There is therefore an asymmetry which this paper’s model predicts and explains.

In the model, risk-averse investors anticipate an asset sale which magnitude, and hence price, are uncertain. First, I show that investors face a trade-off: They can speculate on the difference between the pre-sale and the expected sale prices, or they can hedge the price risk with a long position. Specifically, the need for hedging comes from the uncertainty about the discount at which an investor buys from the seller: To hedge this uncertainty, one can take a long position which appreciates when the sale price is high and, thus, when the discount is low. Second, I show that the equilibrium price is above the expected sale price due to hedging. Third, as uncertainty about the sale price decreases, short speculative positions increase and the price decreases.

To test the model’s implications, I use Italian Treasury auctions over 2000-15. As predicted, I find that bond yields increase by 1.2 bps more during the days when the Treasury meets with primary dealers ahead of an auction and when the Treasury announces the auction size than during other pre-auction days. Finally, this paper’s setting allows to exclude alternative explanations such as the on/off-the-run phenomenon.

Understanding the gradual price decrease ahead of Treasury auctions is important for several reasons. First, pre-auction prices serve as benchmarks for auction prices and may be used in issuance decisions (Faulkender (2005)). In addition, if the price decrease were due to front-running (Brunnermeier and Pedersen (2005)), the issuer might be better off revealing little information about the auction size rather than announce it as is common in practice (Sundaresan (1994)). Second, while the literature has studied prices *following* a large sale (Grossman and Miller (1988)),

little is known about prices *before* a sale. Moreover, existing theories of *post-sale* prices do not apply to *pre-sale* prices. For instance, Grossman and Miller (1988) assume that liquidity provider are as likely to buy as they are to sell, which does not apply to issuances.

The main features of this paper's model are as follows. There are three periods ($t=1,2,3$), a risky asset (e.g. a Treasury bond), a riskless asset, infinitely risk-averse liquidity traders and CARA liquidity providers. At $t=3$, the assets pay off. At $t=2$, liquidity traders sell a quantity of risky asset, Z . At $t=1$, liquidity providers trade under uncertainty about the sale quantity Z , assumed to have a positive mean. Quantity Z can be interpreted as the *net supply*: The difference between the auction size and the quantity bought by natural buyers. Indeed, even though issuers typically disclose in advance issuance sizes, net supply is uncertain because it depends on the presence or not of natural buyers on auction day.

The model's central result is that the demand from liquidity providers has two components: A hedging demand and a speculative demand. The hedging demand implies taking a long position in the asset to hedge the uncertainty about the net supply, Z . The speculative demand consists in trading on the difference between the price at $t=1$ and the expected price at $t=2$. Moreover, I show that the speculative demand decreases when the uncertainty about Z is larger.

Indeed, the sale constitutes an investment opportunity while the net supply, Z , is a state variable which determines how lucrative the opportunity is. Hence, risk-averse liquidity providers will seek to hedge these changes in investment opportunities (Merton (1973)) with an investment which negatively correlates to the state variable Z . Said differently, investors would like to diversify away the risk of Z : Therefore, their valuation of investment opportunities depends on the *beta* of that investment with Z . In that regard, a long position in the risky asset is valuable because the return of that investment is high when Z is low. Beside hedging, liquidity providers have a speculative demand: They can increase their expected final wealth by selling (buying) the asset at $t=1$ and buying (selling) it back at $t=2$ if the price at $t=1$ is above (below) the expected price at $t=2$.

I then derive the price at $t=1$ and show that it exceeds the expected price at $t=2$ because of the existence of the hedging demand. In particular, without hedging demand (or, equivalently, when all investors have a short horizon), the price would be below the expected sale price: Indeed, investors would demand a discount for holding the asset at $t=1$ because of the uncertainty about the net supply. Moreover, I show that the difference between the price at $t=1$ and the expected price at $t=2$ increases in the uncertainty about the net supply, Z : This is because speculation is less intense when the uncertainty about the price at $t=2$ is larger. Consequently, as the uncertainty

about Z decreases, speculation increases and the price decreases.¹

Finally, I study how heterogeneity among investors affects trading. First, I consider the case where liquidity providers have heterogeneous risk aversion. Second, I introduce risk-averse short-term investors. In particular, I show that short-term investors short-sell the asset and that short-selling decreases in the uncertainty about net supply, Z .

The model has a new implication: Upon the arrival of a *missing* piece of information about the net supply, the price should react more in cases of *negative* than in cases of *positive* information.

Specifically, I define as *missing* any piece of information which allows to better estimate the net supply. First, and obviously, the price should reflect the nature of the information: It decreases (increases) in case of larger- (smaller-) than-expected net supply. Second, there is an additional component of price movement which is always negative, regardless of whether the information is *negative* or *positive*: Indeed, the arrival of the information reduces uncertainty and intensifies the decrease of the pre-auction price towards the expected auction price. Overall, a *negative* (*positive*) piece of information will entail a price decrease (increase) to reflect the information and a simultaneous price decrease to reflect the higher speculation due to lower uncertainty. Hence, the price will move more in *negative* than in *positive* cases.

Next, I test the following corollary of my implication: When the sample contains as many *negative* as *positive* news, the arrival of a missing piece of information about the net supply entails a price decrease on average. The sample consists of 800 auctions of Italian Treasuries over 2000-2015. To test the corollary, I exploit two pre-auction events: First, the meeting between the Italian Treasury and the primary dealers; second, the announcement of the issuance size. Both the dealers' meeting and the size announcement represent missing pieces of information about net supply, Z : Therefore, their arrival reduces the uncertainty about Z . Conveniently, this paper's setting allows to observe before the auction the secondary price of the issued bonds. Indeed, I study *reopenings*: These are auctions which increase the outstanding volume of existing bonds.

As predicted, I find that the yield of the reopened bond increases on average by 1.2 bps more on those two days than on no-information days. Finally, I am able to exclude the on/off-the-run phenomenon (Krishnamurthy (2002)) because there is no change in on/off-the-run status after *reopenings*.

¹To be clear, there is no intermediate date in the model where the risk of the net supply, Z , decreases. The implication is obtained via a dynamic interpretation of a comparative static.

This paper's main contribution is to propose and test a new mechanism to explain the price pattern around Treasury auctions as reported in Lou et. al. (2013), Duffie (2010) and Beetsma et. al. (2016). Importantly, the theoretical contribution of the paper extends to a broader asset pricing literature which studies prices around predictable events. Indeed, this paper's theoretical mechanism can explain why prices have been shown to decrease ahead of predictable sales such as Seasoned Equity Offerings (e.g. Corwin (2003), Meidan (2005)), rebalancing of future contracts (Bessembinder et. al. (2016)) and the gold market fix (Abrantes-Metz and Metz (2014)). In particular, my model shows that the decrease in price is not necessarily symptomatic of front-running (Brunnermeier and Pedersen (2005)) or other price manipulations (Abrantes-Metz and Metz (2014)).

This paper's model is related to four papers: Bessembinder et. al. (2016), Vayanos and Wang (2012), Vayanos and Woolley (2013) and Duffie (2010). Bessembinder et. al. (2016) study prices before an anticipated trade of future contracts by an oil ETF. In their model, the decrease in price may occur due to front-running. Conversely, in my model, investors are not strategic: They do not take into account their own price impact. In addition, Bessembinder et. al. (2016) assumes no randomness whereas, in my model, the auction price is uncertain.

Vayanos and Wang (2012) study how uncertainty about endowments in the second period affect prices in the first period. Similarly, I study how uncertainty about an auction's net supply affects prices in the first period (where net supply is modeled as an endowment). However, in their model, the uncertainty relates to endowments of investors who trade both in the first and the second periods; while, in my model, the uncertainty relates to traders who arrive in the market in the second period. Moreover, in my model, the average endowment has a positive mean. Finally, I show that the price in the first period is higher than the expected price in the second period, while Vayanos and Wang (2012) show the opposite.

Vayanos and Woolley (2013) and my paper both feature a mechanism of uncertain supply. And both papers generate a gradual price decrease. However, the mechanism of gradual price decrease is different. In my model's comparative statics, the price gradually decreases because the uncertainty of the supply gradually decreases. On the contrary, in Vayanos and Woolley (2013), the price gradually decreases because investors are assumed to only gradually adjust their positions. In particular, Vayanos and Woolley (2013) do not explore the consequence of a gradual decrease in supply uncertainty. Hence, I derive implications which Vayanos and Woolley (2013) do not. Finally, unlike Vayanos and Woolley (2013), I empirically test some my model's implications.

Duffie (2010) and my paper both use a portfolio management approach to study price pattern around anticipated events. Both papers generate the pattern of gradual price decrease. However, the mechanism is different. In Duffie (2010), the price pattern is generated by the fact that some traders cannot trade in a continuous fashion. In particular, some investors cannot trade on the date of the anticipated event. On the contrary, in my model, all investors can trade on the date of the anticipated event. However, some of them do not trade before the anticipated event. This generates an uncertainty about net supply and –as the uncertainty is gradually resolved– a gradual price decrease.

The paper proceeds as follows. Section 2 develops the model. Section 3 tests implications. Section 4 reviews alternative explanations. Section 5 extends the implications to other contexts. Section 6 concludes.

2.2 Model

2.2.1 Objectives and key characteristics of the model

I build a model with the primary objective to rationalize why Treasury bond prices have been documented to progressively decrease before an auction. Lou, Yan and Zhang (2013) find that, in the few days ahead of an auction of a new U.S. treasury bond, the price of the current issue progressively decreases and reaches a minimum on auction day. Duffie (2010) also analyzes this price pattern.

Figure 2.1 offers a graphical representation of the market reaction around a reopening: The secondary yield –which moves inversely to the price– is seen to increase and to reach a maximum on auction date. Figure 2.1 is qualitatively similar to the pattern documented in Lou, Yan and Zhang (2013) but is built using a different setting and dataset which I present in detail in the empirical section of the paper. Note that this paper’s setting allows to observe the secondary yield of the auctioned bond before the auction, as well as to exclude the possibility that the increase in yield in Figure 2.1 is due to the on/off-the-run phenomenon.² Finally, note that the yield decreases back after the auction as illustrated in Figure 2.1: This phenomenon is studied in Grossman and Miller (1988) and is outside the scope of this paper’s model.

²Indeed, I use reopenings instead of using new issuances. A reopening is the increase in outstanding volume via for a bond which has been issued in the past. This bond does not lose its on-the-run status after the reopening. Therefore, it cannot be argued that this bond is less valuable after than before the reopening.

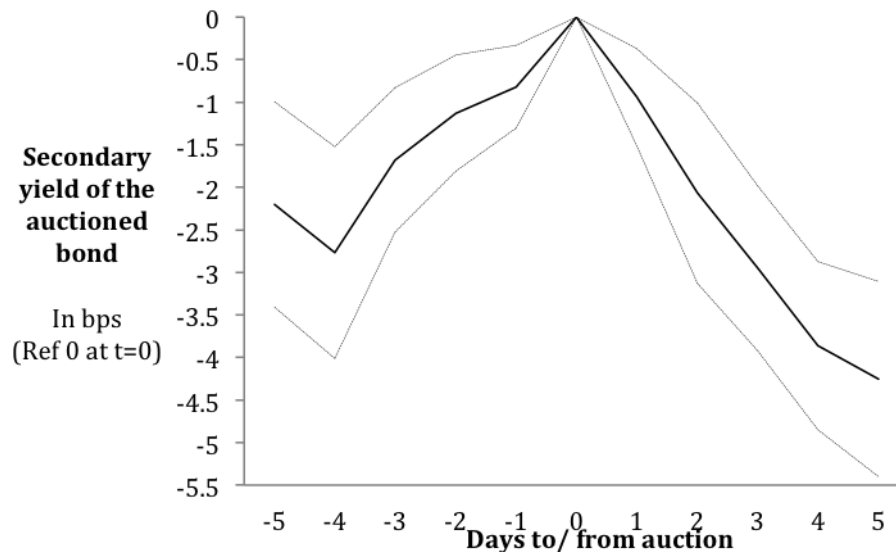


FIGURE 2.1: Reports the result of ten t-test specifications which test the null hypothesis that the secondary yield of the auctioned security t days before the auction is equal to the secondary yield on auction day, where t belongs to $(-5,+5)$. I use 800 Italian reopenings over 2000-15, excluding 2011. A reopening is a primary auction which results in the increase in outstanding volume of a bond that was first issued in the past. The solid line is the point estimate. The two other lines corresponds to the 90% interval confidence. The secondary yield data come from Datastream (RY datatype). Standard errors are clustered at the maturity and daily levels

I build a three-period portfolio management model with the entry of liquidity traders in the intermediate period. There are two sets of crucial assumptions in the model. First, the demand for liquidity is imperfectly known in advance by the other traders and has a positive mean. Second, traders are risk-averse and have a long-term horizon.

2.2.2 Set-up

There are three periods ($t = 1, 2, 3$), a riskless and a risky asset. The size of the riskless and risky assets at $t=1$ are, respectively, $\bar{\eta}$ and $\bar{\theta}$. The risky asset pays off D units at $t=3$, with $D \sim N(\bar{D}; \sigma^2)$. I use the riskless asset as numeraire. I denote by P_t the price of the risky asset in Period t , where $P_3 = D$. There are two types of investors at $t=1$: Investors with a low risk-aversion (for which I use the letter A as in “Adventurous”) and investors with a high risk-aversion (for which I use the letter B). More precisely, there is a measure δ of investors A and $1-\delta$ of investors B with the following utility function:

$$U_i(W_3) = -exp\left\{-\alpha_i W_{i,3}\right\} \quad (2.1)$$

where i is in $\{A;B\}$, $W_{i,3}$ is the individual's wealth in Period 3, $\alpha_i > 0$ is the coefficient of absolute risk aversion, with an endowment at start of $t=1$ $C_{0,i}$ and $\theta_{0,i}$ in the risk-free and risky assets, respectively. The endowment is equal to the per-capita supply of each asset.³

At $t=2$, there is an entry of new traders called "Liquidity Trader" (for which I use the initial L). L are in measure one and seek to hedge an endowment Z in the risky asset which they receive at $t=3$. Z is determined at $t=2$ and uncertain at $t=1$ with a known distribution of $Z \sim N(\bar{Z}; \sigma_Z^2)$, where \bar{Z} is strictly positive ($\bar{Z} > 0$) and Z orthogonal to D . In the main sections of the paper, I only solve the case where L is infinitely risk-averse. In the internet appendix, I solve the general case where L has a utility function of $-exp - \alpha_L W_3$ where α_L is finite. Figure 2.2 illustrates the timing of the model.

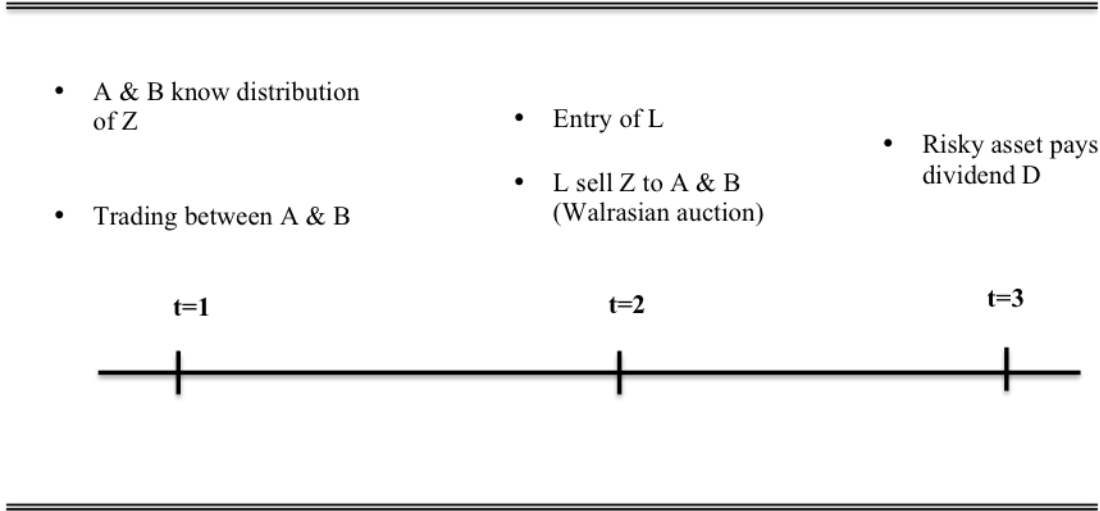


FIGURE 2.2: Model Timeline

Like in Vayanos and Wang (2012), to guarantee that the ex-ante expected utility is finite, I assume that the variances of D and Z satisfy the following conditions:

$$\alpha_i^2 \sigma^2 \sigma_Z^2 < 1; \alpha_A^2 \alpha_B^2 \sigma^2 \sigma_Z^2 < 1 \quad (2.2)$$

where i is in $\{A;B\}$

³More precisely, at the start of $t=1$, they have an endowment of $C_{0,i} = \frac{\alpha_{-i}}{\delta \alpha_B + (1-\delta) \alpha_A} \bar{\eta}$ in the risk-free asset and $\theta_{0,i} = \frac{\alpha_{-i}}{\delta \alpha_B + (1-\delta) \alpha_A} \bar{\theta}$ in the risky asset.

2.2.3 Interpretation in the Treasury auction context

Table 2.1 illustrates the interpretation of the various investors and variables in the context of Treasury auctions.

TABLE 2.1: Interpretation of the model in the context of Treasury auctions

Model	Treasury auction context
A	Primary Dealers with low capital constraints
B	Primary Dealers with high capital constraints
L	Treasury Office + Natural Buyers (foreign, investment funds, individuals)
\bar{Z}	Amount issued by Treasury Office = amount that dealers expect to buy
$\bar{Z} - Z$	Part of issuance demanded by Natural Buyers (may be negative)
Z	Part of the issuance sold to Primary Dealers (may be negative)
If $Z > 0$	Dealers increase inventory: they provide liquidity to (=buy from) Treasury
If $Z < 0$	Dealers decrease inventory: they provide liquidity to (=sell to) Natural Buyers
If $Z > \bar{Z}$ or $Z < -\bar{Z}$	Dealers provide more liquidity than expected (=good for them)
If $-\bar{Z} < Z < \bar{Z}$	Dealers provide less liquidity than expected (=bad for them)

In a general context, investors A and B could be any opportunistic investors seeking to buy assets at a discount from L. In an auction context, investors A and B are dealers with different capital constraints, while \bar{Z} is the issuance size and Z is the net supply, i.e. the share of the new issue which cannot be sold to “natural buyers” and is therefore sold to liquidity providers. Hence, investors L can be thought as both the Treasury office and the natural buyers.

Net supply Z is uncertain because it depends on the demand of “natural buyers”(i.e. occasional investors) such as foreign and international investors, investment funds, individuals, pension funds and insurance companies (Fleming (2007)). Those natural buyers are investors who are not usually on the market and who tend to participate to auctions indirectly through a primary dealer. Some of them even participate directly to the auction by placing competitive or non-competitive bids (TreasuryDirect (2016); Fleming (2007)). In the US between 2003 and 2005, 40% of long-term

bond volume is bought by non-primary dealers (Fleming (2007)). The two largest categories are foreign and international investors (21%) and investment funds (11%). The share of non-primary participants varies from auctions to auctions: In the US between 2003 and 2005, it has varied from 0% to 67% (Fleming (2007)).

Primary dealers might not perfectly know in advance the demand from these investors: The demand of the direct bidders will not be known until the auction result, while the demand of the indirect bidders will remain uncertain until the primary dealer has collected orders from her clients. Even then, a given primary dealer will receive only an imperfect signal of the overall demand as each primary dealer collects a fraction of the total orders.

2.2.4 Model's solution

In this part, I present the model's solution. I start by deriving the equilibrium at $t=2$. The results at $t=2$ are standard but, of particular interest, is how the investors' value function changes with net supply Z : In that regard, Lemma 1 gives some intuition about the model's central results.

Investors of type i maximize

$$\mathbb{E}_D \left[- \exp \left\{ - \alpha_i (\theta_{2,i} D + C_{0,i} - (\theta_{1,i} - \theta_{0,i}) P_1 - (\theta_{2,i} - \theta_{1,i}) P_2) \right\} \middle| \Omega_2 \right] \quad (2.3)$$

i.e. the expectation over the risky pay-off D , conditional on a set of information Ω_2 , of minus the exponential of minus the following quantity: The value $\theta_{2,i} D$ of the total risky portfolio at $t=3$, plus the endowment in cash $C_{0,i}$ minus the cost $\theta_{1,i} - \theta_{0,i} P_1$ of the additional risky position taken at $t=1$, minus the cost $\theta_{2,i} - \theta_{1,i} P_2$ of the additional risky position taken at $t=2$.

I show that the demand function for the risky asset in Period 2 of investors of type i is

$$\theta_{2,i}^*(P_2) = \frac{\bar{D} - P_2}{\alpha_i \sigma^2} \quad (2.4)$$

where $\theta_{2,i}$ is the investor's total holding at Period 2.

As for investors L , their demand function for the risky asset in Period 2 is

$$\theta_{2,L}^*(P_2) = -Z \quad (2.5)$$

Now, I compute the equilibrium prices and holdings. The market clearing condition is

$$\bar{\theta} = \delta\theta_{2,A}^*(P_2^*) + (1 - \delta)\theta_{2,B}^*(P_2^*) + \theta_{2,L}^*(P_2^*) \quad (2.6)$$

Using (2.4), (2.5) and (2.6), I show that the equilibrium price for the asset at t=2 is

$$P_2^* = \bar{D} - \frac{\alpha_i\alpha_{-i}}{\bar{\alpha}}\sigma^2(\bar{\theta} + Z) \quad (2.7)$$

where I define $\bar{\alpha} = \delta\alpha_B + (1 - \delta)\alpha_A$ and (i,-i) is (A,B) or (B,A)

Moreover, using (2.4) and (2.7), I show that the equilibrium holdings at t=2 for investors of type i is

$$\theta_{2,i}^* = \frac{\alpha_{-i}}{\bar{\alpha}}(\bar{\theta} + Z) \quad (2.8)$$

Finally, using (2.3), (2.7) and (2.8), I show that the value function at t=2 of investors of type i is

$$V_2(Z, W_{2,i}) = -exp - \left\{ \alpha_i \left(W_{2,i} + \frac{1}{2}\alpha_i\sigma^2 \left(\frac{\alpha_{-i}(\bar{\theta} + Z)}{\bar{\alpha}} \right)^2 \right) \right\} \quad (2.9)$$

where $W_{2,i} = C_{1,i} + \theta_{1,i}P_2$

Lemma 1: Investors i's value function at t=2 is a function of Z, symmetric in a certain value Z_1 and increasing over $[Z_1; +\infty)$. Moreover, if $\theta_{1,i}$ is lower than a certain threshold, then $Z_1 < \bar{Z}$ and the value function is concave over an interval comprising of $[\bar{Z}; +\infty)$.

