

Primary Market Design: Mechanisms And When-Issued Markets*

Pegaret Pichler[†] Alex Stomper[‡]

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Abstract

We analyse the pricing and allocation of unseasoned securities by means of mechanisms such as auctions or bookbuilding. Our analysis allows for the pricing and allocation rules to be based not only on investors' bids, but also on information revealed through pre-issue trading of the securities in a when-issued or betting market. The results explain why mechanisms for pricing equity securities typically allow information from pre-issue markets to affect the issue price, while those for pricing Treasuries do not.

Keywords: mechanism design; when-issued trading; primary security markets

JEL Classifications: G32

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[†]Vienna Graduate School of Finance at the Institute for Advanced Studies & Northeastern University, pegaretp@ihs.ac.at.

[‡]MIT Sloan, Institute for Advanced Studies, University of Vienna.

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Abstract

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1 Introduction

In this paper we analyze mechanisms for selling unseasoned securities in primary markets. These mechanisms are simply sets of rules that map reports from potential buyers into prices and allocations. The rules effectively specify a game in which investors participate by submitting reports (often called bids). The design of pricing mechanisms has been studied in the context of Treasury auctions and initial public offerings (IPOs) of equity securities.¹ A recent contribution also proposes a mechanism for the pricing of nontraded securities held by banks in the Troubled Asset Relief Program (TARP).²

The distinguishing feature of our analysis is that we consider the mechanism participants' reports as one, but not necessarily the only source information that can be mapped into prices and allocations. Another potential source of such information is when-issued trading of the securities, i.e., trading of forward contracts with a delivery date after the securities are issued. Such trading regularly takes place in a number of primary markets, such as US and European Treasury markets and European IPO markets.

Our analysis is motivated by the observation that, even though when-issued trading may reveal information about the value of securities issues, such information is not always used for pricing the issues. For example, the pricing of Treasury issues is fully determined by auction bids, even though when-issued trading may reveal information beyond what is contained in the bids. There are, however, other primary markets where when-issued trading does affect the pricing of securities issues. IPOs are commonly priced by means of "bookbuilding" mechanisms in which underwriters (acting on behalf of the issuers) elicit "indications of interest" from investors. There are no strict pricing rules, and the underwriters can exercise discretion in order to condition their pricing decisions both on the indications of interest and on information revealed through when-issued trading.³ Cornelli, Ljungqvist and Goldreich (2006) and Aussenegg, Pichler and Stomper (2006) find evidence that the pricing of European IPOs takes into account information contained in when-issued market prices.

¹See Back and Zender (1993), Biais, et al (2002) and Maksimovic and Pichler (2006) for a few references.

²See Ausubel and Cramton (2008). The mechanism that they propose is a reverse auction in that the participants submit offers to sell, rather than bids to buy.

³Even in IPOs that use auctions the allocation rule is typically well specified, but the pricing rule is not. Thus, even in auctioned IPOs information other than the bids can affect the issue price. See www.wrhambrecht.com for a description of their OpenIPO auction.

Our objective in this article is to both explain why we observe such differences in mechanisms for pricing unseasoned securities, and to analyze general advantages and disadvantages of allowing the pricing to depend on when-issued market prices. We consider a generic model of a securities issue, and compare pricing mechanisms of two types. “Constrained” mechanisms are similar to Treasury auctions in that the issuer commits to set the price and allocations based only on the participants’ bids. The participants on their part commit to accept the price and allocations, as long as the securities are not overpriced relative to the bids. “Unconstrained” mechanisms are similar to methods used for pricing IPOs: no commitments are made by any of the players, and the issue price and allocations can depend both on the participants’ bids and on information that is revealed through when-issued trading.

After determining the optimal mechanism of each type, we next determine which type of mechanism, constrained or unconstrained, is optimal. Our optimal mechanism design thus consists of three parts: a choice of mechanism type (constrained or unconstrained) and optimal pricing and allocation rules, given that type.

Our analysis reveals that the optimal choice of mechanism type depends on a variable that captures differences in the incidence of when-issued trading across different primary markets. We introduce this variable into the analysis since there are in fact striking differences between primary markets in the extent to which when-issued trading takes place. In some markets, such as US Treasury markets, this trading occurs prior to virtually all issues. In other markets, such as European IPO markets, only a fraction of all issues are traded in when-issued markets.⁴ We model these differences between primary markets by assuming that when-issued trading takes place with a given probability that is one of the model parameters and can be interpreted as the probability that a market failure does not occur. Our analysis reveals how this probability affects the optimal choice of mechanism type.

Our analysis proceeds in several steps. We first show that the probability with which when-issued trading will take place is a key determinant of the structure of the optimal allocation rule in unconstrained mechanisms. If this probability is sufficiently low, then the optimal allocation rule satisfies the standard “implementability” condition: investors’ allocations are nondecreasing in their bids.⁵ If, however, the probability of when-issued

⁴See the following section for a description of existing markets and empirical evidence.

⁵See Myerson (1981), Krishna (2002), Maskin and Riley (1989) and Bennouri and Falconieri (2008)

trading is sufficiently high, then larger allocations must be made to investors whose reports are more consistent with information revealed through the trading, if it takes place. In this case, allocations may be decreasing in bids. A different result is obtained for constrained mechanisms, i.e., mechanisms where the issue price and allocations cannot depend on information revealed through when-issued trading. For constrained mechanisms, optimal allocations are always nondecreasing in investors' bids.