The interpretation of Lemma 1 is the following. The monotonicity and the symmetric feature of the function tells us that the more investors L buy or sell, the higher are the expected utilities of investors A and B. Said differently, investors A and B are better-off when net supply Z is very positive or very negative; and they are worse-off when net supply Z is somewhat positive or somewhat negative.

In addition, the concavity of the value function tells us that investors A and B are eager to avoid situations where net supply turns out to be smaller than this point. To that end, they are ready to forego the extra expected utility derived from a situation where the net supply turns out

to be larger than this point.

Overall, Lemma 1 gives the intuition that investors A and B will try to hedge at $t=1$ the possibility that Z turns out to be smaller than \bar{Z} .

I now derive the demand functions and the equilibrium price at $t=1$. This derivation leads to Proposition 1 which is the model's most important result.

The problem of investors of type i at $t=1$ consists in maximizing the expectation over Z of the value function given in (2.9). More precisely, they choose $\theta_{1,i}$ such as maximizing the following:

$$\mathbb{E}_Z \left[- \exp - \left\{ \alpha_i \left(W_{1,i} + \theta_{1,i} \left(\bar{D} - \frac{\alpha_i \alpha_{-i}}{\bar{\alpha}} \sigma^2 (\bar{\theta} + Z) - P_1 \right) + \frac{1}{2} \alpha_i \left(\frac{\alpha_{-i}}{\bar{\alpha}} \right)^2 \sigma^2 (\bar{\theta} + Z)^2 \right) \right\} \right] \quad (2.10)$$

where $W_{1,i} = C_{0,i} + \theta_{0,i} P_1$

I show the demand function of the investors of type i is

$$\theta_{1,i}^*(P_1) = \frac{\mathbb{E}_Z(P_2) - P_1}{\alpha_i \text{Var}(P_2) / (1 + \bar{\alpha}^{-2} \alpha_i^2 \alpha_{-i}^2 \sigma^2 \sigma_Z^2)} + \alpha_i \left(\frac{\alpha_{-i}}{\bar{\alpha}} \right)^2 \sigma^2 (\bar{\theta} + \bar{Z}) \frac{-\text{Cov}(P_2, Z)}{\text{Var}(P_2)} \quad (2.11)$$

where the second part of equation 2.11 is equal to $\mathbb{E}_Z(\theta_{2,i}^*) = \frac{\alpha_{-i}}{\bar{\alpha}} (\bar{\theta} + \bar{Z})$

Proposition 1 (also holds when $\alpha_A = \alpha_B$) : Investors i 's demand function for the risky asset at $t=1$ is composed of a speculative demand and a positive hedging demand. In particular, the speculative demand is negatively related to σ_Z^2 .

Proposition 1 is based on equation 2.11 which offers a clear decomposition of the demand function. The first term is speculative because it depends on the risk and reward of trading on the difference between the price at $t=1$ and the expected price at $t=2$: The demand for the risky asset is negative (positive) when the price at $t=1$ is higher (lower) than the expected price at $t=2$. The second term is a hedging demand because it depends on the covariance of the price with Z . The hedging demand translates into a positive demand for the risky asset because the correlation between the price at $t=2$ and Z is negative (it is equal to -1).

The economic interpretation of Proposition 1 is the following. The sale constitutes an investment opportunity while the net supply, Z , is a state variable which determines how lucrative the opportunity is. Hence, risk-averse liquidity providers will seek to hedge these changes in investment opportunities (Merton (1973)) with an investment which negatively correlates to the state variable Z . Said differently, investors would like to diversify away the risk of Z : Therefore, their valuation of investment opportunities depends on the *beta* of that investment with Z . In that regard, a long position in the risky asset is valuable because the return of that investment is high when Z is low.

I now study some comparative statics about the speculative and hedging demands. First, the absolute value of the speculative demand decreases in σ_Z^2 . Indeed, the uncertainty regarding net supply Z represents a cost of arbitrage for risk-averse investors: The higher σ_Z^2 , the less willing they are to speculate.

Second, the hedging demand is of the opposite sign of $\frac{Cov(P_2, Z)}{Var(P_2)}$, which is the "beta" of Z with P_2 : The lower the beta, the better the insurance provided by the risky asset.

Third, after simplification, the hedging demand is equal to $\mathbb{E}_Z(\theta_2^*)$. This means that investors will buy in advance what they otherwise expect to buy at $t=2$ if Z turns out to be equal to \bar{Z} . In particular, the larger \bar{Z} , the larger the hedging demand.

Finally, while the absolute amount of hedging does not vary with σ_Z^2 , the relative proportion of hedging in the investor's total demand increases in σ_Z^2 . The relative proportion of hedging can be defined as the ratio between the absolute value of hedging and the sum of the absolute value of hedging and the absolute value of speculation.

Importantly, the investors' willingness to buy or sell does not necessarily translates into trading between investors A and B. In particular, the price can adjust to the investors' demand without any trade.

Replacing the expression of $\mathbb{E}_Z(P_2)$, $Var(P_2)$ and $Cov(P_2, Z)$ I get that investors i 's demand for the asset at $t=1$ is:

$$\theta_{1,i}^*(P_1) = \frac{\bar{\alpha}^2 + \alpha_i^2 \alpha_{-i}^2 \sigma^2 \sigma_Z^2}{\sigma^4 \sigma_Z^2 \alpha_i^3 \alpha_{-i}^2} (\mathbb{E}_Z(P_2) - P_1) + \mathbb{E}_Z(\theta_{2,i}^*) \quad (2.12)$$

Having derived the demand, I now turn to the equilibrium at $t=1$. For the market to clear, aggregate demand must equal the supply $\bar{\theta}$

$$\delta\theta_{1,A}^* + (1 - \delta)\theta_{1,B}^* = \bar{\theta} \quad (2.13)$$

I then show that the equilibrium price for the asset at $t=1$ is

$$P_1^* = \mathbb{E}_Z(P_2) + \frac{\sigma^4 \sigma_Z^2 \alpha_i^3 \alpha_{-i}^3 \bar{Z}}{\bar{\alpha}^3 + \bar{\alpha} \alpha_i^2 \alpha_{-i}^2 \sigma^2 \sigma_Z^2} \quad (2.14)$$

Proposition 2 (also holds when $\alpha_A = \alpha_B$): The average return from investing in the risky asset between $t=1$ and $t=2$ is negative and decreases in the uncertainty regarding the net supply, σ_Z^2 . In particular, it is null when $\sigma_Z^2 = 0$.

The relationship between the uncertainty regarding net supply, σ_Z^2 , and the average return between $t=1$ and $t=2$ can be explained as such. As shown in equation 2.11, investors have a speculative component in their demand. The speculative component makes them seek to sell when P_1 is above $E_Z(P_2)$. As the uncertainty regarding net supply Z decreases, speculators are seeking to short more of the risky asset and the price decreases.

Note that the link between returns and net supply uncertainty is solely driven by the speculative component of the investors' demand function. This is because the other component of the investors' demand function –hedging– depends solely on the average net supply \bar{Z} and on the correlation between the return of the risky asset and the net supply Z . This correlation is fixed and equal to -1.

However, had this correlation not been fixed, the hedging demand would have increased in the uncertainty regarding net supply Z , thus providing another mechanism through which the average return from investing in the risky asset between $t=1$ and $t=2$ decreases in the uncertainty regarding the net supply. Indeed, a higher uncertainty regarding Z brings closer to -1 the correlation between Z and the return of the hedging position. This means that a higher uncertainty regarding Z increases the quality of the hedge which, in turn, increases the hedging demand, and ultimately increases the equilibrium price at $t=1$.

In particular, such link between the price at $t=1$ and the uncertainty regarding Z would exist in

a setting where the price in period 2 of the asset used as a hedge is imperfectly correlated to the price in period 2 of the asset which investors seek to hedge. An example of such imperfect hedging is when investors use the off-the-run bond to hedge the price of a to-be-issued on-the-run bond.

Lemma 2: P_1^* is above $\mathbb{E}_Z(P_2) - \left(\frac{\alpha_i \alpha_{-i}}{\alpha}\right)^3 \sigma^4 \sigma_Z^2 \bar{\theta}$ and below $\bar{D} - \frac{\alpha_i \alpha_{-i}}{\alpha} \sigma^2 \bar{\theta}$. In addition, P_1^* decreases in \bar{Z} .

Lemma 2 offers benchmarks for P_1^* from two alternative economies: An economy where investors care only about one-period returns; and an economy where investors do not expect any sale.

Lemma 2 also offers comparative statics. Lemma 2 says that the price at $t=1$ is higher than the price that would prevail if investors cared only about one-period returns. Note that, interestingly, if the investors cared only about one-period returns, there would be no hedging and the price at $t=1$ would be below the expected price at $t=2$. Lemma 2 also indicates that the price at $t=1$ is lower than the price that would prevail if the market did not expect any sale.

Finally, Lemma 2 says that the price at $t=1$ decreases in the expected net supply. Said differently, the price at $t=1$ when the market expects a large net supply is lower than the price at $t=1$ when the market expects a low net supply. This is true even though the hedging demand increases in the expected net supply.

Figure 2.3 illustrates the model's mechanism as reported in Proposition 1, Proposition 2 and Lemma 2.

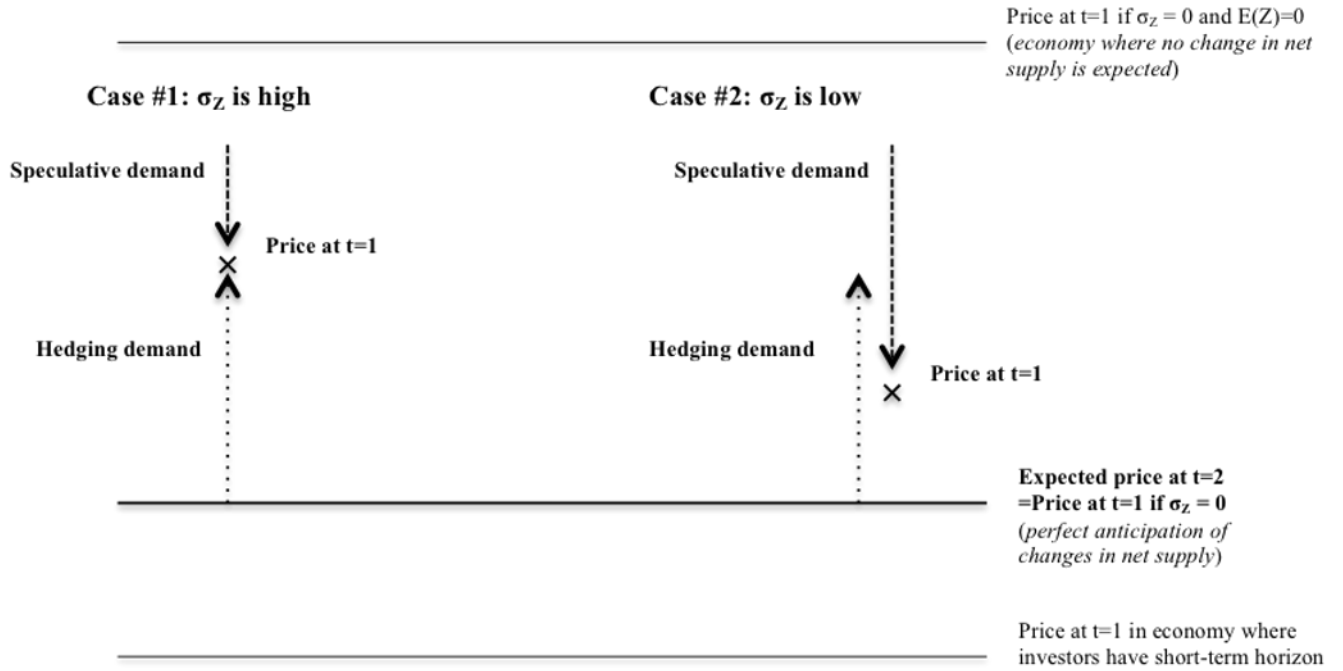


FIGURE 2.3: Illustration of the model's mechanism. The equilibrium price at $t=1$ is above the expected issuance price at $t=2$. It is also below the price prevalent in an economy where no change in net supply is expected. The equilibrium price at $t=1$ is the result of two opposite components of investors' demand functions : A speculative demand and a hedging demand. Through the speculative demand, investors seek to sell the security at $t=1$, conditional on the price at $t=1$ being above the expected issuance price at $t=2$. Through hedging demand, investors seek to have a long position in the security at $t=1$. The speculative demand is stronger when this uncertainty is lower. Hence, a lower uncertainty entails more selling pressure and a lower equilibrium price. The hedging demand ensures that the equilibrium price at $t=1$ is above the expected issuance price at $t=2$. Indeed, in an economy where all investors are short-term, investors would hold the risky asset but would ask for a compensation due to the uncertainty regarding next-period price. Hence, in such economy, the price at $t=1$ would be below the expected issuance price at $t=2$

Note that all results and propositions stated above go through if considering the special case where $\alpha_A = \alpha_B$ and $\delta = 1$. I now derive the equilibrium holdings at $t=1$ and make use of the heterogeneity in risk-aversion.

I show that the equilibrium holdings are the following:

$$\theta_{1,i}^* = \mathbb{E}_Z(\theta_{2,i}^*) - \alpha^{-i} \frac{\bar{\alpha}^2 + \sigma^2 \sigma_Z^2 \alpha_i^2 \alpha_{-i}^2}{\bar{\alpha}^3 + \bar{\alpha} \alpha_i^2 \alpha_{-i}^2 \sigma^2 \sigma_Z^2} \bar{Z} \quad (2.15)$$

After simplification, I find

$$\theta_{1,i}^* = \frac{\bar{\theta}}{\bar{\alpha}} \alpha_{-i} \quad (2.16)$$

Lemma 3: The hedging demand as a proportion of total demand is the same for investors of type A and B. Furthermore, the equilibrium holdings are invariant in σ_Z^2 and \bar{Z}

The first part of Lemma 3 is derived from Proposition 1. Investors of type A have both a larger speculative demand and a larger hedging demand, so that the ratio of the two demands is equal to that of investors of type B. In particular, the larger absolute demand for hedging of investors of type A comes from the fact that hedging demand is solely determined by the amount of investor's wealth tied to the sale (this is due to the CARA utility function): Since that investors of type A buy more at the sale than the other type, they have a larger wealth tied to the sale and therefore hedge more.

The second part of Lemma 3 is related to equation (2.16). It tells us that, contrary to the equilibrium price, equilibrium holdings are unaffected by the upcoming sale. In particular, the risk sharing among each types of investors is identical to that of standard one-period models.

2.2.5 Extension: Rationalizing trading and short-selling

In this section, I modify the model in order to rationalize an empirical fact documented in the next section: Higher-than-usual trading and short-selling volumes around auctions. To that end, I introduce a difference in investment horizons among investors. More precisely, investors A are now short-term investors which exit the market at $t=2$, while B investors exit the market at $t=3$. Furthermore, I suppose that the two types of investors have the same coefficient of risk-aversion and that the mass of investors A is δ while the mass of investors B is 1.

For brevity, I give only the equilibrium in Period 1.

The equilibrium price for the risky asset in Period 1 is

$$P_1^* = \mathbb{E}_Z(P_2) + \frac{\alpha^3 \sigma^4 \sigma_Z^2 \bar{Z}}{1 + \delta + \alpha^2 \sigma^2 \sigma_Z^2} \quad (2.17)$$

Investors A's equilibrium holding of the risky asset in Period 1 is

$$\theta_{1,A}^* = \frac{-\bar{Z}}{1 + \delta + \alpha^2 \sigma^2 \sigma_Z^2} < 0 \quad (2.18)$$

Investors B's equilibrium holding of the risky asset in Period 1 is

$$\theta_{1,B}^* = \bar{\theta} + \frac{\delta \bar{Z}}{1 + \delta + \alpha^2 \sigma^2 \sigma_Z^2} > 0 \quad (2.19)$$

Proposition 3 (extension with investor A being short-term): At $t=1$, short-term investors have a negative holding in the risky asset (i.e. they short-sells). Furthermore, short-selling is inversely related to the uncertainty regarding net supply, σ_Z^2 .

2.2.6 Implications

I now formulate the model's implications. In this section, I call *to-be-issued asset*, any asset with the same fundamental value as an asset which is scheduled to be issued in the near future. I also recall that I call *net supply*, the part of an asset issuance which is bought by liquidity providers (e.g. primary dealers) as opposed to natural buyers or occasional investors (e.g. mutual funds).

Implication 1: Before an issuance, the *to-be-issued asset* trades at a price above the expected issuance price. The price decreases as the auction date approaches.

Implication 1 is based on Proposition 2 using a dynamic interpretation of comparative statics, and supposing that the uncertainty about net supply decreases as the auction date approaches.⁴

The predicted price pattern is documented in the empirical literature. Lou, Yan and Zhang (2013) show that, on average, the price of a on-the-run US Treasury bond is higher before the issuance of a new issue than on issuance day.

Implication 2: Before an issuance, the arrival of a missing piece of information about the net supply will entail an asymmetric change in the price of the *to-be-issued asset*:

⁴Note that, in order to generate an increasing short-selling pattern, one would have to twist the model by introducing a period (say $t=1.5$) where σ_Z^2 decreases

The size of the price decrease in case of a “negative” information is larger than the size of the price increase in case of “positive” information.

This implication is based on Proposition 1, Lemma 2 and Proposition 2 using a dynamic interpretation of comparative statics. Indeed, the lower σ_Z^2 , the lower the price before the auction, holding constant $\mathbb{E}(Z)$.

The intuition of Implication 2 is as follows. Missing pieces of information may come in the form of announcements about the auction size or the publication of an expert’s opinion about what will be the demand for the asset on auction day: These pieces of information are informative about the net supply, Z . First, the price should trivially reflect the information: As show in Lemma 2, the price should increase (decrease) when the information reveals that the net supply is lower (larger) than expected. This effect has the same magnitude and opposite sign for “good” and “bad” news.

Second, the information arrival also decreases the uncertainty about net supply, regardless of whether the information is positive or negative: Hence, upon information arrival, the price before the auction should decrease towards the expected auction price (Proposition 2) due to larger arbitrage (Proposition 1). This effect has the same magnitude and the same sign for “good” and “bad” news.

Overall, a “positive” piece of information entails a price increase to reflect the information and a simultaneous price decrease to reflect the lower uncertainty. Similarly, a “negative” piece of information entails a price decrease to reflect the information and another simultaneous price decrease to reflect the lower uncertainty. Hence, the price will move more in cases where the information reveals larger-than-expected net supply than in cases where the information reveals smaller-than-expected net supply.

Implication 2 is new to the literature. In particular, this relationship is not predicted in Duffie (2010). In addition, one-period models of portfolio allocation would predict an opposite relationship. Indeed, using comparative statics, an increase (decrease) in the expected cash-flows of an asset in positive supply combined with a simultaneous decrease in the cash-flow’s uncertainty would result in a large (smaller) change in the asset price. Another difference with one-period models is that, in my model, the change is about the asset’s supply not the cash-flows.

***Implication 2’s corollary:* Take a sample of asset returns corresponding to a strategy of buying *to-be-issued assets* before and selling it after an arrival of information about the**

assets' net supplies. Suppose that as many positive as negative pieces of information arrived in the sample. Then, the average return over that sample is negative.

The intuition for this corollary is as follows. Suppose that, in a given sample, the arrival of information about the asset's net supply entails an asymmetric price reaction as predicted by Implication 2. For example, suppose that the price systematically increases (decreases) by 0.75 bps (1.25 bps) after the arrival of a positive (negative) piece of information. If there are as many positive as negative pieces of information, then on average the arrival of information entails a decrease of 0.25 bps. I test this corollary in the paper's empirical section.

Implication 3: The difference between the pre-auction price and the expected auction price for the to-be-issued asset is larger (lower) when the auction size is invariant in (varies with) the demand of natural buyers.

Implication 3 is new to the literature. This implication is based on Proposition 2 using a dynamic interpretation of comparative statics. In a primary auction of Treasury assets, the size of the issuance is usually fixed and known in advance but the demand from other participants might not be. For example, mutual funds may demand more of the new issue than expected: In that particular case, this means that liquidity providers absorb less than expected because supply is fixed.

On the contrary, when supply is not fixed in advance but matches the demand observed on auction day, the issuance size would increase (decrease) in case the demand from mutual funds is larger (smaller) than expected. This would reduce the uncertainty regarding net supply, σ_Z^2 . A lower σ_Z^2 leads to a lower price difference between the first period and the intermediate period (Proposition 2). Hence, the implication that the difference in price between the auction price and the price before the issuance would be reduced if the Treasury Office adopts a flexible supply.

Implication 4: Before an issuance, trading and short-selling volumes of the to-be-issued asset are higher than usual and increase as the auction date approaches.

Implication 4 is based on Proposition 3.⁵ The implication appears in the empirical literature. Keane (1996) shows that specialness of a US Treasury bond issue increases as the auction date of

⁵Note that, in order to generate a increasing short-selling pattern, one would have to twist the model by introducing a period (say $t=1.5$) where σ_Z^2 decreases

a new issue approaches. Similarly, Lou, Yan and Zhang (2013) documents the special repo rate of an old US Treasury issue is lower before than after the auction of a new issue. Finally, Sigaux (2017, chapter 1) finds that the demand for short-selling –as defined by an increase in volume and specialness of repo transactions collateralized by the to-be-auctioned security– increases prior to an auction and it is not informed about auction results.

2.3 Tests

The section is composed of two parts. In the first part, I verify that Implications 1 and 4 are present in the data. Specifically, I investigate whether the price of a to-be-issued bond decreases gradually and whether short-selling increases gradually ahead of the auction. In the second part, I test Implication 2’s corollary which is one of the model’s new implications. The corollary predicts that the price of the to-be-issued bond should decrease after the arrival of information about the bond’s net supply. In both parts, I use a setting that allows to observe the market price of the to-be-issued bond before the auction.

I recall that I define *net supply* as the share of the issue which is sold to liquidity providers (e.g. primary dealers) at an auction, as opposed to the share of the issue sold to natural buyers or occasional investors (e.g. mutual funds or insurance companies). As is conventional when studying fixed income products, note that I use yields instead of prices. I recall that yields move inversely to prices.

2.3.1 Institutional details

In Italy, two to thirty-year bonds are systematically *reopened* one or several times until reaching a certain minimum outstanding volume: *Reopenings* are identical to regular issuances, except that they do not result in the issuance of new bonds but in the increase in the outstanding amount of bonds that were issued in the past (e.g. six months ago) and that are already trading on secondary markets. Therefore, this setting allows me to observe the price of a bond before it is reopened. Admittedly, reopenings are not specific to Italy; in particular, they also exist in the U.S. (Fleming (2002)). However, in Italy, reopenings are systematic and extend to all medium-to-long maturities.

The tests presented in the second part of this empirical section rely on the specificities of the Italian issuance timeline. Therefore, I now comment three important points of the timeline represented in Figure 2.4. I also state an assumption used in the empirical tests.

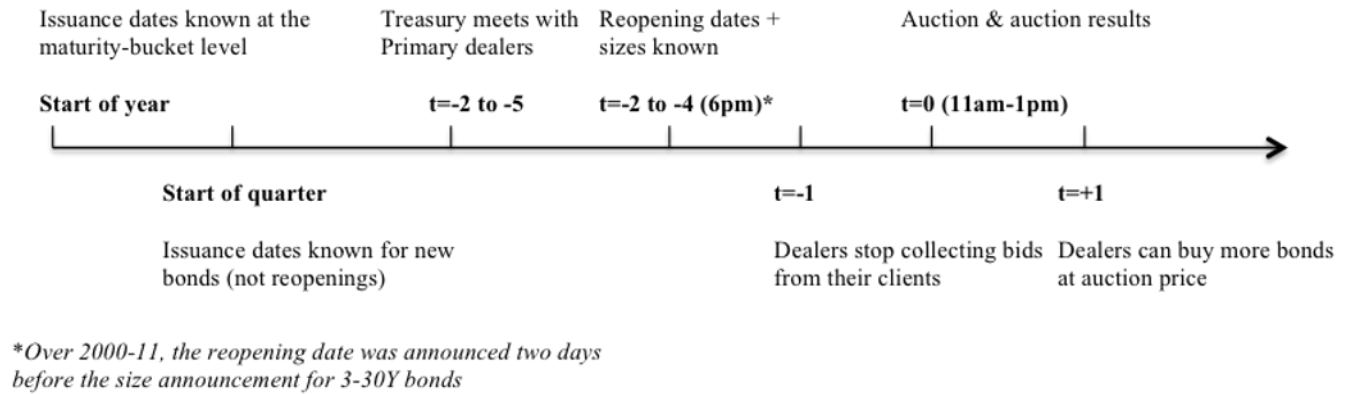


FIGURE 2.4: Issuance timeline for re-openings of Italian sovereign bonds

The first point of interest is the reopening date. At the start of each quarter, the Treasury communicates the date of some of the quarter's issuances. Specifically, the Treasury announces the date of new issuances but not the date of reopenings: The dates of reopenings are officially announced only two to five days in advance. However, as indicated in Table B.1 in the appendix, the market is able to precisely predict the reopening dates of many on-the-run bonds, notably by using historical data. For example, 10-year bonds have always been issued or reopened at the end of each month on a date inferred from a calendar made available each January. Consequently, at the start of each quarter, the market can perfectly predict the date of all of the quarters' reopenings of on-the-run 10 year bonds: These reopenings occur every end-of-month, on a well-identified day, unless a new issuance has been scheduled on that date. Similarly, the reopening date of 2, 3, 5-year bonds and floating-coupon bonds can be inferred. In the paper, I assume that the market perfectly predicts all reopening dates before the official announcement. In the robustness section, I relax this assumption and keep only reopenings of on-the-run bonds for which Table B.1 indicates a perfectly predictable pattern.

The second point of interest is the dealers' meeting. Twice a month, the Treasury organizes a meeting where all the primary dealers are present and share their views about which bond should be reopened in the next two weeks and what should be the issuance sizes. The date of this meeting can be precisely inferred from the calendar made available each year. Specifically, the meeting occurs on the day where the Treasury is scheduled to communicate about the first issuance of that part of

the month. Interestingly, there exists a cross-sectional heterogeneity regarding the relative date on which the meeting takes place: This is because bonds of different maturity are not reopened on the same day while the dealers' meeting take place on the same day for all maturities. For example, a given meeting may take place five days before the reopening date of a 3-year bond while occurring only three days before the reopening date of a 2-year bond.

The final point of interest is the announcement of the auction size. Two to four days before the issuance, the Treasury communicates to the market the size of the reopening. The date of the communication is indicated on the yearly calendar while the relative date on which this communication occurs depend on the bond's maturity and the time period.

Table B.2 in the appendix indicates the relative date on which the dealers' meeting and the size announcement take place for each maturity and period.

2.3.2 Data

I study reopenings of 2-30 year Italian sovereign bonds over 2000-2015, provided there exists yield data on Datastream for the reopened bond prior to the reopening date. I exclude 2011 from the sample, due to the market conditions linked to the Eurobond crisis. In some robustness tests, I re-integrate 2011 into the sample. The largest sample is composed of 831 reopenings.

The yield data comes from Datastream (RY datatype). However, the sample includes price data from MTS which I exploit in the robustness section. More precisely, Italian bonds trade on two MTS platforms: The MTS and the Euro-MTS platforms. The secondary trading volume used in this analysis is the sum of the trading volume on the MTS platform and on the Euro-MTS platform.

The reverse (a.k.a special) repo data covers January 2005-October 2012 and comes from MTS's repo platform. The reverse repo volume for a given bond corresponds to the volume of transactions on the MTS repo platform for which the bond was expressively specified as collateral in the repo contract. Finally, note that traders on the MTS platforms are large financial institutions.

In the appendix, Table B.3, Table B.4 and Table B.5 report some summary statistics regarding the sample, including the amount sold at reopenings as well as secondary and repo trading variables.

2.3.3 Are Implications 1 and 4 verified in the data?

In this part, I verify that the increasing yield, trading and short-selling volume patterns predicted by Implication 1 and 4 exist in the data. To do so, I perform a series of t-tests which compare the value of a market variable (e.g. the yield) at date t and at date 0 for each t in a $(-5,+5)$ window, where t denotes the number of trading days from/since the reopening date. Then, I report the point estimates in Table 2.2.

More precisely, for each t in $(-5,+5) \setminus \{0\}$, I test for the null hypothesis $\alpha_t = 0$ in the following t-test specification:

$$X_{it} - X_{i0} = \alpha_t + \epsilon_{it} \quad (2.20)$$

where X_{it} denotes a relevant market variable (secondary yield, log of secondary trading volume, or log of special repo volume) for the to-be-reopened bond at reopening i in t business days.

Table 2.2 reports the results. The first column suggests that the yield increases progressively, reaches a maximum on reopening day and decreases back. Similarly, in the second and third column, I find that the trading volume and the special repo volume progressively increase, reach a maximum on reopening day and revert (the volume of special repo volume is an indicator of short-selling activity). In the appendix, I introduce alternative measures of prices and find that the result of the first column do not change qualitatively.

Overall, Implications 1 and 4 are verified by the data. Interestingly, this paper's setting allows to disregard the possibility that the price pattern is due to a type of on/off-the-run phenomenon (Krishnamurthy (2002)) where the price of the current issue would progressively decrease before the auction of a new issue. Such price decrease could be the result of investors deriving less benefits from the current issue: Indeed, this issue will soon lose its on-the-run status and, therefore, its superior liquidity. However, a reopening does not entail any change in on-the-run status: The reopened bond keeps its current status, and so do the other bonds.

TABLE 2.2: I study if the yield, trading and short-selling volumes of the reopened bond increase before the reopening day as predicted by Implication 1 and 4. The table reports the coefficient of t-test specifications which test the nullity of the difference in yield or in log trading volume or log special repo volume between date t and the reopening day, where t belongs to (-5,+5) and 0 denotes the reopening day. Sample: all 2-30 year Italian sovereign bonds reopened over 2000-15 (excluding 2011) for which yield data are available on Datastream. A reopening is a primary auction that results in the increase in the outstanding volume of a bond that was first issued in the past. t statistics in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

	Δ Yield (bps)	Δ Trading vol. (%)	Δ Special Repo vol. (%)
t=-5 vs. t=0	-2.52*** (-3.28)	-180.50*** (-11.74)	-32.20*** (-11.39)
t=-4 vs. t=0	-2.92*** (-3.90)	-162.34*** (-15.55)	-29.40*** (-11.56)
t=-3 vs. t=0	-1.82*** (-3.49)	-164.12*** (-12.49)	-30.49*** (-16.82)
t=-2 vs. t=0	-1.09*** (-2.69)	-149.18*** (-15.87)	-23.86*** (-9.92)
t=-1 vs. t=0	-0.84*** (-2.82)	-123.17*** (-13.87)	-15.36*** (-6.39)
t=+1 vs. t=0	-0.96*** (-2.76)	-132.84*** (-21.90)	-48.82*** (-11.45)
t=+2 vs. t=0	-2.00*** (-3.18)	-163.58*** (-14.12)	-56.61*** (-24.71)
t=+3 vs. t=0	-2.85*** (-4.93)	-163.43*** (-15.60)	-56.92*** (-10.66)
t=+4 vs. t=0	-3.77*** (-6.43)	-158.84*** (-17.95)	-55.73*** (-15.30)
t=+5 vs. t=0	-4.17*** (-6.15)	-169.36*** (-13.97)	-60.34*** (-11.51)
Observations	831	360	349
Sample period	2000-15 ex.11	2004-12 ex.11	2005-12 ex.11
Cluster	Maturity and day-level	Maturity and day-level	Maturity and day-level

2.3.4 Tests of Implication 2's corollary

In this section, I test Implication 2's corollary and reject alternative explanations.

This paper’s empirical strategy consists in using the dealers’ meeting and the announcement about the auction size as arrivals of information about the net supply. These are pieces of information that the market were expecting to receive and which reduce uncertainty regarding the net supply, i.e. it reduces σ_Z^2 .

More precisely, in the model, liquidity providers are uncertain about how much profit they will realize at the auction. The profit depends on Z , i.e. the auction’s net supply. In real life, this uncertainty about Z may arise from two sources of uncertainty: First, uncertainty about the auction size; second, uncertainty about the demand of “natural buyers” at the auction. The announcement of the auction size will suppress the first source of uncertainty and may contain information about the demand of natural buyers.

In addition, during the dealers’ meeting, liquidity providers are likely to acquire information about both the auction size and about what will be the demand of natural buyers on auction day. Overall, it is appropriate to use the dealers’ meeting and the auction size announcement as events which reduce uncertainty about net supply Z .

Importantly, the empirical strategy relies on the following assumption: There are as many positive as negative pieces of information about changes in net supply over the sample. This assumption is reasonable given that I use 15 years of auction data.

Main test

In this part, I test whether the yield increases (i.e. price decreases) more after the arrival of information than on non-information days, as predicted by Implication 2’s corollary.

More precisely, this paper’s model predicts that $\beta > 0$ (null hypothesis $\beta = 0$) in the following regression:

$$Yield_{it} - Yield_{it-1} = \beta * 1_{Info_{it}} + FixedEffects + \epsilon_{it} \quad (2.21)$$

t belongs to $(-5,-1)$; $1_{Info_{it}}$ takes the value 1 if the Treasury meets with dealers t days before reopening i or if the Treasury announced the auction size $t+1$ days (after market close) before reopening i ; 0 otherwise. $Yield_{i;t}$ measures the datastream yield t business days before reopening i of the bond reopened at reopening i ; $FixedEffects$ includes maturity, time and days-to-auction fixed effects.

Table 2.3 gives some summary statistics and shows that the average change in yield is more positive on info days than no-info days. This is true in a pooled sample and within maturities, time periods or days-to-auction.

Table 2.4 shows the regression results. In the first column, I find that the info dummy is positive, is equal to 1.2 bps and is significantly different from zero. This result confirms that the yield increases more on the days when information about the net supply arrives than on other days.

In the other two columns, I perform robustness tests. Specifically, in the second column, I add time fixed effects at the quarter-level, I control for the bond's maturity and I cluster standard errors at the day-level. I find that the info dummy is still significantly different from zero and is equal to 1.2 bps.

In the third column, I control for the possibility that the information days are systematically closer to the auction date. In particular, Duffie (2010) predicts that the price decrease should accentuate as the auction date approaches. To control for the possibility that the results are driven by Duffie (2010)'s prediction, I add fixed effects which capture the number of days that separate one observation to the auction date. By doing so, I select price movements which occurred on the same relative date (e.g. three days before an auction) and, within this group, I compare the information day to the no-information days. I find that the info dummies is significantly different from zero and is equal to 1.9 bps.

Overall, what is observed in the data is consistent with Implication 2's corollary.

In the Appendix, I separate the effect of the dealer's meeting from the effect of the size announcement. Specifically, I create a dummy equal to one for days when the dealer's meeting take place, and zero otherwise. I also create a dummy equal to one for days following the auction size announcement; zero otherwise. I then regress the change in yield on those two dummies. Column 1 of appendix Table B.7 shows the results. I find that both dummy are positive and significantly different from zero, albeit weaker since that the information days are not pooled anymore. Specifically, the yield increases on dealer meeting days by 0.96 bps more than on no-information days; while the yield increases on announcement size days by 1.44 bps more than on no-information days.

Finally, I also include changes in yields occurring on auction day. Indeed, the entire uncertainty is resolved on that day: Therefore, the model predicts that the yield decreases on auction day. I create a dummy equal to one for auction days, and zero otherwise. I then regress the change in yield on the auction dummy, the announcement size dummy and the dealer meeting dummy. Column 2 of appendix Table B.7 shows the results. I find that the three dummies are positive and

significantly different from zero. Specifically, the dealer and size dummies have not quantitatively changed, while the yields increase by 0.95 bps more on auction days than on no-information days. This suggests that the pre-auction price decline is around 2.5 times as large as the auction-day price decline.

TABLE 2.3: Summary statistics - Daily yield change before reopenings on info-days and no-info days. 1_{Info} takes the value 1 if t is either the day on which the Treasury meets with dealers or the day following the announcement of the auction size, where t belongs to a (-5, -1) window before the reopening date, and 0 otherwise. The yield data comes from Datastream (RY datatype). Sample: all 2-30 year Italian sovereign bonds reopened over 2000-15 (excl. 2011). A reopening is a primary auction that results in the increase in the outstanding volume of a bond that was first issued in the past

$Yield_t - Yield_{t-1}$	$1_{Info} = 1$			$1_{Info} = 0$		
	Mean	Std.	Obs.	Mean	Std.	Obs.
All	1.073	10.70	1572	-0.129	9.18	2583
2Y	0.646	5.61	305	-0.12	5.78	460
3Y	0.92	10.03	311	-0.475	8.92	519
5Y	2.139	18.14	257	-0.768	14.14	458
10Y	0.723	11.77	319	0.069	9.88	511
15Y	1.782	6.23	132	0.638	6.56	228
30Y	0.865	4.37	142	0.625	4.23	238
2000-2004	0.23	7.52	521	-0.391	6.32	889
2005-2009	0.821	4.45	440	0.574	4.59	725
2010-2015 (ex.11)	1.974	15.20	611	-0.413	13.11	969
t=-5	0.798	8.44	442	-0.384	6.49	389
t=-4	0.809	8.59	151	-0.866	14.28	680
t=-3	3.754	23.27	178	0.361	6.54	653
t=-2	0.521	6.92	769	0.891	4.32	62
t=-1	4.497	9.74	32	0.144	6.43	799

TABLE 2.4: Main results- I test if the yield increases more after the arrival of information than on non-information days, as predicted in Implication 2's corollary. The left-side variable is the one-day change in the yield of the reopened bond between t and $t-1$, where t belongs to a $(-5, -1)$ window before the reopening date, and 0 is the reopening date. The variable of interest is 1_{Info} which takes the value 1 if t is either the day on which the Treasury meets with dealers or the day following the announcement of the auction size; 0 otherwise. The yield data comes from Datastream (RY datatype). Sample: all 2-30 year Italian sovereign bonds reopened over 2000-15 (excl. 2011). A reopening is a primary auction that results in the increase in the outstanding volume of a bond that was first issued in the past. t statistics in parenthesis. $*p < 0.10$, $**p < 0.05$, $***p < 0.01$

	Δ Yield	Δ Yield	Δ Yield
	One-day change (bps)	One-day change (bps)	One-day change (bps)
1_{Info}	1.202*** (3.84)	1.212** (2.34)	1.884** (2.21)
Constant	-0.129 (-0.67)		
Observations	4,155	4,155	4,155
Time fixed effect	None	Quarter	Quarter
Other fixed effects	None	Maturity	Maturity, Days-to-auction
Cluster	None	Day-level	Day-level

2.3.5 Robustness section

First, in unreported specifications, I reproduce the main findings using Datastream's clean prices or MTS transactions prices instead of yields. The results are robust to that change.

Second, I provide three additional robustness checks. First, I check whether the results in Table 2.4 are robust to keeping only the following reopenings: Those which date can be predicted at least before the dealers' meeting by the econometrician using historical data. More precisely, I keep the reopening of on-the-run bonds for which appendix Table B.1 indicates the existence of a predictable reopening pattern. Therefore, the following reopenings are removed from the sample: Off-the-run bonds, 15 and 30-year bonds, 5-year floating bonds, as well as the months where there might not be any reopening for a given maturity (those are defined as the months where there was no reopening on those months for at least two years in the sample).

In addition, I control for macroeconomic events by using daily changes in interests rates computed from maturity-matched German sovereign bond prices. The results are shown in column 1 and 2 of Appendix Table B.6 and are robust to these two changes.

I also replicate column 2 of Table 2.4 while re-integrating into the sample auctions occurring in year 2011. The results are shown in column 3 of Appendix Table B.6 and are qualitatively robust to this change as well, albeit slightly weaker (p-values = 5.4%). However, note that the model is not designed to explain price movements in 2011. Indeed, the model rely on the assumption that information about the auction is orthogonal to the bond's value. This is clearly not the case in 2011: During the European sovereign bond crisis, any piece of auction information was likely to be interpreted as information about Italy's economy.

Finally, I provide some robustness checks of the general price pattern as documented in Table 2.2. First, I use two alternative pricing variables: The mid quote price from Datastream and the ask quote price for a €5M trade from the MTS platform. Second, I decompose the price and volume change in the (-5,0) window into two components: The change in the (-5,-1) window and the change in the (-1,0) window. Finally, I include the year 2011 into the analysis. The results can be found in Table B.8 and are robust to all these changes.

The following is of particular interest: Over 2009-11, an investor who buys €5M of the reopened bond at $t=-1$ pays on average 0.28% above the expected price at $t=0$. This extra cost is large since that it equals to the average half spread for a €5M trade over that period (0.27%). Therefore, there seems to be a benefit from buying the reopened bond before the auction instead of buying it on auction day, as suggested by this paper's model.

2.4 Alternative explanations for the Treasury price pattern

This paper's model explains why Treasury bond prices have been documented to decrease before auctions. Crucially, the model rationalizes why investors agree to pay a negative return for obtaining a bond before the auction instead of buying the bond on secondary markets on auction day. In my model, the premium paid before the auction reflects the cost of hedging the possibility that the auction is a worse investment opportunity than expected for liquidity providers.

In this part, I review the alternative explanations which could be considered. First, there exist

models where the premium paid reflects the informational, technological or institutional disadvantage of the buyers. In Brunnermeier and Pedersen (2005) and Bessembinder et. al. (2016), some agents are not informed about the price difference, do not have the technology or do not wish to exploit the price difference. They buy from “superior agents” before the liquidation and sell back to them after. In Duffie (2010), some agents are constantly on the market while others are periodically on the market. Agents that are periodically on the market are not sensitive to price movements that occur while they are away from the market. In particular, agents that are not present during the auction (i.e. when prices are lower) agree to buy the asset ahead of the auction at a higher price. Similarly, in models with market segmentation, some agents have access to the primary market while others do not: The agents that cannot participate in auctions agree to buy at a premium before or after the auction.

These models do not study the link between uncertainty and trading ahead of scheduled events. Therefore, they do not show the paper’s main theoretical and empirical results. Also, my model differs from these models in that I suppose that any investor is aware of the auction, aware of the price pattern and able to participate to the auction (or, at least, access the secondary market on auction day).

Second, some alternative explanations are based on inventory management. In the empirical paper of Lou, Yan and Zhang (2013), the authors explain and show evidence that dealers are hedging: They are selling in advance their to-be-acquired participation in the auction. The fact that some investors are short-selling could explain a progressive drop in the price. But this rationale does not provide an explanation as to why some agents are buying from the short-sellers at the high price instead of buying later. Also, this paper does not study the link between uncertainty and trading ahead of auctions: Hence, it cannot account for the findings in Table 2.4.

Finally, some alternative explanations can be drawn from the *when-issued* literature. In the empirical paper of Nyborg and Sundaresan (1996), investors trade in the when-issued market. Notably, investors trade before the auction in order to be sure to get the desired quantity of new bond. I argue that a model based on this trading motive could rationalize the price premium paid by some investors and would provide a credible alternative to my model. Such model would feature a cost for failing to deliver the bond and risk-averse agents with heterogeneous levels of commitment regarding bond delivery. However, to my knowledge, such model has not been put forward in the literature.

2.5 Extension to cases other than Treasury auctions

2.5.1 Additional implications

This paper's model makes the following three additional implications which I explain in more details in the next subsections.

Implication 5: The price of an asset ahead of a predictable sale on the futures markets is higher than the expected sale price. It progressively decreases towards the expected sale price as the date of the sale approaches.

Implication 6: After controlling for the informational content of a Seasoned Equity Offering (SEO) about the stock's fundamental value, the stock price ahead of a SEO is higher than the offer price. It progressively decreases as the SEO date approaches. In addition, the short-selling volume of a stock before a SEO is larger than usual and increases as the SEO date approaches.

Implication 7: Conditional on the expected "fixing demand" being negative, the price of an asset (e.g. gold) before the fix is higher than the price at the time of the fix. It progressively decreases as the time of the fix approaches.

2.5.2 Predictable trades on the futures markets

Some investors roll-over their futures contracts in a predictable fashion. Bessembinder et. al. (2016) study a large ETF which tracks oil prices by investing in oil futures. On some predictable dates, the ETF sells its future contracts and invests in newer contracts. The strategy is known and the trading date is announced on the ETF's website. Possibly, the amount sold by the ETF is perfectly known in advance as well. However, the presence of buyers on the futures market at the time of the trade might not be known in advance by would-be liquidity providers.

This paper's model applies to this context where an ETF sell an asset and where the date and the quantity are known but not the demand for the asset at the time of the trade.

The price pattern predicted in Implication 5 is documented in Bessembinder et. al. (2016). In table 5 of their paper, for each day in a (-10;10) window, they compare the one-day return of

the future oil contract which is sold by the ETF (“front contract”) to the one-day return of the contract which is bought by the ETF (“second contract”). Finally, they build a measure which cumulates the one-day differences. They find that the cumulated return difference is less negative before the date of the trade than on the date of the trade. This means that the price of the front contract is higher before the date of the trade than on the date of the trade. Also, they find that the cumulated return difference becomes more and more negative as the date of the trade approaches. This means that the price of the front contract decreases as the rebalancing date approaches.

2.5.3 In Seasoned Equity Offerings context

Seasoned Equity Offerings (SEOs) are predictable liquidations of stocks. The date of the offering is known in advance. There are several types of SEOs. One type is called “bought deal” whereby the issuer states the issuance amount, then an auction is realized among investment banks and the bank with highest bid buys the entire issue (Gao and Ritter (2010)). The issuance size is fixed but a given investment bank might not precisely know the demand of the other banks.

This paper’s model applies to this context where an issuer issues equity and where the date and the quantity are known but not the demand for the asset at the time of the issuance. The “liquidity traders” in my model and their stochastic endowment (with positive mean) can represent the combination of two features of SEOs: First, the sale of a deterministic volume of risky asset by the issuer; second, the fact that a particular bank does not precisely know the demand of other banks (captured by the random part of Z).

Admittedly, contrary to the sale of Treasury assets, a SEO is not a true liquidity shock: The size of the SEO might send a signal about the fundamental value of the asset. Therefore, this paper’s model can apply only after controlling for the informational content of a SEO about the stock’s fundamental value.

The price decrease predicted in Implication 6 is documented in Corwin (2003) and Meidan (2005). In figure 2 in Corwin (2003), the author shows that the cumulated abnormal return of holding the stock five days before the SEO and selling it one day before SEO day is equal to -2.2%. This means that the price one day before the SEO is lower than the price three days before. Similarly, table 1 in Meidan (2005) shows that holding the stock three days before the SEO and selling it one day before would result in an abnormal negative return of -1.1% to -2.3%. Moreover, the short-selling pattern predicted in Implication 6 is documented in Henry and Koski (2010). In their table 2, it can be seen that the mean and the median volume of short-selling (as percentage

of trading volume) is abnormally high in a window of one day after the SEO announcement and one day before the SEO date. In addition, short-selling volume is larger on that window than on the announcement date.

2.5.4 In fixing context

In some markets such as the gold market or the FX market, a large part of trading is realized at particular benchmarks, called “fixes”. Similarly, in the equity market, there is a large demand for trading at the close. For example, the London Gold Fixing occurs twice each day at 10:30am and 3pm: On these two occasions, an auction is conducted. Market-makers collect the orders from their clients and their own proprietary desks and then communicate their demand schedules. The “fix” is the clearing price (US District Court (2014)). On the FX market, the 4pm London fix is similarly determined (Melvin and Prins (2015)). Finally, on other markets such as the equity market, a call auction is organized at the close (Hillion and Suominen (2004)).

This paper’s model applies to the context of fixing in the special case where market-makers expect that natural investors will sell on average at the fix.

The price pattern predicted in Implication 7 is compatible with some of the findings in Abrantes-Metz and Metz (2014). They find that, on some occasions, the price of gold is higher before the time of the fix than at the time of the fix. The price decreases as the time of the fix approaches, with a minimum reached at the time of the fix. The findings in Abrantes-Metz and Metz (2014) are published in a context of potential fraudulent manipulation of the price of gold. My model shows that some of the findings are compatible with portfolio management from gold market-makers who expect the demand to be negative but are not able to perfectly forecast what will be the demand at the fix.

2.6 Conclusion

I develop and test a model explaining the gradual price decrease observed in the days leading to large anticipated asset sales such as Treasury auctions. In the model, risk-averse investors anticipate an asset sale which magnitude, and hence price, are uncertain. I show that investors face a trade-off between hedging the price risk with a long position, and arbitraging the difference between the pre-sale and the expected sale prices. Due to hedging, the equilibrium price is above the expected sale price. As the sale date approaches, uncertainty about the sale price decreases, short arbitrage

positions increase and the price decreases. In line with the predictions, I find that the yield of Italian Treasuries increases by 1.2 bps after the release of auction price information, compared to non-information days.

References

- Abrantes-Metz, R., and Albert D., 2014. Are gold prices being fixed? Cited in Southern District of New York Case Number 1:14-md-02548, <http://www.bergermontague.com/media/434667/gold-complaint.pdf>.
- Beetsma, R., Giuliadori, M., De Jong, F. and Widijanto, D., 2016. Price effects of sovereign debt auctions in the Euro-zone: the role of the crisis. *Journal of Financial Intermediation*, 25, pp.30-53.
- Bessembinder, H., Carrion, A., Tuttle, L. and Venkataraman, K., 2016. Liquidity, resiliency and market quality around predictable trades: Theory and evidence. *Journal of Financial Economics*, 121(1), pp.142-166.
- Brunnermeier, M.K. and Pedersen, L.H., 2005. Predatory trading. *The Journal of Finance*, 60(4), pp.1825-1863.
- Corwin, S.A., 2003. The determinants of underpricing for seasoned equity offers. *The Journal of Finance*, 58(5), pp.2249-2279.
- Duffie, D., 2010. Presidential Address: Asset Price Dynamics with Slow?Moving Capital. *The Journal of finance*, 65(4), pp.1237-1267.
- Faulkender, M., 2005. Hedging or market timing? Selecting the interest rate exposure of corporate debt. *The Journal of Finance*, 60(2), pp.931-962.
- Fleming, M.J., 2002. Are larger treasury issues more liquid? Evidence from bill reopenings. *Journal of Money, Credit and Banking*, pp.707-735.
- Fleming, M.J., 2007. Who Buys Treasury Securities at Auction?. *Current Issues in Economics and Finance*, 13(1), p.1.
- Gao, X. and Ritter, J.R., 2010. The marketing of seasoned equity offerings. *Journal of Financial Economics*, 97(1), pp.33-52.
- Grossman, S.J. and Miller, M.H., 1988. Liquidity and market structure. *the Journal of Finance*, 43(3), pp.617-633.

Henry, T.R. and Koski, J.L., 2010. Short selling around seasoned equity offerings. *Review of Financial Studies*, 23(12), pp.4389-4418.

Hillion, P. and Suominen, M., 2004. The manipulation of closing prices. *Journal of Financial Markets*, 7(4), pp.351-375.

Keane, F., 1996. Repo rate patterns for new Treasury notes. *Federal Reserve Bank of New York Current Issues in Economics and Finance*, 2(10).

Krishnamurthy, A., 2002. The bond/old-bond spread. *Journal of financial Economics*, 66(2), pp.463-506.

Lou, D., Yan, H. and Zhang, J., 2013. Anticipated and repeated shocks in liquid markets. *Review of Financial Studies*, p.hht034.

Meidan, D., 2005. A re-examination of price pressure around seasoned equity offerings.

Melvin, M. and Prins, J., 2015. Equity hedging and exchange rates at the London 4p. m. fix. *Journal of Financial Markets*, 22, pp.50-72.

Merton, R.C., 1973. An intertemporal capital asset pricing model. *Econometrica: Journal of the Econometric Society*, pp.867-887.

Nyborg, K.G. and Sundaresan, S., 1996. Discriminatory versus uniform Treasury auctions: Evidence from when-issued transactions. *Journal of Financial Economics*, 42(1), pp.63-104.

Sigaux, J.D, 2017. Are Short-Sellers of Sovereign Bonds Informed About Auctions? Doctoral thesis, chapter 1.

Sundaresan, S., 1994. An empirical analysis of US Treasury auctions: Implications for auction and term structure theories. *The Journal of Fixed Income*, 4(2), pp.35-50.

U.S. District Court, 2014. Southern District of New York Case Number 1:14-md-02548.

TreasuryDirect, 2016. <http://www.treasurydirect.gov>.

Vayanos, D. and Wang, J., 2012. Liquidity and asset returns under asymmetric information and imperfect competition. *Review of Financial Studies*, 25(5), pp.1339-1365.

Vayanos, D. and Woolley, P., 2013. An institutional theory of momentum and reversal. *Review of Financial Studies*, 26(5), pp.1087-1145.

Chapter 3

Do Prices Reflect Collateral Value During a Crisis?

A low-repo-rate bond is more expensive than an otherwise identical bond: The price difference is equal to the interest saved on cash loans when using the low repo-rate bond as collateral instead of the other bond (Duffie (1996)). Using 54 pairs of identical sovereign bonds over 2005-12, I study the link between prices and repo rates during the subprime crisis. I find that the no-arbitrage relationship between prices and repo rates in Duffie (1996) fares worse during the crisis. However, I find that low-repo-rate bonds have an 18.0% higher probability of being more expensive than identical high-repo-rate bonds during the crisis, compared to only 9.0% before the crisis. Overall, while there are high limits of arbitrage, prices and repo rates feature larger co-movements during the crisis, likely due to market-making and liquidity shocks.

3.1 Introduction

Some securities can be more readily used as collateral to get cheap financing than others: These are deemed to have a *high collateral value*. For example, before an auction, bonds that are similar to the to-be-auctioned bond are in high demand on the repo market: Investors are ready to lend cash at a low rate to be able to borrow these bonds, thus allowing the owners of these bonds to get cheap financing during that period (Keane (1996), Moulton (2004)). Similarly, some asset classes provide higher collateral value than others (Bartolini et. al. (2011)).

All else equal, a security with a high collateral value should be more expensive than an otherwise identical security. If not, arbitrageurs can step in: They buy the high-collateral-value security and sell the other until the collateral value is reflected in prices. In that regard, Duffie (1996) develops a no-arbitrage relationship where a bond with a low repo rate (i.e. a high-collateral-value bond which allows cheap financing) is more expensive than an otherwise identical bond with high repo

rate. The price difference is equal to the interest saved on cash loans when using the low repo-rate bond as collateral instead of using the high-repo-rate bond.

In this paper, I ask if prices reflect collateral value during a crisis. The answer is not obvious. On the one hand, if collateral value is only reflected in prices through arbitrage activity, then it is unlikely to be reflected in prices during a crisis. Indeed, crises are known to be periods where arbitrage is more difficult, potentially due to financing constraints (Gromb and Vayanos (2010)): In case prices and collateral value fail to be in line, arbitrageurs are not able to correct the distortion. On the other hand, investors are typically cash constrained during a crisis. Hence, during a crisis, they are likely to favor securities that provide a better collateral to finance their purchases or to obtain cheap cash in case they suffer a liquidity shock. In that respect, collateral value is likely to be reflected in prices during a crisis and the price gap between high and low collateral quality securities is likely to widen (Garleanu and Pedersen (2011)).

In this paper, I use 54 pairs of identical sovereign bonds over 2005-12 (same issuer, coupon rate and remaining maturity). First, I find that the no-arbitrage relationship in Duffie (1996) fares worse during the subprime crisis than outside of the crisis: The difference in price between two bonds of a same pair during the crisis is further away from the difference in financing cost than prior to the crisis. Second, however, I find that low-repo-rate bonds have an 18.0% higher probability of being more expensive than otherwise identical bonds during the crisis, compared to 9.0% before the crisis. Overall, there exist limits of arbitrage that prevent collateral value from being fully reflected in prices, especially during the crisis. Still, part of the collateral value is reflected in prices because prices and repo rates feature a larger co-movement during the crisis: A bond that is expensive (cheap) also features a low (a high) repo rate.

The two potential mechanisms of this larger co-movement –which I develop in the last section of the paper but do not investigate– are market-making and cash needs. More precisely, a bond that is expensive has a low repo rate during a crisis because bond market-makers have smaller inventories and need to borrow the bonds to face demand. Accordingly, I find that the order imbalance (i.e. the difference between buy and sell orders) increased during the crisis: This is consistent with market-makers having to rely on the repo markets. Similarly, during the crisis, a cheap bond has a high repo rate because investors face sudden cash needs: While some investors sell their bond holdings, others use the bonds as collateral to borrow cash on the repo market.

Studying the link between repo rates and bond prices during the crisis is important. First, it allows to deepen our understanding of how limits of arbitrage affect prices. In particular, while

the literature has been studying how these frictions impact equity or bond prices (Garleanu and Pedersen (2011)), it has yet to study the impact on repo rates. Second, the repo market is a large market with a daily trading volume of 184 Billion euros for European bonds. In spite of this large size, the determinants of repo rates have not been extensively studied in the literature.

The stylized setting is as follows. Let A and B be two strictly identical bonds. Duffie (1996) develops the following no-arbitrage relationship between their prices (P_A and P_B) and their repo rates (r_A and r_B):

$$P_B = P_A \frac{1 + r_A}{1 + r_B} \quad (3.1)$$

In this paper, I pair each bond of my sample with an identical bond (same issuer, same coupon rate, same maturity date). I first examine if the relationship in Duffie (1996) holds better during the crisis. I then test if the bond with the lower repo rate is more likely to be the bond with the higher price, within a same pair, especially during the crisis.

Specifically, each pair is composed of a 12-month zero-coupon bond and of a 3-month zero-coupon bond. Both bonds were issued by the Italian government and they mature at the same time. The only difference is that the first bond was issued 9 months before the second bond, and has typically a greater issuance volume. Therefore, although the two bonds feature similar bid-ask spreads, I control for potential differences in liquidity.

My paper contributes to the literature that studies the link between secondary prices and repo rates (Duffie (1996), Jordan and Jordan (1997), Bartolini et. al. (2010), D'Amico, Fan and Kitsul (2015), Corradin and Maddaloni (2017)). In particular, I contribute to the literature that studies the prediction in Duffie (1996).

This paper's main contribution resides in its ability to directly observe the difference in repo rate of two identical bonds. In contrast, other papers compare a bond's repo rate to an estimate of the repo rate of a replicating portfolio.

D'Amico, Fan and Kitsul (2015) find that repo rates are sensitive to shocks on the relative supply of bonds. They also find that the shock on repo rate is passed on to the price of off-the-run bonds via the mechanism in Duffie (1996). Our papers are different, however. First, I compare the relationship during and before a crisis period, which D'Amico, Fan and Kitsul (2015) do not. Second, the two papers differ in their identification strategy. D'Amico, Fan and Kitsul (2015) relies

on comparing bonds which received an exogenous supply shock and bonds that did not: They ask if the price of the bonds that experienced a decrease in supply increased more (via the change in repo rate) than the bonds that did not. On the contrary, I compare pairs of identical bonds (same issuer, maturity and coupon rate) that should have the same price. These identical bonds happen to differ in their repo rates for reasons that I assume to be unrelated to their fundamental value. I ask if the bond with the lower repo rate is the more expensive of the two.

Jordan and Jordan (1997) test a re-statement of the no-arbitrage relationship in Duffie (1996) and find that bonds that are “on special” –i.e. which feature a lower repo rate than the prevailing rate– are more expensive than otherwise-identical bonds. Unlike Jordan and Jordan (1997), I study whether the relationship holds better or worse during a crisis period. Also, our papers differ in term of estimation technics. For each sample bond, Jordan and Jordan (1997) estimate what would be the market price of a bond with same characteristics but with a higher repo rate. To do so, each bond in their sample is matched to a synthetic bond which price is derived from the observed market prices of a time-varying pool of securities. Instead, I form pairs of bonds: Each bond is matched to another bond that has the same issuer, the same coupon rate and the same maturity date. The pairs are therefore stable through time: A pair is composed of the same two bonds, from issuance to maturity.

The remaining of the article is organized as follows. Section 2 reviews the institutional details and theoretical backgrounds. Section 3 explains the empirical strategy adopted and details the data used. Section 4 presents and interpret the results. Section 5 concludes.

3.2 Institutional details and theoretical background

In this section, I briefly remind the institutional details of repo transactions. I also review the papers’ theoretical background.

3.2.1 Institutional details

A repo transaction is an operation in which one party lends cash to the other party, while receiving a security as collateral. The rate at which the cash lender is remunerated is called the repo rate.

There are two main types of transactions: “General collateral repo” and “special repo”. The cash lender in a general collateral repo does not know in advance the precise bond that she will receive: Therefore, those transactions are solely motivated by cash lending and borrowing.

In contrast, the cash lender in a special repo knows in advance which exact bond she will receive: Therefore, the transaction could be motivated by security lending. The repo rate in a special repo transaction –called special rate– is typically lower than the general collateral rate. When this is the case, the bond is said to be “on special”. The difference between the general collateral and the special rates is called “specialness”.

For our purposes, one can consider that the repo rates that are mentioned are all special rates.

3.2.2 No-arbitrage relationship in Duffie (1996)

In Duffie (1996), two identical bonds A and B that mature at time T have respective market prices and repo rates of P_A and P_B , r_A and r_B . According to the no-arbitrage relationship, the four prices should verify

$$P_B = P_A \frac{1 + r_A}{1 + r_B} \quad (3.2)$$

As in Jordan and Jordan (1997), the relationship can be re-stated as such

$$P_B - P_A = P_A r_A - P_B r_B \quad (3.3)$$

The left part measures how much more expensive it is to buy B compared to A. The right part measures the savings in interest realized by a trader who would finance a long position in B on the repo market compared to financing a long position in A. Therefore, the relationship states that the difference of prices between two identical assets is equal to the difference of the cost of financing those assets on the repo market.

Duffie (1996) argues that, in equilibrium, the relationship must hold. If that is not the case, an arbitrageur can make a profit by holding the following position until maturity: 1) She buys the cheaper bond and she finances the trade on the repo market; 2) She shorts the other bond and she borrows the security on the repo market.

Table I illustrates Duffie (1996) with an example. At t, an agent with access to the repo market sees that $P_B - P_A = 0.05 < P_A r_A - P_B r_B = 0.099 - 0.009905 = 0.089095$. Therefore, bond B costs € 0.05 more than bond A but can be financed at a cost that is € 0.089095 lower than

bond A. The potential interest rate saving (€ 0.089095) is more important than the extra cost (€ 0.05). Consequently, the agent could decide to buy 10,000 units of bond B for €990,500 and enter a repo contract at a rate of 0.01% to borrow €990,500 between t and T using bond B as collateral. Simultaneously, she could short-sell 10,000 units of bond A for €990,000, enter a repo contract to lend €990,000 at a rate of 0.1% between t and T while receiving bond A as collateral and transferring the bond to her counterparty on the secondary market. The net cash flows at t is equal to €0.

At T , the agent pays back the cash that she borrowed for an amount of $P_B(1+r_B) = 990,500(1+0.01\%) = 990,599$, gets back the cash that she lent for an amount of $P_A(1+r_A) = 990,000(1+0.1\%) = 990,990$, sells bond B for $10,000V_T$ and buys back bond A for $10,000V_T$. The net cash flow at T is equal to €391. As a result, the agent realized a risk-free profit of €391. This arbitrage opportunity will push the price and the repo rate at t of bond B (bond A) upwards (downwards) until there is no more risk-free profit to be made, i.e. until equation 3.3 holds.

TABLE 3.1: Example of situation when the no-arbitrage relationship in Duffie (1996) does not hold.

	Price A	Price B	Repo Rate A	Repo Rate B
t	99.00	99.05	0.10%	0.01%
T (maturity)	$V_t + 1$	$V_t + 1$		

3.3 Empirical strategy

3.3.1 My settings vs. required setting to test Duffie (1996)

In this sub-section, I review the setting in Duffie (1996) and I compare it to the setting that my data allow me to use. I also discuss the periods that I indicate as being crisis periods or no-crisis periods.

The two crucial elements in an empirical design of Duffie (1996) are the sample selection and the selection of the repo contracts. First, I discuss sample selection. In Duffie (1996), the two bonds are identical, which means that they have the same issuer, coupon rate, maturity date and liquidity. In my setting, I use pairs of bonds that have the same issuer, same coupon rate, same

maturity date but that may differ in liquidity since that they do not have the same issuance date nor the same issuance volume.

More precisely, I use 54 pairs of Italian sovereign bonds. Each pair is composed of a 12-month zero-coupon bond (bond A) and of a 3-month zero-coupon bond (bond B). Both bonds were issued by the Italian government and they mature at the same time. But A was issued 9 months before B and has a greater issuance volume than B. Therefore, in some tests, I control for the difference in bid-ask spread between A and B in order to tackle potential liquidity differences. Figure 3.1 illustrates the composition of the bond pairs as well as the analysis framework.

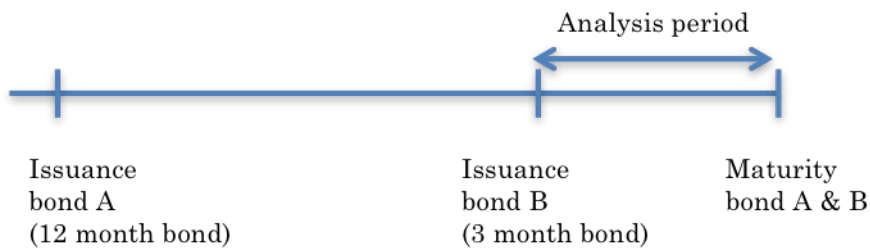


FIGURE 3.1: Illustration of the empirical methodology

Second, I discuss the selection of the repo contracts. Three points are to be considered: 1) The maturity of the contracts; 2) Whether to use only special rates or both special and general collateral rates; and 3) The settlement date.

First, concerning the maturity of the repo contracts, the no-arbitrage relationship relies on the use of contracts that mature at the same time as the bonds. However, those long-term contracts are not liquid enough to be used in my empirical framework. I decide to use one-day contracts, which are more liquid. Importantly, I suppose the following: On day t , an arbitrageur who does the trading strategy –described in the previous section– expects that the price of the two bonds will be identical on day $t+1$. In some robustness checks, I modify that assumption.

Second, in Duffie (1996), in order to profit from deviations of the no-arbitrage relationship, the arbitrageurs must be able borrow on the repo market the bond that they short on the bond market. This can only be done at what is called the special rate, as opposed to the general collateral rate. Therefore, I decide to use special rates.

Finally, in Duffie (1996), the arbitrageurs must be able to simultaneously trade on the bond markets and the repo markets. Also, trade settlement should occur at the same time on all markets. Short-term Italian government bills (called BOTs) settle at $t+2$. One should therefore choose to use repo contracts that also settle at $t+2$. However, to get more variation between the bond's

pairs, I decide to use a simple average rate composed of three rates: Repo rates for contracts which settle at $t+2$ (“Spot Next”), rates for contracts which settle at $t+1$ (“Tomorrow Next”) and rates for contracts which settle at t (“Overnight”).

Table II summarizes the required setting, my setting and the possible robustness checks.

TABLE 3.2: Summary of the required setting, my setting and the possible robustness checks.

	Required setting to test Duffie (1996)	My setting	Potential Robustness
Bonds	2 identical bonds	Pairs of Italian sovereign Both zero-coupon Same maturity date Different issue date and size	Control for liquidity
Repo contracts	Mature at T Special contracts Written at t Start at $t+2$	Mature after 1 day Special contracts Written at t Start at $t+2$, $t+1$ or t	Use only $t+2$

A last point is my identification for crisis and no-crisis periods. August 2007 - October 2009 is set as a crisis period, as it corresponds to the subprime crisis. January 2005 - July 2007 is set as a non-crisis period, as it precedes the subprime crisis. Although my data span until October 2012, I do not include the December 2009 - October 2012 period when comparing the added effect of the crisis. Indeed, although the subprime crisis had ended by December 2009, there was a sovereign bond crisis in 2010-2011 in the EU. This crisis was different from the subprime crisis: In particular, investors may not have been cash constrained as during the subprime crisis.

Crucially, my identification relies on the assumption that the errors introduced by the several approximations that I use (e.g. using one-day repo rates instead of long-term repo rates) do not vary across time periods; in particular, I assume that these errors are not more severe during the crisis than during the no-crisis periods.

3.3.2 Data source

My main data are at the ISIN-day level and span from January 2005 to October 2012. I use 54 pairs of Italian sovereign bonds. Each pair is composed of a 12-month zero-coupon bond (bond A) and of a 3-month zero-coupon bond (bond B). The two bonds have the same issuer, coupon rate

and remaining maturity. The bond pricing data comes from Datastream, while the bid-ask spread and trading volume data comes from the MTS platform. The repo transaction data comes from the MTS repo platform. The MTS and the MTS repo platforms are one of the largest platforms in Europe of bond and repo trading, respectively.

Table 3.3 gives some summary stats for bond A and B. The following points are of interest. First, bond A and B have a very similar distribution of yield, repo rate, bid-ask spread, bond trading volume and repo trading volume. In particular, given the similar bid-ask spread and bond trading volume, there is no evidence of first-order differences in liquidity between bond A and B. Second, repo rates can take values that are close to zero, or even negative. These are situations when the bonds are very "special": They are in high demand on the repo market. Third, as expected, the volatility of both yields and repo rates increased during the crisis. Finally, the volume of repo trading greatly increased in the third period of the sample. One potential explanation is that the European Central Bank (ECB) implemented a large-scale program of bond purchases called Security Market Program (SMP). This program might have had an impact on the repo market (Corradin and Madaloni (2017)).

3.4 Empirical Results

3.4.1 Formal test of Duffie (1996): Does the relationship hold better during the crisis?

In this part, I study if the relationship holds more during the crisis than outside of the crisis. I also check if the relationship performs better than other models.

Table 3.4 gives some descriptive statistics of the actual price, the predicted price and the pricing errors, in particular before and during the crisis. The signed pricing errors are defined as the log difference between the actual and the predicted prices, while the unsigned pricing errors are defined as the absolute value of the difference. Table 3.4 also reports the pricing errors for a simple model that predicts that the price of bond A and B should be equal, regardless of their repo rates.

First, I study if the relationship holds more during the crisis than outside of the crisis. Whether the relationships between prices and repo rates holds more or holds less during a crisis is unclear. On the one hand, during crises, limits of arbitrage are higher since that arbitrageurs have less

TABLE 3.3: Reports some summary stats for the total sample, the non-crisis period (Jan 05 - Jul 07), the crisis period (Aug 07 - Nov 09) and the Dec 09 - Oct 2012 period. Bond A and Bond B have same issuer, same remaining maturity and maturity date. Bond A (Bond B) is originally a 12-month (3-month) bond

	Bond A					Bond B				
	Obs	Mean	Std.	Min	Max	Obs	Mean	Std.	Min	Max
2005-2012										
Yield (%)	3,107	2.24	1.33	0.00	5.79	3,107	2.26	1.37	-0.92	5.87
Repo rate (%)	3,107	2.08	1.38	-0.22	5.59	3,107	2.08	1.40	-0.85	5.74
Spread (€cent)	1,819	0.25	0.14	0.00	0.75	1,885	0.25	0.14	0.00	0.70
Bond trading volume (€MM)	3,107	28.94	45.33	0.00	567.50	3,107	33.31	53.17	0.00	462.50
Repo trading volume (€MM)	3,107	49.49	91.31	0.00	962.00	3,107	40.10	64.91	0.00	715.50
2005-Jul07 (Pre-subprime)										
Yield (%)	1,258	2.78	0.77	0.88	4.75	1,258	2.81	0.81	0.19	5.87
Repo rate (%)	1,258	2.66	0.76	0.64	5.10	1,258	2.68	0.77	0.78	5.09
Spread (€cent)	1,070	0.22	0.08	0.10	0.46	1,036	0.21	0.08	0.10	0.58
Bond trading volume (€MM)	1,258	39.03	49.84	0.00	377.5	1,258	44.83	62.19	0.00	462.50
Repo trading volume (€MM)	1,258	31.77	39.11	0.00	332.50	1,258	30.66	44.91	0.00	628.00
Aug07-Nov09 (Subprime crisis)										
Yield (%)	1,257	2.40	1.53	0.00	5.79	1,257	2.44	1.56	-0.92	5.79
Repo rate (%)	1,257	2.31	1.50	0.04	5.59	1,257	2.32	1.51	0.08	5.74
Spread (€cent)	502	0.31	0.18	0.00	0.75	586	0.31	0.17	0.00	0.70
Bond trading volume (€MM)	1,257	18.93	33.84	0.00	366.50	1,257	22.27	37.49	0.00	276.00
Repo trading volume (€MM)	1,257	14.32	17.40	0.00	282.50	1,257	18.96	26.60	0.00	251.50
Dec09-2012										
Yield (%)	592	0.75	0.41	0.00	3.67	592	0.71	0.39	-0.78	3.67
Repo rate (%)	592	0.34	0.25	-0.22	1.66	592	0.30	0.29	-0.85	1.63
Spread (€cent)	247	0.28	0.18	0.01	0.71	263	0.27	0.17	0.00	0.70
Bond trading volume (€MM)	592	28.73	51.50	0.00	567.50	592	32.27	55.72	0.00	382.00
Repo trading volume (€MM)	592	161.84	154.84	0.00	962.00	592	105.05	104.79	0.00	715.50

capital to exploit inefficiencies. The limits of arbitrage may weaken the link between the bond and the repo markets. On the other hand, during a crisis, traders may rely more heavily on repo financing since that own capital becomes rare (see, e.g. Garleanu and Pedersen (2011)).

Table 3.4 indicates that the no-arbitrage relationship performed worse during the crisis than outside of the crisis. Indeed, there was an increase in the average and the standard deviation of the pricing errors. The difference between the predicted and the actual price has an average of 2.04 bps during the subprime crisis versus 0.79 in the pre-crisis period. More importantly, the standard deviation of these unsigned errors is 3.35 bps during the crisis versus 1.57 for the pre-crisis period.

I formally study if the relationship performed worse during the crisis. I test if the variance of the signed errors during the crisis is equal to the variance of the errors before the crisis. Table 3.5 gives the results of the variance test. I can reject the null hypothesis that the variance of the signed pricing error during the crisis is equal to the variance before the crisis. These results confirm that the no-arbitrage relationship performed worse during the crisis than outside of the crisis.

Second, I study if the relationship performed better than a simpler model that predicts that two bonds with same issuer, same duration and same remaining maturity have same prices. Table 3.4 gives some indication that the relationship in Duffie (1996) does not substantially fare better than the simpler model; be it during the crisis or before the crisis. Indeed, the difference between the mean error or the standard deviation of the errors is very similar for the two models.

TABLE 3.4: Reports the actual price, the predicted price by the no-arbitrage relationship and the difference thereof for bond B. Also reports the pricing error for a simple model that predicts that the price of bond B is equal to the price of bond A. Bond A and B have same issuer, same coupon rate and same remaining maturity.

	Obs	Mean	Std.	Min	Max
2005-2012					
Actual Price (€)	3,232	99.7184	0.2454	98.948	100.199
Predicted Price (€)	3,232	99.7204	0.2444	98.710	100.228
Unsigned error: $ Log(Predicted/Actual) (bps)$	3,232	1.3772	2.5601	0	49.321
Signed error: $Log(Predicted/Actual)$ (bps)	3,232	0.2051	2.9000	-49.321	24.768
Signed error of simple model	3,232	0.2067	2.9098	-49.468	24.773
2005-Jul07 (Pre-subprime)					
Actual Price (€)	1,270	99.6562	0.2199	99.024	99.998
Predicted Price (€)	1,270	99.6580	0.2199	99.026	100.228
Unsigned error: $ Log(Predicted/Actual) (bps)$	1,270	0.7940	1.5655	0	25.143
Signed error: $Log(Predicted/Actual)$ (bps)	1,270	0.1781	1.7464	-25.143	24.768
Signed error of simple model	1,270	0.1811	1.7544	-25.137	24.773
Aug07-Nov09 (Subprime crisis)					
Actual Price (€)	1,296	99.6904	0.2807	98.948	100.103
Predicted Price (€)	1,296	99.6951	0.2802	98.710	100.188
Unsigned error: $ Log(Predicted/Actual) (bps)$	1,296	2.0418	3.351	0	49.321
Signed error: $Log(Predicted/Actual)$ (bps)	1,296	0.4781	3.8953	-49.321	23.853
Signed error of simple model	1,296	0.4821	3.9073	-49.468	23.831
Dec09-2012 (Post-subprime crisis)					
Actual Price (€)	664	99.8921	0.0878	99.570	100.199
Predicted Price (€)	664	99.8894	0.0873	99.560	100.010
Unsigned error: $ Log(Predicted/Actual) (bps)$	664	1.1989	1.9403	0	20.216
Signed error: $Log(Predicted/Actual)$ (bps)	664	-0.2759	2.2646	-20.216	19.682
Signed error of simple model	664	-0.2822	2.2719	-20.221	19.621

I formally test if the no-arbitrage relationship fared better than the simple model. In that

TABLE 3.5: Variance ratio test for the pricing error. I compare the variance of the pricing errors during the crisis and before the crisis. I define the signed pricing error as the log difference between the price predicted by Duffie (1996) and the actual price of bond B ($\text{Log}(\text{Predicted}/\text{Actual})$). The crisis period is between August 07 and November 09. The non-crisis period is between January 05 and July 07. Due to very similar results, I only report the results for bond B (the bond with original maturity of 3 months). I use pairs of bonds with same issuer, coupon rate and remaining maturity to compute the price predicted by Duffie (1996).

Variance ratio test for the signed pricing error

Group	Obs	Mean	Std. Err	Std. Dev	90% Conf. Interval
Group 0 (Before Crisis)	1,272	0.178	0.049	1.745	0.098 0.259
Group 1 (Crisis)	1,296	0.478	0.108	3.895	0.300 0.656
Combined	2568	0.330	0.060	3.031	0.231 0.428

ratio = $\text{sd}(0) / \text{sd}(1)$

Ho: ratio = 1

Ha: ratio < 1

Ha: ratio \neq 1

Ha: ratio > 1

$\text{Pr}(F < f) = 0.0000$

$2 * \text{Pr}(F < f) = 0.0000$

$\text{Pr}(F > f) = 1.0000$

respect, I test if the variance of the pricing error is lower for the no-arbitrage relationship than for the simple model. Table 3.6 shows the result for the whole sample as well as for the crisis period. In both cases, I cannot reject the hypothesis of equality of variance between the two models.

Overall, I found that the no-arbitrage relationship in Duffie (1996) performed worse during the crisis and no better than a simple model of equality of prices.

So far, I assume that arbitrageurs perform the arbitrage strategy at day t and unwind at day $t+1$. I also assume that arbitrageurs expect that the price of the two bonds would have converged by $t+1$. In unreported robustness checks, I change these assumptions. First, I assume that arbitrageurs perform the arbitrage strategy at day t and unwind at day $t+2$. I also assume that arbitrageurs expect that the repo rates of day $t+1$ will be equal the repo rates of day t . I find that the average pricing errors and the standard deviations are slightly lower, but the main conclusions of this section remain unchanged. I perform the same exercise for $t+3$, $t+4$ and $t+5$ and I reach the same conclusion. From $t+6$ onwards, the model performs worse than under the original assumption but the main conclusions are left unchanged.

TABLE 3.6: Variance ratio test for the pricing error. Compares 1) the variance of the pricing errors for the no-arbitrage relationship in Duffie (1996) and 2) The variance of the pricing errors for a simple model which predicts equality of prices, regardless of repo rates. I define the signed pricing error as the log difference between the price predicted by Duffie (1996) and the actual price of bond B ($\text{Log}(\text{Predicted}/\text{Actual})$). Panel A studies the whole sample. Panel B restricts the sample to the non-crisis and crisis periods. The crisis period is between August 07 and November 09. The non-crisis period is between January 05 and July 07. I use pairs of bonds with same issuer, coupon rate and remaining maturity to compute the price predicted by Duffie (1996).

Panel A: Variance ratio test for the signed pricing error - Whole sample

Group	Obs	Mean	Std. Err	Std. Dev	90% Conf. Interval
Group 0 (Price-repo relationship)	3,232	0.205	0.051	2.900	0.121 0.289
Group 1 (Simple model)	3,232	0.206	0.051	2.909	0.122 0.290
Combined	6,464	0.205	0.036	2.904	0.146 0.265

ratio = $\text{sd}(0) / \text{sd}(1)$

Ho: ratio = 1

Ha: ratio < 1

Ha: ratio \neq 1

Ha: ratio > 1

$\text{Pr}(F < f) = 0.4238$ $2*\text{Pr}(F < f) = 0.8476$ $\text{Pr}(F > f) = 0.5762$

Panel B: Variance ratio test for the signed pricing error - During crisis

Group	Obs	Mean	Std. Err	Std. Dev	90% Conf. Interval
Group 0 (Price-repo relationship)	1,296	0.478	0.108	3.895	0.300 0.656
Group 1 (Simple model)	1,296	0.482	0.108	3.907	0.303 0.660
Combined	2,592	0.480	0.076	3.900	0.354 0.606

ratio = $\text{sd}(0) / \text{sd}(1)$

Ho: ratio = 1

Ha: ratio < 1

Ha: ratio \neq 1

Ha: ratio > 1

$\text{Pr}(F < f) = 0.4562$ $2*\text{Pr}(F < f) = 0.9124$ $\text{Pr}(F > f) = 0.5438$

Second, I assume that arbitrageurs perform the arbitrage at t and unwind at maturity. I also assume that they can perfectly forecast future repo rates until maturity. I find that the model

performs worse than under the original assumption, but the main conclusions are unchanged.

Finally, I change the type of repo contracts used. More precisely, I was using an average rate composed “Spot Next”, “Tomorrow Next” and “overnight” rates. However, to perform the arbitrage strategy, trade settlement should occur at the same time on all markets. Short-term Italian government bills settle at $t+2$. Therefore, an arbitrageur should choose to use repo contracts that also settle at $t+2$, i.e. “Spot Next” contracts. In unreported robustness checks, I use only these contracts. I find that the model perform worse but the main conclusions are unchanged.

3.4.2 Is a low-repo-rate bond more likely to be expensive than a high-repo-rate bond? Is it more the case during the crisis?

In the previous section, I found that the no-arbitrage relationship in Duffie (1996) performed worse during the crisis and no better than a simple model of equality of prices between identical bonds.

The relationship in Duffie (1996) is demanding: A low-repo-rate bond should be more expensive than the other bond *and* the difference of prices is equal to the interest saved on cash loans when using the low repo-rate bond as collateral instead of the other bond. In this part, I test a less demanding relationship: I simply test if a bond with a low repo rate is more likely to be "expensive" than an otherwise identical bond with high repo rate. In particular, I ask if this relationship holds better during the crisis.

To that end, I look at a series of joint events, such as "bond B has a lower repo rate and is more expensive than bond A". I then compare the actual frequency of these events in the data to their theoretical probability of occurrence under the assumption that prices and repo rates are independent. Finally, I look at if the difference of these probability is consistent with the relationship in Duffie (1996).

The first column of Table 3.7 states some predictions. For example, there should be a high likelihood for the event "bond B has a lower repo rate and is more expensive than bond B". More generally, Table 3.7 is organized in three main sections. The relationship in Duffie (1996) would imply a high probability of occurrence for the events in the first section; and a low probability of occurrence for the other two sections.

In the second column, I report the actual frequency in the data. In particular, I indicate the frequency in the data of basic events: For example, bond B is 51.3% likely to have a lower repo rate than bond A and 40.7% likely to be more expensive than bond A. I also indicate the frequency

for joint events: For example, the frequency of bond B having a lower repo rate and of being more expensive than bond A is 24.1%.

TABLE 3.7: Reports the difference between 1) The realized frequency of some events regarding Bond B and 2) The theoretical frequency thereof under the assumption that prices are independent from specialness. Bond A and B have same issuer, same coupon rate and same remaining maturity.

Events	Predicted Frequency	Frequency In data	Theoretical Frequency	Δ Frequency
	Consistent with Duffie (1996)		Under independence of price and repo rate	
Lower repo rate, More expensive	High	24.1%	20.9% (=51.3% x 40.7%)	3.2%
Higher repo rate, Less expensive	High	27.0%	23.0%	4.0%
Same repo rate, As expensive	High	0.3%	0.2%	0.1%
Lower repo rate, Less expensive	Low	21.1%	25.0%	-3.9%
Higher repo rate, More expensive	Low	15.9%	19.2%	-3.3%
Lower repo rate, As expensive	Low	6.1%	5.4%	0.7%
Higher repo rate, As expensive	Low	4.3%	5.0%	-0.7%
Same repo rate, Less expensive	Low	0.7%	0.8%	-0.1%
Same repo rate, More expensive	Low	0.6%	0.65%	-0.05%
Lower repo rate		51.3%		
Higher repo rate		47.1%		
Same repo rate		1.6%		
More expensive		40.7%		
Less expensive		48.8%		
As expensive		10.6%		

In the third column, I compute the theoretical probability of the joint events under the assumption that prices and repo rates are independent. For example, the theoretical probability for bond B of having a lower repo rate and being more expensive than bond A is the product of 1) The actual probability of having a lower repo rate and 2) The actual probability of being more expensive; i.e. $51.3\% \times 40.7\% = 20.9\%$.

In the fourth column, I report the difference between the actual frequency and the theoretical probability. For example, the difference for the event "bond B having a lower repo rate and being

more expensive than bond A" is positive and equal to 3.5%. Duffie (1996) would predict such positive difference since that a bond with a low repo rate is more likely to be more expensive than if repo rates and prices were independent. The relationship in Duffie (1996) implies a positive difference in the first section; and a negative difference in the other two sections. I find that it is indeed the case, except for one event.

Next, I check if the relationship holds more during a crisis than in normal times. In Table 3.8, I repeat the analysis presented in Table 3.7 except that I distinguish the crisis period from the non-crisis period.

First, Table 3.8 shows that, for both periods, the events that entail a positive (negative) relationship between prices and repo rates are mostly over-represented (under-represented) in the data compared to the theoretical probability that we should observe if prices and repo rates were independent. Second, importantly, the magnitude of the over and under-representation is often larger during the crisis than in the non-crisis period: All else equal, this suggests that the relationship seems to hold more during the crisis than during the non-crisis period.

All in all, Table 3.8 mostly indicates that the relationship between repo rates and prices holds more during the subprime crisis than during the period before the crisis.

TABLE 3.8: Reports the difference between 1) The realized frequency of some events regarding Bond B and 2) The theoretical frequency thereof under the assumption that prices are independent from specialness. Compares the crisis period (Aug 07 - Nov 09) to the non-crisis period (Jan 05 - Jul 07). Bond A and B have same issuer, same coupon rate and same remaining maturity.

Events	Δ Frequency	Δ Frequency
	(=data frequency minus theoretical frequency) Aug07-Nov09 Crisis	(=data Frequency minus theoretical frequency) Jan05-Jul07 Not crisis
More special and More expensive	4.5%	2.2%
Less special and Less expensive	5.0%	2.2%
As special and As expensive	0.2%	0.3%
More special and Less expensive	-4.9%	-2.0%
Less special and More expensive	-4.4%	-2.1%
More special and As expensive	0.43%	-0.24%
Less special and As expensive	-0.59%	-0.04%
As special and Less expensive	-0.07%	-0.18%
As special and More expensive	-0.09%	-0.10%

Next, I formally assess if the difference in probability found in Table 3.7 and 3.8 is significantly different from zero. To that end, I perform a probit regression analysis.

More precisely, I first test if I can reject the null hypothesis that β_1 is equal to 0 in the following specification:

$$1_{MoreExpensive,it} = \alpha + \beta_1 1_{Morespecial,it} + \beta_2 1_{MoreLiquid,it} + \epsilon \quad (3.4)$$

where $1_{MoreExpensive,it}$ is a dummy that takes 1 if bond B of pair i has a lower yield than bond A at date t , and 0 otherwise; $1_{Morespecial,it}$ is a dummy that takes 1 if bond B of pair i has a lower repo rate than bond A at date t ; $1_{MoreLiquid,it}$ is a dummy that takes 1 if bond B of pair i has a lower average spread than bond A at date t .

In the first column of Table 3.9, I test a basic specification. I find that the probability of being more expensive conditional on being more special is associated to a z-score of -0.074 ($= -0.416 + 0.342$), i.e. a probability of 47.08%; while the probability of being more expensive conditional on being less special is associated to a z-score of -0.416, i.e. a probability of 33.88%. Overall, being the more special increases the probability by 13.20% of being the more expensive. In column 2, I add the liquidity dummy as a control and I cluster standard errors at the month-level. The results are qualitatively unchanged.

Note that, while Table 3.9 studies conditional probabilities, the earlier Table 3.7 studies joint probabilities. In order to reconcile -say- the 47.08% of being more expensive conditional on being more special obtained in Table 3.7, one has to go to Table 3.7, look up the probability of the event "Bond B has a lower repo rate and is more expensive" and divide it by the probability of the event "Bond B has a lower repo rate" obtained.

I then test if this effect is increased during the crisis. More precisely, I test the following specification:

$$1_{MoreExpensive,it} = \alpha + \beta_1 1_{Morespecial,it} * 1_{Crisis,t} + \beta_2 1_{MoreLiquid,it} + \epsilon \quad (3.5)$$

where $1_{Crisis,t}$ takes the value 1 for the August 07 - Oct09 period; and 0 for the January 05 - July 07 period. I restrict the sample to the January 05 - October 09 period.

The third columns of Table 3.9 shows the results. During the crisis, the probability of being more expensive conditional on being more special is associated to a z-score of -0.004 ($= -0.383 + 0.234 + 0.233 - 0.088$), i.e. a probability of 49.83%; while the probability of being more expensive conditional on being less special is 33.88% (z-score of $-0.383 - 0.088 = -0.471$). Hence, during the crisis, being the more special increases the probability by 17.95% of being the more expensive.

Before the crisis, these two conditional probabilities are 44.08% (z-score of $-0.383 + 0.234 = -0.149$) and 35.08% (z-score of -0.383). Hence, before the crisis, being the more special increases the probability by 9.00% of being the more expensive of the two bonds of a same pair. This is lower than the 17.95% I found for the crisis period.

I conclude that being more special has a $17.95\% - 9.00\% = 8.95\%$ higher probability of translating into a high price during the crisis than before the crisis. These are the main results of this section.

In column 4, I add the liquidity dummy and the results are qualitatively unchanged.

Overall, the results of Table 3.9 confirm the informal observations of Tables 3.7 and 3.8: On average, between two identical bonds, the bond that has the lower repo rate is more likely to be the more expensive of the two, even more so during the crisis.

In an unreported analysis, I study whether the effect measured in Table 3.9 mostly comes from the pre-Lehman (August, 1, 2007 - September,14, 2008) or the post-Lehman (September,15, 2008 - November, 30, 2009) part of the crisis. I find that the entire effect comes from the pre-Lehman part of the crisis, while the post-Lehman part of the crisis is no different from the pre-crisis period.

I also perform the following robustness tests. First, I get rid of the effect coming from the auction process. To that end, I eliminate the observations corresponding to the first few days when bond B has just been issued. Similarly, I eliminate the last few days before bond A and bond B's maturity, in order to avoid capturing any potential effect from that specific period. I find that the results go through. Second, I cluster by bond pair instead of clustering at the month-level. The results are unaffected. Third, I change the way the dummies are defined. Specifically, I include into the *More expensive* dummy the cases when the two bonds have the same price, and into the *More special* dummy the cases when the two bonds have the same repo rate. The results are even stronger.

TABLE 3.9: Probit regressions. Dependent variable: a dummy that takes a value 1 if bond B has a lower yield than bond A. Bond A and B have same issuer, same coupon rate and same remaining maturity. Independent variable: a dummy that takes a value 1 if bond B is more special than bond A. The crisis dummy takes a value 1 if inside the August 07 - November 09 period; and 0 if inside the January 05 - July 07 period. Column 1 and 2 (Column 3 and 4) cover the period January 05 - October 12 (January 05-November 09). Special repo rates are computed as the simple average of Spot Next, Tomorrow Next and Overnight Repo rates. When the bond is not on special, the General Collateral rate is used. t statistics in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

	Dummy bond B more expensive than bond A	Dummy bond B more expensive than bond A	Dummy bond B more expensive than bond A	Dummy bond B more expensive than bond A
Dummy bond B more special than A	0.342*** (7.48)	0.325*** (5.90)	0.234*** (3.26)	0.212*** (2.78)
Dummy bond B more special than A * Crisis			0.233** (2.28)	0.249** (2.04)
Dummy crisis			-0.088 (-1.23)	-0.111 (-0.95)
Dummy bond B more liquid than A		-0.154* (-2.11)		-0.177** (-2.10)
Constant	-0.416*** (-12.50)	-0.353*** (-6.82)	-0.383*** (-7.59)	-0.300*** (-3.51)
Observations	3107	3107	2515	2515
Month-level clustering	No	Yes	No	Yes
Sample period	2005-Oct 2012	2005-2012	2005-Nov2009	2005-Nov2009

3.4.3 Interpretation and reconciliation of the findings

In the first part of the empirical analysis, I found that the no-arbitrage relationship in Duffie (1996) performed worse during the crisis and no better than a simple model of equality of prices. In the second part of the empirical analysis, I found that low-repo-rate bonds had a 17.95% higher probability of being more expensive than otherwise identical bonds during the crisis, compared to solely 9.00% before the crisis.

In this part, I first interpret the two findings separately. I then propose a way to reconcile the findings.

In the first part of the empirical analysis, I found that the no-arbitrage relationship in Duffie (1996) performed worse during the crisis and no better than a simple model of equality of prices. The most likely interpretation is that there are limits of arbitrage. In particular, the arbitrage strategy relies on the following assumption: When an arbitrageur buys the “cheap” and sells the “expensive” bonds, she knows for sure that the price and the repo rate of the expensive bond will equal those of the cheap bond on the next day. In reality, however, there is a probability that the prices and rates do not fully converge on the next day; they can even diverge. This is a clear limit to arbitrage that is likely to be stronger during the crisis because price and rate volatility increases.

These limits of arbitrage also exists for a simple model of equality of prices. In fact –according to the assumption that a bond is more special only during one day and then becomes as special as the other bond until maturity– the difference in repo rates has a very small influence on the predicted prices. What matters most in the predicted price of -say- bond B is bond A’s price. This is why I found that Duffie (1996) does not fare much better than a model that ignores repo rates.

To be clear, the assumption of equality of prices and repo rates prior to maturity does not exist as such in Duffie (1996): The no-arbitrage relationship in Duffie (1996) assumes equality of prices and repo rates at maturity only, not before maturity. However, I introduced this assumption because in Duffie (1996) arbitrageurs can use repo contracts that have a duration equal to the bond’s time-to-maturity, while in reality arbitrageurs can only use one-day repo contracts.

In the second part of the empirical analysis, I found that low-repo-rate bonds had a 17.95% higher probability of being more expensive than otherwise identical bonds during the crisis, compared to solely 9.00% before the crisis. The most credible interpretation is that commonalities between the bond and the repo markets increased. More precisely, there was an increase in demand for safe collateral during the crisis. As investors bought these bonds, bond dealers borrowed these securities on the repo market to face the large demand; hence an increase in bond price was accompanied with a decrease in repo rates. Similarly, investors faced liquidity shocks during the crisis, i.e. they needed cash. This led some investors to sell their bond holdings, while others lent their bonds on the repo market; hence a decrease in bond price was accompanied with an increase in repo rates.

Note that my explanation implies the existence of a segmentation between the markets of bond A and the markets of bond B. Indeed, if demand shocks occur at the same time for both bonds and

have the same magnitude, then bond B becomes special and expensive at the same time as bond A and to the same extent as bond A.

Figure 3.2 illustrates my explanation for the link between repo rates and bond prices. In Figure 3.2, before the crisis, there were shocks to each of the four individual markets: The two bond markets and the two repo markets. Said differently, the shocks to the demand to borrow or lend a given bond were different from the shocks to buy or sell the bond. During the crisis, the shocks were common to the bond and the repo markets of a given bond: There were shocks to both the demand to buy or sell and the demand to borrow or lend a given bond. This is due to market-making and liquidity shocks.

Now, is there evidence in favor of this explanation? More precisely, is there evidence that market-makers borrowed securities during the crisis to face temporary increases in demand; while investors lent their bonds to face temporary cash demand? Table 3.10 gives some summary statistics about the order imbalance of bond A and bond B before and during the crisis. Order imbalance is defined as the difference between buy and sell orders, scaled by trading volume: A positive order imbalance means that investors bought more than sold.

The first line in Table 3.10 shows that the mean of the distribution of the order imbalance increased during the crisis for bond A. This is evidence that episodes of large positive demand for the bonds were more frequent during the crisis, consistent with a need by bond traders to borrow the bonds. The second line in Table 3.10 shows that, conditional on being positive, order imbalance was larger during the crisis; thus confirming these episodes of large demand. Gorton and Metrick (2012) showed that only repo transactions using high quality collateral such as government bonds survived the crisis: This may have created temporary increases in demand for government bonds.

Finally, the third line of Table 3.10 shows that, conditional on being negative, order imbalance was also larger during the crisis: This is consistent with liquidation of bond holdings, possibly in order to obtain cash. The fourth, fifth and sixth line of Table 3.10 shows similar results for bond B.

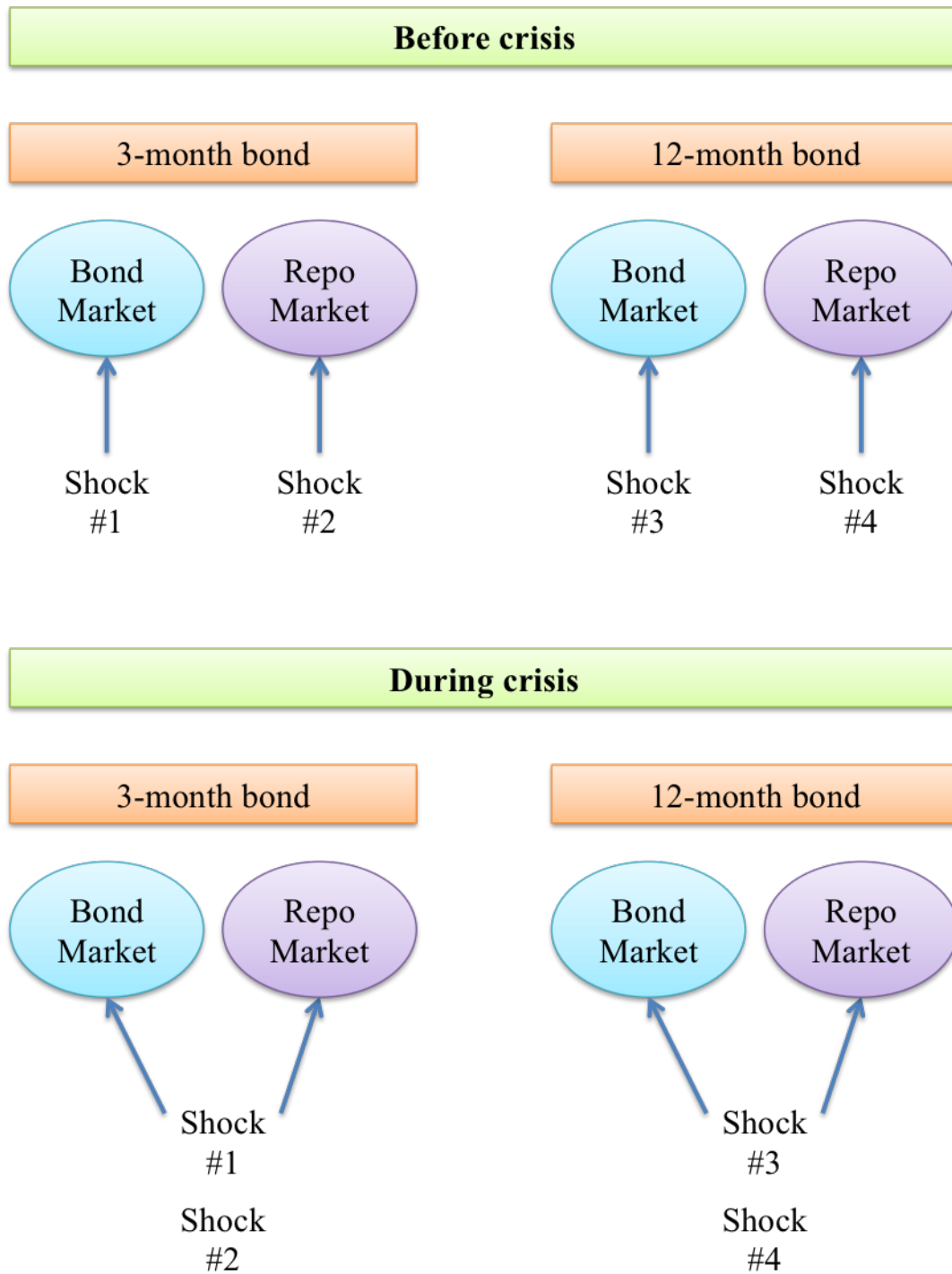


FIGURE 3.2: Illustration of the explanation of the link between prices and repo rates during the crisis

Overall, the increase in positive order imbalance during the crisis as evidenced in Table 3.10 is an indication that market-makers had to borrow securities on the repo market to face the demand; while the increase in negative order imbalance is an indication of episodes of cash needs leading investors to either sell their holdings or lend them on the repo market.

TABLE 3.10: Summary statistics about order imbalance for bond A and B. Order imbalance is defined as the difference between the buy and the sell volume, scaled by the total trading volume. A positive order imbalance means that investors are buying more than selling.

	Before crisis			During crisis		
	Mean	25th	75th	Mean	25th	75th
Bond A						
Imbalance	0.00	-0.69	0.67	0.13	-0.84	1.00
Positive imbalance	0.67	0.41	1.00	0.81	0.62	1.00
Negative imbalance	-0.67	-1.00	-0.38	-0.77	-1.00	-0.54
Bond B						
Imbalance	0.05	-0.67	0.76	0.24	-0.62	1.00
Positive imbalance	0.68	0.40	1.00	0.83	0.72	1.00
Negative imbalance	-0.68	-1.00	-0.38	-0.75	-1.00	-0.52

Finally, I propose a way to reconcile the two findings, i.e. the apparent contradiction that 1) Duffie (1996) holds less during the crisis and 2) A special bond is more likely to be expensive during the crisis. Table 3.10 shows an example where the two findings cohabit. In the example, the pricing errors are larger in the crisis than before the crisis: €1.996 vs. €1.00. However, the bond with the lower repo rate is consistently the more expensive of the two during the crisis, unlike before the crisis.

As shown in the example in Table 3.11, the fact that there are more co-movement between bond and repo trading during the crisis is not enough to make the relationship in Duffie (1996) hold more during the crisis than before the crisis. Indeed, during the crisis, the difference between the price of bond A and the price of bond B may have increased for reasons orthogonal to the mechanism in Duffie (1996). This would increase the pricing error if the price difference experienced a large dollar increase while the one-day interest difference experienced a more modest increase. In fact, because I only look at one-day repo rates, the difference in interest saved is very small. Hence, an increase in price volatility is likely to increase pricing errors, regardless of price and repo rate co-movements.

In Table C.1 in the appendix, I find that the data resembles the example shown in Table 3.11. Specifically, the correlation between the difference in prices and the difference in repo rates increased during the crisis. In addition, the price difference experienced a large increase during the crisis.

TABLE 3.11: Example where the fact that Duffie (1996) holds less during the crisis can cohabit with the fact that co-movement between bond and repo trading increased during the crisis. Repo rates are yearly interest rates. I use a 360-day year to compute the one-day interest rate.

Bond	Day	Repo rate	Price	Predicted price	Pricing error
Before crisis					
A	t	0%	100	101.003	1.003
B	t	1%	101	99.997	-1.003
A	t'	0%	101	100.003	-0.997
B	t'	1%	100	100.997	0.997
Crisis					
A	t	0%	102	100.003	-1.997
B	t	1%	100	101.997	1.997
A	t'	1%	100	101.997	1.997
B	t'	0%	102	100.003	-1.997

3.5 Conclusion

I ask if prices reflect collateral value during a crisis. I use 54 pairs of identical sovereign bonds over 2005-12 (same issuer, coupon rate and remaining maturity). First, I find that the no-arbitrage relationship in Duffie (1996) fares worse during the subprime crisis than outside of the crisis: The difference in price between two bonds of a same pair during the crisis is further away from the difference in financing cost than prior to the crisis. Second, however, I find that low-repo-rate bonds have an 18.0% higher probability of being more expensive than otherwise identical bonds during the crisis, compared to 9.0% before the crisis. Overall, there exist limits of arbitrage that prevent collateral value to be fully reflected in prices, especially during the crisis. Still, part of the collateral value is reflected in prices because prices and repo rates feature a larger co-movement during the crisis: A bond that is expensive (cheap) also features a low (a high) repo rate. I posit that it is due to market-making and liquidity shocks.

References

- Bartolini, L., Hilton, S., Sundaresan, S. and Tonetti, C., 2011. Collateral values by asset class: Evidence from primary securities dealers. *Review of Financial Studies*, 24(1), pp.248-278.
- Corradin, S. and Maddaloni, A., 2017. The importance of being special: repo markets during the crisis. Unpublished working paper. European Central Bank, Frankfurt, Germany.
- D'Amico, S., Fan, R. and Kitsul, Y., 2015. The scarcity value of Treasury collateral: Repo market effects of security-specific supply and demand factors.
- Duffie, D., 1996. Special repo rates. *The Journal of Finance*, 51(2), pp.493-526.
- Garleanu, N. and Pedersen, L.H., 2011. Margin-based asset pricing and deviations from the law of one price. *Review of Financial Studies*, 24(6), pp.1980-2022.
- Gorton, G. and Metrick, A., 2012. Securitized banking and the run on repo. *Journal of Financial economics*, 104(3), pp.425-451.
- Gromb, D. and Vayanos, D., 2010. Limits of arbitrage. *Annu. Rev. Financ. Econ.*, 2(1), pp.251-275.
- Jordan, B.D. and Jordan, S.D., 1997. Special repo rates: An empirical analysis. *The Journal of Finance*, 52(5), pp.2051-2072.
- Keane, F., 1996. Repo rate patterns for new Treasury notes. *Federal Reserve Bank of New York Current Issues in Economics and Finance*, 2(10).
- Moulton, P.C., 2004. Relative repo specialness in US Treasuries. *The Journal of Fixed Income*, 14(1), pp.40-47.

Appendix A

Chapter 1 - Appendix

A.1 Short survey of the equity short-selling literature

Dechow et. al. (2001, JFE). Short sellers target firms with low fundamental-to-price ratios. They unwind their positions as the ratios revert.

D’Avolio, (2002, JFE). Short selling constraints are rare. The likelihood of short selling constraints increases in the divergence of opinion between the short sellers and the (non-lenders) investors

Geczy, Musto, and Reed, (2002, JFE). Short selling constraints are rare. IPOs are easy to borrow. Merger arbitrage is difficult: borrowing the acquirer is expensive, especially when the target is small

Jones, and Lamont, (2002, JFE). Stocks that are highly shorted experience lower return than other stocks. For holders of such stocks, the lending revenue is lower than the capital loss.

Duffie, Gerleanu and Pedersen, (2002, JFE). They develop a model where one must first locate a security before borrowing it. For securities difficult to borrow, there might be a temporary overpricing followed by a predictable negative return. The perspective of earning lending revenue can initially push the price of a stock above the most optimistic valuation of the firm’s future dividends. This suggests why newly issued stocks are overpriced right after the IPO.

Desai et. al., (2002, JF). Show that both the level of short-interest and any increase in short-interest are predictors of future negative abnormal return.

Chen, and Singal, (2003, JF). The week-end effect is larger for stocks with high short interest. It is compatible with the hypothesis that the week effect is due to short sellers closing their positions on Friday and re-opening them on Monday.

Lamont, and Stein, (2004, AER). The aggregate short interest is counter-cyclical: it decreases (increases) when prices are sharply increasing (decreasing). It is because of the open-end nature of professional short-sellers: during rising market, funds may lose money on their short positions, may face redemption and, therefore, cut their short positions.

Asquith, Pathak, and Ritter, (2005, JFE). Equal-weighted portfolio of highly constrained stocks underperform during the 1998-2002 period.

Nagel, (2005, JFE). Underperformance of firms with high book-to-market, high analyst dispersion, high volatility, and high turnover is higher for firms with low institutional ownership. The price of stocks with low institutional ownership under-react to bad news, and over-react to good news

Christoffersen, Geczy, Musto, and Reed, (2007, JF). There exists an active market for trading vote: borrowing volume increases before a vote. The authors argue that main motivation is information asymmetries: investors grant higher voting powers to investors with superior knowledge. The phenomenon is stronger in less transparent environments

Cohen, Diether, and Malloy, (2007, JF). In order to understand the impact of short selling on price, one should distinguish supply shift (indication of constraints) and demand shift (indication of informed trading). They use pairs of indicators (price and volume) to determine whether a demand shift occurred. They find that demand shift are a predictor of future abnormal negative return. The relationship is stronger in environment with less public information flow.

Boehmer, Jones, and Zhang, (2008, JF). Short sellers are well informed: Heavily-shorter stocks underperform lightly-shorter stocks by a risk-adjusted average of 1.16% over the following 20 trading days (15.6% annualized). Institutional short-sales are the most informative; stocks heavily shorted by institutions underperform by 1.43% the next month (19.6% annualized).

Evans, Geczy, Musto, and Reed, (2009, RFS). Market makers are allowed to short-sell prior to borrowing the security. When the stock is expensive to borrow, they choose to fail to deliver which triggers a margin call and amounts to a de-facto stock loan with a zero rebate rate. This triggers abnormally low option premium when the rebate rate becomes negative. It also reduces competition among market makers because only the bigger market makers can effectively carry this strategy

Karpoff, and Lou, (2010, JF). Short sellers are able to detect financial misrepresentation. They start building short positions 19 months before the public revelation. Short interest increases in the degree of the misrepresentation. The presence of short sellers is associated with a faster

public revelation of the misrepresentation and lower overpricing. **Fang, Huang and Karpoff (2015, JF)** reach similar conclusions.

Boehmer, Huszar, and Jordan, (2010, JFE). Short interest also indicates positive information: stocks that are lightly shorted and heavily traded have a positive alpha that is often more significant than the negative alpha experienced by heavily shorted stocks. It poses problems of market efficiency: there are impediments to the incorporation of positive information

Kaplan, Moscovitz, and Sensoy (2013, JF). They create an exogenous positive supply shock to the lendable volume of expensive-to-borrow stocks. The shock significantly decreases specialness but does not affect prices nor returns.

Beber and Pagano (2013, JF). Short-selling bans have negative consequences for liquidity and price discovery. They fail to support prices.

Boehmer and Wu (2013, RFS). Equity prices are more accurate when short-sellers are more active.

Berkman, McKenzie and Verwijmeren (2013, WP). Short-selling increases before the announcement of a private placement. Short-sellers are able to predict the returns on announcement days.

Grullon, Michenaud and Weston (2015, RFS). Increases in short-selling cause drops in equity prices. Small firms react by reducing equity issuance and investment.

Christophe et. al. (2015, WP). Short-selling intensity in a firm's equity is inversely correlated with contemporaneous and future returns in the firm's corporate bonds.

Akbas, (2016, JF). Low trading volume announces negative earning surprises, especially for stock with short-selling constraints.

A.2 Using the Over-The-Counter dataset

In this Appendix section, I present the OTC dataset and replicate my tests using this dataset.

The dataset is composed of Over-The-Counter (OTC) security lending transactions, is provided by DataExplorer (which was then bought by Markit) and covers the 2006-2012 period. Markit collects daily inventory and loan data at the security-level from Custodian Banks and brokers. For example, a given custodian bank will report how much of a given bond is available for lending, a much is currently lent and what is the average lending fee. Similarly, a given broker who represents security borrowers will report how much of a given security they borrow. Note that the information

is provided by participants on a voluntary-basis. Participants who provide information get access to the database. Finally, note that I applied some filters to increase data quality.

Table A.1 gives some summary statistics. In particular, the average onloan percentage is between 19% and 28%, which means that 19-28% of the inventory labelled as lendable by custodian banks is currently lent. There exists time where nearly the entire inventory is lent, especially for 2-10Y bonds. Fees range from 5 to 17 bps, with a maximum reached for 10Y bonds. This means that the interest paid on the cash collateralized by the security borrower is 5-17 bps lower than the prevalent interest rate. Note that this fee is not too far from the average specialness on Repo transactions (which ranges from 8 to 28 bps). Finally, outstanding loans around reopenings have an average duration which ranges from 15 to 63 days.

TABLE A.1: Sample summary statistics of the OTC loans of the reopened security over a (-6,+6) window around reopenings. First panel: Onloan percentage and fee; Second panel: Lendable volume and outstanding loan volume; Third panel: Loan number and loan duration. Onloan percentage is computed as the ratio of the outstanding loan volume and the lendable volume. A reopening is a primary auction which results in the increase in the outstanding volume of a bond which was first issued in the past. Data from the MTS Repo platform.

Issuer	Maturity	Onloan percentage					Fee				
		(pct pt)					(bps)				
		Mean	Std.	Min	Max	Obs	Mean	Std.	Min	Max	Obs
Italy	2Y	13.86	28.31	0.00	100.00	627	4.78	9.25	-35.31	29.86	165
Italy	3Y	26.21	23.93	0.00	92.31	639	11.13	21.12	-53.30	102.85	479
Italy	5Y	18.66	19.77	0.00	93.04	623	10.62	17.32	-47.22	113.37	518
Italy	10Y	26.54	21.59	0.00	94.98	977	17.20	38.27	-32.70	363.67	907
Italy	15Y	38.72	22.14	0.00	83.65	462	15.72	19.38	-35.68	126.92	455
Italy	30Y	27.48	19.20	0.00	74.09	324	7.38	17.60	-46.78	92.16	322

Issuer	Maturity	Lendable volume					Total loan volume				
		(\$ MM)					(\$ MM)				
		Mean	Std.	Min	Max	Obs	Mean	Std.	Min	Max	Obs
Italy	2Y	384	432	1	1,733	627	70	139	0	670	627
Italy	3Y	616	502	16	2,536	639	181	210	0	898	639
Italy	5Y	577	367	26	1,554	623	113	136	0	749	623
Italy	10Y	789	586	22	2,868	977	203	229	0	1,186	977
Italy	15Y	742	363	145	1,734	462	294	209	0	1,166	462
Italy	30Y	1,346	593	272	2,407	324	381	378	0	1,694	324

Issuer	Maturity	Loan duration					Number of loans				
		(days)					(actual)				
		Mean	Std.	Min	Max	Obs	Mean	Std.	Min	Max	Obs
Italy	2Y	14.79	11.46	0	46	205	1.50	3.04	0	24	667
Italy	3Y	20.50	18.33	0	84	502	4.76	5.11	0	20	663
Italy	5Y	18.49	16.15	0	78	583	5.19	5.42	0	29	689
Italy	10Y	37.77	46.94	0	330	961	13.87	16.08	0	87	1031
Italy	15Y	62.87	59.79	2	350	461	18.15	14.30	0	94	468
Italy	30Y	54.90	39.20	0	234	323	22.38	18.82	0	67	325

Figure A.1 shows how onloan percentage and lending fees evolve around auctions. Similarly to the pattern found for Repo transactions, the onloan percentage and the lending fee are seen to increase from $t=-5$ to $t=+1$ and to decrease afterwards.

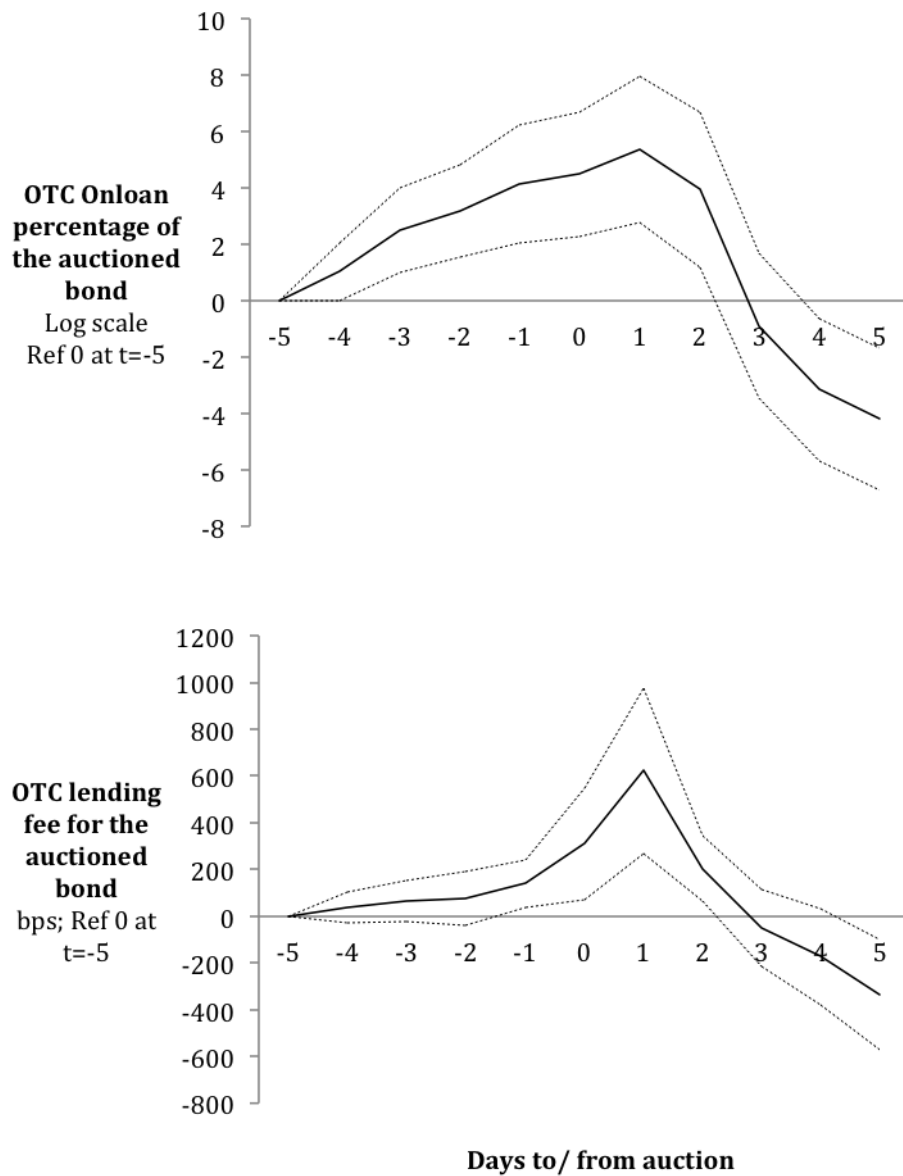


FIGURE A.1: Result of ten t-test specifications which test the null hypothesis that the onloan volume (First panel) or fee (Second panel) of OTC loans of the reopened bond t days after the auction is equal to the onloan percentage or fee 5 days before the auction, where t belongs to $(-5,+5)$. Onloan percentage is defined as the ratio of the volume of lendable securities divided by the volume of outstanding loans. I use Italian reopenings over 2006-12. A reopening is a primary auction that results in the increase in outstanding volume of a bond that was first issued in the past. The solid line is the point estimate. The two other lines corresponds to the 90% interval confidence. The repo data come from Markit (Ex-DataExplorer). Standard errors are clustered at the maturity and daily levels

Table A.2 shows the results of a test of whether pre-auction short-selling through OTC markets is predictive of the return between $t=-1$ and $t=0$. The test is identical to the one reported on Table 1.2, except that an increase in short-selling is defined as an increase in onloan percentage and lending fees. Table A.2 shows that the coefficient of interest is not significantly different from zero.

There is, therefore, no indication that short-sellers who borrow securities on the OTC markets are informed about auction results.

TABLE A.2: Link between (1) An increase in short-selling demand on the OTC markets at $t=-1$ compared to $t=-5$, and (2) Yield change between $t=-1$ and $t=0$ for the auctioned bond, where $t=0$ is the auction day. I measure changes in short-selling demand by simultaneous changes in both the onloan percentage and the fee of OTC loans of the auctioned bond. Onloan percentage is defined as the ratio of the volume of lendable bonds divided by the volume of outstanding loans of bonds. *IncreaseDemand* is an indicator equal to 1 if both the onloan percentage and fee increased over $(-5,-1)$; 0 otherwise. Italian sample over 2005-12. Secondary yield data from Datastream (RY datatype). OTC security lending data from the Markit (ex-DataExplorer). t statistics in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

	Δ Yield (-1,0)	Δ Yield (-1,0)	Δ Yield (-1,0)
IncreaseDemand (Coef. of interest)	-0.0953 (-0.10)	0.609 (0.75)	0.433 (0.55)
Log trading volume at -1			-0.275 (-0.46)
Δ Yield (-2,-1)			0.137 (1.32)
Δ Yield (-3,-2)			-0.0818 (-0.65)
Δ Yield (-4,-3)			0.0686 (1.10)
Δ Yield (-5,-4)			0.0734 (1.12)
Δ Yield (-6,-5)			-0.113 (-1.33)
Constant	1.979*** (3.66)		
Observations	201	201	196
Controls (duration, coupon rate, tranche, remaining maturity)	No	Yes	Yes
Fixed-effects (original maturity, year, weekday)	No	Yes	Yes
Month-level clustering	No	Yes	Yes

Similarly, Table A.3 shows the results of a test of whether short-selling on auction day through

OTC markets is predictive of the return between $t=0$ and $t=+5$. The test is identical to the one reported on Table 2.4, except that an increase in short-selling is defined as an increase in onloan percentage and lending fees. Table A.3 shows that the coefficient of interest is not significantly different from zero. In fact, the coefficient is negative, whereas one would have expected a positive coefficient. There is, therefore, no indication that short-sellers who borrow securities on the OTC markets are better at interpreting auction results than the market.

Finally, Table A.4 performs some robustness checks, similarly to Table 1.4. I still find that the coefficient of interest is insignificantly different from zero. In particular, Table A.4 do not confirm the results reported in Table 1.4.

In unreported tests, I use the change in dollar-amount of outstanding loans instead of using the change in onloan percentage. I find that bonds with an increase in short-selling demand on OTC markets at $t=0$ have a significantly higher return between $t=0$ and $t=+5$ than other bonds. This mean that short-sellers are losing money. This is the opposite of one might expect if short-sellers were to be informed. These results can be explained by a demand for the auctioned bond which translates into both an increase in its secondary price and an increase in the fee for borrowing it.

TABLE A.3: Link between (1) An increase in short-selling demand on the OTC markets at $t=0$ compared to $t=-1$, and (2) Yield change between $t=0$ and $t=-5$ for the auctioned bond, where $t=0$ is the auction day. I measure changes in short-selling demand by simultaneous changes in both the onloan percentage and the fee of OTC loans of the auctioned bond. Onloan percentage is defined as the ratio of the volume of lendable bonds divided by the volume of outstanding loans of bonds. *IncreaseDemand* is an indicator equal to 1 if both the onloan percentage and fee increased over $(-5,-1)$; 0 otherwise. Italian sample over 2005-12. Secondary yield data from Datastream (RY datatype). OTC security lending data from the Markit (ex-DataExplorer). t statistics in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

	Δ Yield	Δ Yield	Δ Yield
	(-1,0)	(-1,0)	(-1,0)
IncreaseDemand (Coef. of interest)	-3.228	-2.016	-2.588
	(-1.22)	(-0.96)	(-1.19)
Log trading volume at $t=0$			-2.425
			(-0.84)
Δ Yield (-1,0)			0.497
			(1.61)
Δ Yield (-2,-1)			0.121
			(0.46)
Δ Yield (-3,-2)			-0.147
			(-0.63)
Δ Yield (-4,-3)			-0.344**
			(-2.43)
Δ Yield (-5,-4)			-0.283**
			(-2.12)
Δ Yield (-6,-5)			-0.0495
			(-0.14)
Amount offered at auction			-4.767
			(-0.56)
Amount bid at auction			14.57
			(1.54)
Constant	-5.158***		
	(-4.19)		
Observations	217	217	217
Controls (duration, coupon rate, tranche, remaining maturity)	No	Yes	Yes
Fixed-effects (original maturity, year, weekday)	No	Yes	Yes
Month-level clustering	No	Yes	Yes

TABLE A.4: Robustness table OTC. Link between (1) An increase in short-selling demand at $t=0$ on OTC markets compared to $t=-1$, and (2) Yield change between $t=0$ and $t=+5$ for the auctioned bond, where $t=0$ is the auction day. I measure short-selling demand by changes in the onloan percentage and the fee of loans of the auctioned bond on OTC markets. Onloan percentage is defined as the ratio of the volume of lendable bonds divided by the volume of outstanding loans of bonds. *IncreaseDemand* is defined differently in column 1 and column 2. In column 1, *IncreaseDemand* is an indicator equal to 1 if both the onloan percentage and the fee increased over $(-1,0)$; 0 otherwise. In column 2, *IncreaseDemand* is an indicator equal to 1 if the following two conditions are satisfied: 1) The change in fee over $(-5,-1)$ is positive and belongs to the sample's top 50th, and 2) Within this subsample, the change in onloan percentage is positive and belongs to the top 50th; 0 otherwise. In the first column, I restrict the sample to 10-year bonds. Italian sample over 2005-12. Secondary yield data from Datastream (RY datatype). OTC security lending data from the Markit (ex-DataExplorer). t statistics in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

	Δ Yield (0,+5)	Δ Yield (0,+5)
	10Y only Double sorting	
IncreaseDemand (Coef. of interest)	-9.718 (-1.59)	-2.325 (-0.86)
Log trading volume at $t=0$	0.802 (0.12)	-3.436 (-1.04)
Δ Yield (-1,0)	0.360 (0.69)	0.0889 (0.24)
Δ Yield (-2,-1)	0.644 (1.29)	-0.286 (-0.62)
Δ Yield (-3,-2)	-0.560* (-1.70)	-0.119 (-0.32)
Δ Yield (-4,-3)	-0.0203 (-0.08)	-0.235* (-1.88)
Δ Yield (-5,-4)	0.0761 (0.31)	-0.275** (-2.31)
Δ Yield (-6,-5)	-0.230 (-0.40)	-0.141 (-0.43)
Observations	69	360
Controls (duration, coupon rate, tranche, auction results)	Yes	Yes
Fixed-effects (original maturity, year, weekday)	Yes	Yes
Month-level clustering	Yes	Yes

Appendix B

Chapter 2 - Appendix

B.1 The reopening process and summary statistics

TABLE B.1: Historical reopening frequency of Italian sovereign bonds over 2000-15. A potential exception is a month were there might not be any reopening because there was no reopening on that month for at least two years in the sample. A reopening is a primary auction which results in the increase in the outstanding volume of a bond which was first issued in the past.

Maturity	Monthly reopening frequency	Part of month	Potential exceptions
30Y	Unclear	mid	
15Y	Unclear	mid	
10Y	1/month	end	Nov
7Y	1/month	mid	Aug, Dec
5Y	1/month (Q3 2000-15)	mid (Q3 2000-11), end (12-15)	Aug, Nov, Dec
3Y	1/month (04-15) 2/month (2000-3)	end (2004-11), mid (12-15)	Aug, Nov, Dec
2Y	1/month (2000; Q302-15) 2/month (2001-Q2 02)	end (2000; 04-15)	Nov, Dec
5Y floating	Unclear	end	

TABLE B.2: Relative dates of dealers' meeting (D) and auction size announcement (S). For example, the dealers' meeting takes place five days before the reopening date for 5 year bonds over 2000-11. Note that the auction size announcement occurs after market close.

Maturity	2000-11		2012		2013-15	
	D	S	D	S	D	S
2Y	t-3	t-3	t-2	t-2	t-3	t-3
5/10Y	t-5	t-3	t-4	t-3	t-5	t-3
3/7/15/30Y + floating	t-5	t-3	t-4	t-3	t-4	t-3

TABLE B.3: Sample summary statistics - Italian Treasury reopenings (2000-10, 2012-15). A reopening is a primary auction which results in the increase in the outstanding volume of a bond which was first issued in the past.

Maturity	On/off run	Obs.	Remaining maturity (Years)		Reissued amount (€MM)		Bid-cover ratio	
			Mean	Std.	Mean	Std.	Mean	Std.
30Y	On	65	29.73	2.68	1,508	655	1.86	1.59
	Off	11	24.97	2.73	952	405	1.89	0.4
15Y	On	50	14.77	1.73	1,794	536	1.65	0.32
	Off	22	11.9	2.39	1,256	658	1.77	0.33
10Y	On	130	10.08	0.22	2,627	595	1.59	0.35
	Off	36	8.25	1.92	1,740	797	1.71	0.32
7Y	On	17	7.06	0.18	2,367	282	1.5	0.11
5Y	On	135	4.84	0.37	2,393	683	1.73	0.43
	Off	8	3.69	0.33	730	205	2.28	0.48
3Y	On	163	2.82	0.17	2,367	743	1.81	0.48
	Off	3	2.74	0.24	1,760	885	1.88	0.71
2Y	On	147	1.81	0.17	2,065	629	2.11	0.69
	Off	6	1.8	0.16	1,917	376	1.88	0.08
Floating	On	22	5.7	1.06	1,437	424	1.8	0.47
	Off	16	5.44	0.87	1,366	466	1.72	0.33

TABLE B.4: Sample summary statistics - Secondary market variables for reopened bonds over a (-5,+5) window around reopenings. Prices are from Datastream and are available over 2000-10 and 2012-15. Trading volumes are from the MTS platform and are available over April 2004-December 2010 and Jan 2012-October 2012. A reopening is a primary auction which results in the increase in the outstanding volume of a bond which was first issued in the past.

Maturity	On/off run	Five-day pre-auction yield change (bps)			Daily trading volume (€MM)		
		Obs.	Mean	Std.	Obs.	Mean	Std.
30Y	On	65	4.85	1.13	275	73.75	87.59
	Off	11	4.57	1.21	55	41.9	43.41
15Y	On	50	2.77	1.2	286	99.66	115.99
	Off	22	9.86	1.82	176	53.2	81.71
10Y	On	130	1.69	0.95	630	287.01	227.32
	Off	36	5.86	2.08	396	135.76	178.32
7Y	On	17	-2.72	0.85	na	na	na
5Y	On	135	1.38	1.4	660	191.34	179.42
	Off	8	5.42	3.35	88	31.57	34.43
3Y	On	163	0.92	1.94	735	182.2	179.97
	Off	3	-27.41	3.91	15	130.9	129.16
2Y	On	147	1.99	1.15	672	171.63	156.77
	Off	6	-1.87	1.1	66	272.09	230.93
Floating	On	22	6.1	1.92	39	82.14	101
	Off	16	0.85	1.3	4	16.63	13.33

TABLE B.5: Sample summary statistics - Repo market variables for reopened bonds over a (-5,+5) window around reopenings (2005-10, 2012). A Special Repo contract is a cash loan agreement where the ISIN of the bond serving as collateral is explicitly designated. Special Repo contracts are often thought to be security lending agreements. In particular, this table reports the cost of borrowing the reopened security (i.e. the specialness) and the volume of such agreements. The data comes from the MTS Repo platform. A reopening is a primary auction which results in the increase in the outstanding volume of a bond which was first issued in the past.

Maturity	On/off run	Obs.	Special Repo Volume (€MM)		Specialness (%)	
			Mean	Std.	Mean	Std.
30Y	On	242	561.23	372.96	0.07	0.09
	Off	55	458.71	274.39	0.34	0.52
15Y	On	275	647.21	369.5	0.13	0.22
	Off	176	498.02	293.25	0.19	0.21
10Y	On	557	1023.81	547.36	0.33	0.93
	Off	392	892.74	600.82	0.17	0.41
7Y	On	na	na	na	na	na
5Y	On	605	763.12	546.26	0.12	0.38
	Off	88	485.65	238.41	0.19	0.29
3Y	On	670	665.09	391	0.1	0.33
	Off	15	363.97	168.74	0.17	0.16
2Y	On	609	551.85	458.72	0.09	0.2
	Off	66	864.26	435.47	0.03	0.03
Floating	On	39	194.94	163.25	0.07	0.1
	Off	4	47.38	37.36	0.06	0.07

B.2 Robustness Tables

TABLE B.6: Robustness table. Determinants of one-day change in the yield of the reopened bond between t and $t-1$, where t belongs to a $(-5, -1)$ window before the reopening date, and 0 is the reopening date. I test if the yield increases more after the arrival of information than on non-information days. 1_{Info} takes the value 1 if t is either the day on which the Treasury meets with dealers or the day following the announcement of the auction size. The yield data comes from Datastream (RY datatype). In column 1 and 2, I keep only "predictable" reopenings, as defined by those which dates can be perfectly predicted by the econometrician at least before the corresponding dealers' meeting as indicated in appendix Table B.1. More precisely, the following reopenings are removed from the sample: off-the-run bonds, 15 and 30 year bonds, 5 year floating bonds, as well as reopenings occurring on months where there might not be any reopening for a given maturity. In the second column, I control for macroeconomic events by using daily changes in interests rates computed from maturity-matched German sovereign bond prices. Sample: all 2-30 year Italian sovereign bonds reopened over 2000-15 (excl. 2011). A reopening is a primary auction which results in the increase in the outstanding volume of a bond which was first issued in the past. t statistics in parenthesis. $*p < 0.10$, $**p < 0.05$, $***p < 0.01$.

	Δ Yield One-day change (bps) Predictable	Δ Yield One-day change (bps) Predictable + Macro control	Δ Yield One-day change (bps) Including 2011
1_{Info}	1.930** (2.15)	1.877** (2.10)	1.621* (1.93)
Observations	2,515	2,504	4,480
Sample period	2000-15 ex. 11	2000-15 ex. 11	2000-15 incl. 11
Sample filter	Predictable only	Predictable only	All
Time fixed effect	Quarter	Quarter	Quarter
Other fixed effects	Maturity, Days-to-auction	Maturity, Days-to-auction	Maturity, Days-to-auction
Controls	None	German rate	None
Cluster	Day-level	Day-level	Day-level

TABLE B.7: Test with several betas- I test if the yield increases more after the arrival of information than on non-information days, as predicted in Implication 2's corollary. The left-side variable is the one-day change in the yield of the reopened bond between t and $t-1$, where t belongs to a $(-5, -1)$ window before the reopening date, and 0 is the reopening date. The variable $1_{DealerMeeting}$ takes the value 1 if t is the day on which the Treasury meets with dealers; 0 otherwise. The variable $1_{SizeAnnouncement}$ takes the value 1 if t is the day following the announcement of the auction size; 0 otherwise. The variable $1_{AuctionDay}$ takes the value 1 if t is the auction day; 0 otherwise. The yield data comes from Datastream (RY datatype). Sample: all 2-30 year Italian sovereign bonds reopened over 2000-15 (excl. 2011). A reopening is a primary auction that results in the increase in the outstanding volume of a bond that was first issued in the past. t statistics in parenthesis. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

	Δ Yield	Δ Yield
	One-day change (bps)	One-day change (bps)
$1_{DealerMeeting}$	0.964*	0.965*
	(1.92)	(1.93)
$1_{SizeAnnouncement}$	1.436*	1.430*
	(1.84)	(1.83)
$1_{AuctionDay}$		0.949**
		(2.24)
Observations	4,155	4,986
Time fixed effect	Quarter	Quarter
Other fixed effects	Maturity	Maturity
Cluster	Day-level	Day-level

TABLE B.8: Robustness and complementary tests for Table 2.2. I introduce alternative pricing measures, decompose the (-5,0) window into the (-5,-1) and the (-1,0) windows and I include year 2011. The table reports the coefficient of t-test specifications which tests the nullity of the change in price or volume between t=-5 and t=-1 or between t=-1 and t=0 for a bond which will be re-opened in t days and where 0 is the re-opening day. I use Italian re-openings. A re-opening is a primary auction which results in the increase in outstanding volume of a bond which was first issued in the past. The clean price and mid quote price from Datastream (CP and CMPM datatypes). The ask quote comes from the MTS platform and corresponds to the daily average of executable ask quote for a trade of €5M. The trading volume comes from MTS platform. The special Repo volume is the the trading volume on MTS Repo where the collateral demanded by the cash lender is specified to be the re-opened bond. A reopening is a primary auction which results in the increase in the outstanding volume of a bond which was first issued in the past. t statistics in parenthesis. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

	Δ Clean price	Δ Mid quote	Δ Ask quote €5M	Δ Trad. vol.	Δ Spe. Repo vol.
	(%)	(%)	(%)	(%)	(%)
t=-1 vs. t=-5	-0.20*** (-6.16)	-0.29*** (-4.71)	-0.53*** (-6.91)	53.46*** (10.14)	15.66*** (6.67)
t=0 vs. t=-1	-0.07*** (-5.73)	-0.08*** (-3.35)	-0.28*** (-6.56)	125.07*** (31.79)	15.75*** (7.57)
Observations	1,078	498	214	431	567
Sample maturity	All	All	All	All	All
Sample period	2000-15	2009-15	2009-11	2004-12	2005-12
Source	Datastream	Datastream	MTS	MTS	MTS Repo

B.3 Proofs of Propositions

Proof of Lemma 1:

$$V_{2,i}(Z) = -exp \left\{ -\alpha_i \left(C_{1,i} + \theta_{1,i} P_2 + \frac{1}{2} \alpha_i \sigma^2 \left(\frac{\alpha_{-i}(\bar{\theta} + Z)}{\bar{\alpha}} \right)^2 \right) \right\} \quad (\text{B.1})$$

For all Z , $V_{2,i}(Z_1 + Z) = V_{2,i}(Z_1 - Z)$ where $Z_1 = \theta_{1,i} \frac{\bar{\alpha}}{\alpha_{-i}} - \bar{\theta}$. Therefore, $V_{2,i}(Z)$ is symmetric in Z_1 .

Furthermore, $\frac{dV_{2,i}(Z)}{dZ}$ is positive when $Z > Z_1$. Therefore, $V_{2,i}(Z)$ is an increasing function of Z over $[Z_1; +\infty)$.

Finally, $\frac{d^2V_{2,i}(Z)}{d^2Z}$ is negative when $Z > Z_2$ where $Z_2 = \frac{\bar{\alpha}}{\alpha_{-i}}(\theta_{1,i} + \frac{1}{\alpha_i\sigma}) - \bar{\theta}$. Therefore, $V_{2,i}(Z)$ is a concave function of Z over $[Z_2; +\infty)$.

In particular, when $\theta_{1,i} < \frac{\alpha_{-i}\bar{\theta}}{\bar{\alpha}} - \frac{1}{\alpha_i\sigma}$, then $Z_2 < 0$ and, in particular, $Z_2 < \bar{Z}$.

■

Proof of Proposition 1:

The squared term in Z in equation 2.10 is not normally distributed. However, using lemma 1 in Vayanos and Wang (2012), the problem can be reduced to a mean-variance problem. Specifically, I find that investor i 's problem is equivalent to:

$$\begin{aligned} \text{Max}_{\theta_{1,i}} \left[W_{1,i} + \theta_{1,i} \left(\mathbb{E}_Z(P_2) - P_1 \right) - \frac{\alpha_i}{2} \left(\theta_{1,i}^2 \frac{\text{Var}(P_2)}{1 + \alpha_i^2 \alpha_{-i}^2 \bar{\alpha}^{-2} \sigma^2 \sigma_Z^2} \right. \right. \\ \left. \left. + 2\theta_{1,i} \alpha_i \left(\frac{\alpha_{-i}}{\bar{\alpha}} \right)^2 \sigma^2 (\bar{\theta} + \bar{Z}) \frac{\text{Cov}(P_2, Z)}{1 + \alpha_i^2 \alpha_{-i}^2 \bar{\alpha}^{-2} \sigma^2 \sigma_Z^2} \right) \right] \quad (\text{B.2}) \end{aligned}$$

■

I now detail the intermediary steps to reach to B.2. I first find that investor i 's objective function is:

$$\begin{aligned} \mathbb{E}_Z \left[- \exp \left\{ - \alpha_i \left(W_{1,i} + \theta_{1,i} \left(\mathbb{E}_Z(P_2^*) - P_1 \right) + \frac{\alpha_i}{2} \sigma^2 \alpha_{-i}^2 \bar{\alpha}^{-2} (\bar{\theta} + \bar{Z})^2 + \right. \right. \right. \\ \left. \left. \left. (Z - \bar{Z}) \left(- \alpha_i \alpha_{-i} \bar{\alpha}^{-1} \sigma^2 \theta_{1,i} + \alpha_i \sigma^2 \alpha_{-i}^2 \bar{\alpha}^{-2} (\bar{\theta} + \bar{Z}) \right) + (Z - \bar{Z})^2 \frac{\alpha_i}{2} \sigma^2 \alpha_{-i}^2 \bar{\alpha}^{-2} \right) \right\} \right] \quad (\text{B.3}) \end{aligned}$$

Using Vayanos and Wang (2012)'s notation, the investor i 's objective function can therefore be written as:

$$\mathbb{E}_Z \left[- \exp \left\{ - \alpha_i \left(A + (Z - \bar{Z})B + (Z - \bar{Z})^2 \frac{C}{2} \right) \right\} \right] \quad (\text{B.4})$$

With

$$A = W_{1,i} + \theta_{1,i} \left(\mathbb{E}_Z(P_2^*) - P_1 \right) + \frac{\alpha_i}{2} \sigma^2 \alpha_{-i}^2 \bar{\alpha}^{-2} (\bar{\theta} + \bar{Z})^2 \quad (\text{B.5})$$

$$B = -\alpha_i \alpha_{-i} \bar{\alpha}^{-1} \sigma^2 \theta_{1,i} + \alpha_i \sigma^2 \alpha_{-i}^2 \bar{\alpha}^{-2} (\bar{\theta} + \bar{Z}) \quad (\text{B.6})$$

$$C = \alpha_i \sigma^2 \alpha_{-i}^2 \bar{\alpha}^{-2} \quad (\text{B.7})$$

Noting that $(Z - \bar{Z}) \sim N(0; \sigma_Z^2)$, I can write the following relationship by applying lemma 1 in Vayanos and Wang (2012):

$$\begin{aligned} \mathbb{E}_Z \left[-\exp \left\{ -\alpha_i \left(A + (Z - \bar{Z})B + (Z - \bar{Z})^2 \frac{C}{2} \right) \right\} \right] \\ = -\exp \left\{ -\alpha_i \left(A - \frac{1}{2} \alpha_i B^2 \sigma_Z^2 (1 + \alpha_i C \sigma_Z^2)^{-1} \right) \right\} (1 + \alpha_i C \sigma_Z^2)^{-1/2} \quad (\text{B.8}) \end{aligned}$$

As noted in Vayanos and Wang (2012): 1) When $C = 0$, the equality above gives the moment-generating function of the normal distribution; 2) One can assume $C=0$ by also assuming that $(Z - \bar{Z}) \sim N(0; (1 + \alpha_i C \sigma_Z^2)^{-1} \sigma_Z^2)$ where C is defined as above.

We now have a mean-variance problem. Specifically, investors i 's problem is:

$$\text{Max}_{\theta_{1,i}} \mathbb{E}_Z \left[-\exp \left\{ -\alpha_i \left(A + B(Z - \bar{Z}) \right) \right\} \right] \quad (\text{B.9})$$

where it is assumed that $(Z - \bar{Z}) \sim N(0; (1 + \alpha_i C \sigma_Z^2)^{-1} \sigma_Z^2)$ and where A , B and C are defined as above.

Therefore, the investor's problem is equivalent to

$$\text{Max}_{\theta_{1,i}} \left(\mathbb{E}_Z \left(A + B(Z - \bar{Z}) \right) - \frac{1}{2} \alpha_i \text{Var} \left(A + B(Z - \bar{Z}) \right) \right) \quad (\text{B.10})$$

One then obtains B.2, in particular by developing the term $\text{Var} \left(A + B(Z - \bar{Z}) \right)$.

■

Proof of Proposition 2:

$$P_1^* - \mathbb{E}_Z(P_2) = \frac{\sigma^4 \sigma_Z^2 \alpha_A^3 \alpha_B^3 \bar{Z}}{\bar{\alpha}^3 + \bar{\alpha} \alpha_A^2 \alpha_B^2 \sigma^2 \sigma_Z^2} > 0 \quad (\text{B.11})$$

$$\frac{d(P_1 - \mathbb{E}_Z(P_2))}{d\sigma_Z^2} = \frac{\sigma^4 \alpha_A^3 \alpha_B^3 \bar{\alpha}^3 \bar{Z}}{(\bar{\alpha} + \bar{\alpha} \alpha_A^2 \alpha_B^2 \sigma^2 \sigma_Z^2)^2} > 0 \quad (\text{B.12})$$

■

Proof of Lemma 2

In an economy where investors care only about one-period returns, CARA short-sighted investors of type i maximize at $t=1$

$$\mathbb{E}_Z \left[- \exp \left\{ - \alpha_i (\theta_{1,i} P_2 + C_{0,i} - (\theta_{1,i} - \theta_{0,i}) P_1) \right\} \middle| \Omega_1 \right] \quad (\text{B.13})$$

i.e. the expectation over net supply Z , conditional on a set of information Ω_1 , of minus the exponential of minus the following quantity: The value $\theta_{1,i} P_2$ of the total risky portfolio at $t=2$, plus the endowment in cash $C_{0,i}$ minus the cost $\theta_{1,i} - \theta_{0,i} P_1$ of the additional risky position taken at $t=1$.

This is a mean-variance problem. The equilibrium price is equal to

$$P_{1,shortsighted}^* = \bar{D} - \frac{\alpha_i \alpha_{-i}}{\bar{\alpha}} \sigma^2 (\bar{\theta} + Z) - \left(\frac{\alpha_i \alpha_{-i}}{\bar{\alpha}} \right)^3 \sigma^4 \sigma_Z^2 \bar{\theta} \quad (\text{B.14})$$

and therefore $P_{1,shortsighted}^* < P_2^* < P_1^*$

In addition, in an economy where investors do not expect any sale, the equilibrium price is given by setting Z equal to zero in (2.7). More precisely, it is equal to

$$P_{1,nosale}^* = \bar{D} - \frac{\alpha_i \alpha_{-i}}{\bar{\alpha}} \sigma^2 \bar{\theta} \quad (\text{B.15})$$

$$\text{I find that } P_1^* - P_{1,nosale}^* = -\frac{\alpha_A \alpha_B \sigma^2 \bar{\alpha}}{\bar{\alpha}^2 + \alpha_A^2 \alpha_B^2 \sigma^2 \sigma_Z^2} \bar{Z} < 0$$

Finally, P_1^* decreases in \bar{Z} . Indeed:

$$\frac{dP_1}{d\bar{Z}} = -\frac{\alpha_A \alpha_B \sigma^2 \bar{\alpha}}{\bar{\alpha}^2 + \alpha_A^2 \alpha_B^2 \sigma^2 \sigma_Z^2} < 0 \quad (\text{B.16})$$

■

Proof of Proposition 3

First note that

$$\theta_{1,A}^* = \frac{-\bar{Z}}{1 + \delta + \alpha^2 \sigma^2 \sigma_Z^2} < 0 \quad (\text{B.17})$$

which means that investor A is short-selling at $t=1$

$$\frac{d\delta\theta_{1,A}^*}{d\sigma_Z^2} = \frac{\delta\bar{Z}\alpha^2\sigma^2}{(1 + \delta + \alpha^2\sigma^2\sigma_Z^2)^2} > 0 \quad (\text{B.18})$$

$$\frac{dP_1}{d\sigma_Z^2} = \frac{\alpha^3\sigma^4(1 + \delta)\bar{Z}}{(1 + \delta + \alpha^2\sigma^2\sigma_Z^2)^2} > 0 \quad (\text{B.19})$$

■

Appendix C

Chapter 3 - Appendix

TABLE C.1: Differences in yield and repo rates between bond A and B. This tables indicate that the data ressembles the example in Table 3.11: The yield difference increased during the crisis, while co-movement between bond and repo trading increased. Bond A and B have same issuer, same coupon rate and same remaining maturity.

	Obs	Mean	Std. dev	Min	Max	Correlation between yield and rate differences
Before crisis						0.043
Yield difference (unsigned, bps)	1258	11.40	29.84	0.00	364.98	
Repo rate difference (unsigned, bps)	1258	11.69	23.89	0.00	276.96	
Crisis (Before Lehman)						0.183
Yield difference(unsigned, bps)	506	18.71	32.46	0.00	462.48	
Repo rate difference (unsigned, bps)	506	25.49	41.36	0.00	442.41	

Titre : Essais sur les Marchés des Obligations Souveraines

Mots clés : Obligation souveraine, Marché repo, Vente à découvert, Enchère du Trésor

Résumé : Dans le premier chapitre, j'examine si les vendeurs à découvert sont mieux informés à propos des enchères d'obligation souveraines que le marché. Je trouve, en moyenne, une forte augmentation de la demande de vente à découvert avant les enchères. Néanmoins, la demande de vente à découvert ne prédit pas une augmentation future du rendement. Les vendeurs à découvert ne sont donc pas mieux informés sur le résultat des enchères et n'interprètent pas mieux que le marché.

Dans le second chapitre, je développe et teste un modèle expliquant la baisse graduelle des prix observée dans les jours qui conduisent à des ventes anticipées d'actifs telles que les enchères du Trésor. Dans le modèle, les investisseurs averse au risque anticipent une vente d'actifs dont l'ampleur – et donc le prix – sont incertains. Je montre que les investisseurs font face à un compromis entre se *hedger* au moyen d'une position longue et spéculer sur la différence entre le prix avant la vente et le prix espéré de vente. En raison du *hedging*, le prix

d'équilibre est supérieur au prix de vente espéré. À l'approche de la date de vente, l'incertitude quant au prix de vente diminue, les positions spéculatives à découvert augmentent et le prix diminue. Conformément aux prédictions, je trouve que le rendement des bons du Trésor italien augmente de 1,2 points de base après la publication d'informations sur le prix d'enchère, par rapport aux jours sans information.

Dans le troisième chapitre, j'étudie le lien entre les prix et les taux repo au cours de la crise des *subprimes*. Je trouve que la relation de non-arbitrage entre les prix et les taux repo de Duffie (1996) performe moins bien pendant la crise. Cependant, les obligations à faible taux repo ont 18.0% plus de chance d'être plus coûteuses que les obligations identiques à taux repo élevé lors de la crise, contre seulement 9.0% avant la crise. Dans l'ensemble, bien qu'il existe de fortes limites à l'arbitrage, les prix et les taux repo présentent des co-mouvements plus importants pendant la crise.

Title : Essays on Sovereign Bond Markets

Keywords : Sovereign bonds, Repo market, Short-selling, Treasury auctions

Abstract :

In the first chapter, I ask if short-sellers are superiorly informed about sovereign auctions. I find a large average increase in demand for short-selling prior to auctions. Yet, the demand for short-selling a bond does not predict a subsequent increase in the bond's yield. Overall, there is no evidence that short-sellers predict or interpret auction outcomes better than the market.

In the second chapter, I develop and test a model explaining the gradual price decrease observed in the days leading to large anticipated asset sales such as Treasury auctions. In the model, risk-averse investors anticipate an asset sale which magnitude, and hence price, are uncertain. I show that investors face a trade-off between hedging the price risk with a long position, and speculating on the difference between the pre-sale and the

expected sale prices. Due to hedging, the equilibrium price is above the expected sale price. As the sale date approaches, uncertainty about the sale price decreases, short speculative positions increase and the price decreases. In line with the predictions, I find that the yield of Italian Treasuries increases by 1.2 bps after the release of auction price information, compared to non-information days.

In the third chapter, I study the link between prices and repo rates during the subprime crisis. I find that the no-arbitrage relationship between prices and repo rates in Duffie (1996) fares worse during the crisis. However, low-repo-rate bonds have an 18.0% higher probability of being more expensive than identical high-repo-rate bonds during the crisis, compared to only 9.0% before the crisis. Overall, while there are high limits of arbitrage, prices and repo rates feature larger co-movements during the crisis.