The intuition for the structural differences between constrained and unconstrained pricing mechanisms follows from the effect that the possibility of when-issued trading has on investors' incentives to truthfully report their private information. In a constrained mechanism, the participants know that their bids will determine the primary market price. In an unconstrained mechanism, the participants have incentives to free-ride on price discovery in when-issued trading. If such trading is predicted to take place with a sufficiently high probability, then investors may decide not to condition their bidding on their own private information. They may instead try to simply maximize their expected allocations since they know that the issue will be (at least weakly) underpriced, relative to the when-issued market. This incentive to free-ride is offset if allocations are increasing in the extent to which investors' bids are consistent with the prices that are subsequently observed in when-issued trading, if such trading takes place.

We next consider the optimal choice of mechanism type: constrained or unconstrained. When making this choice, the issuer faces a basic trade-off. On the one hand, an unconstrained pricing mechanism benefits the issuer because when-issued trading is a cost-free source of information. On the other hand, the use of such information may reduce informed investors' incentives to truthfully report their own information. We show that the optimal resolution of this trade-off depends on the probability that when-issued trading will take place. If this probability is sufficiently low, then the use of an unconstrained mechanism is unequivocally optimal. Otherwise, a constrained mechanism may be optimal. These results are consistent with the stylized facts mentioned above. Constrained mechanisms are indeed used in Treasury markets, where when-issued trading regularly takes place, but not in IPO markets, where when-issued trading occurs less regularly.

We conclude our analysis with a robustness check. Throughout most of the paper we assume that the probability of when-issued trading is exogenously given. There is, however, evidence that when-issued trading occurs endogenously in IPO markets: the trading

for discussions of this condition. We derive in the paper the precise cut-off value for the probability.

never starts before the publication of offering prospectuses that contain information which has been elicited from prospective investors. To consider this possibility, we extend our analysis and model the probability of when-issued trading as a function of the reports that investors submit in the mechanism. We show that the possibility of an endogenous market failure provides additional incentives for investors to truthfully report their private information. We thus find a further rationale for the unconstrained mechanism type to be optimal if when-issued trading is sufficiently likely to fail. Again, we obtain predictions that are consistent with the stylized facts mentioned above.

This paper extends the existing literature on the design of mechanisms for pricing financial securities. The paper is most closely related to Biais, Bossaerts and Rochet (2002) and Maksimovic and Pichler (2006) in that we examine optimal mechanisms for eliciting information directly from informed investors. We also build on a growing finance literature that shows how the optimal design of mechanisms depends on an issuer's ability to allocate to non-strategic agents who do not submit pricing relevant reports.⁶ Our paper differs from other contributions to this literature in that we determine the form of such mechanisms when there is a possibility of when-issued trading.⁷

Our work is also related to analyses of auctions for Treasury securities. Back and Zender (1993) and Viswanathan and Wang (2000) model Treasury auctions; the latter paper also allows for when-issued trading. Bikchandani and Huang (1993), Simon (1994) and Nyborg and Sundaresan (1996) discuss concerns regarding the interaction of the when-issued market and auctions for U.S. Treasury securities. Simon (1994) presents evidence that participants in the auction and the post-auction when-issued market possess private information regarding demand for securities. Nyborg and Strebulaev (2004) analyze the optimal design of Treasury auctions that are followed by when-issued trading. The focus of their paper is on how the potential for squeezes leads to endogenous "private values" and thus affects bidders' behavior in a symmetric information framework. Our analysis concerns the optimal design of direct mechanisms for price discovery in primary markets. We allow for asymmetric information across investors in a common values framework.

The paper is organized as follows. In the next section, we provide a brief description of some existing primary markets and the mechanisms used to price and allocate financial

⁶See Wang and Zender (2002), Maksimovic and Pichler (2006) and Bennouri and Falconieri (2008).

⁷Ours is not the first model to consider the effect of when-issued trading on IPO pricing. See Cornelli, Ljungqvist and Goldreich (2006). Ours is the first, that we know of, to do this in the context of mechanism design.

securities. In the third section, we present the basic model and a “benchmark mechanism”, which is optimal if the probability of when-issued trading is zero. Our main results appear in Section 4, in which we determine the optimal mechanism for eliciting information from investors, assuming that when-issued trading takes place with an exogenously given probability. In Section 5 we allow this probability to be endogenously determined. In Section 6 we provide concluding remarks.

2 A selective survey of when-issued trading and pricing mechanisms in financial markets

In this section, we briefly survey the structure of some primary financial markets, with a focus on when-issued trading. When-issued markets are forward markets for trading in not-yet-issued securities. The forward contracts represent commitments to trade when, and if, a security is issued. Net selling in these markets is, by definition, short selling.

When-issued trading of Treasury securities: Bikhchandani and Huang (1993) and Nyborg and Sundaresan (1996) describe institutional features of the primary market for U.S. Treasury securities, including the market for when-issued trading of Treasuries. The contracts in this market specify physical delivery of the underlying security. Trading of these contracts starts on the date of the announcement of a Treasury auction and continues after the auction takes place, up until the issue date.⁸ The issue price and the allocations to auction participants are determined by the bids in the auction.⁹ The pricing of issues can depend on information revealed by when-issued trading, but only to the extent that this information is contained in the auction bids. The bidding however regularly closes before the end of when-issued trading.

It is generally accepted that the fundamental valuation of government securities typically does not involve significant amounts of private information. However, the price of any given issue can be strongly affected by demand, and information about demand may be privately held by auction participants. Hortaçsu and Sareen (2005), using data from Canadian Treasury auctions, provide evidence that this is indeed the case. Both Nyborg and Sundaresan (1996) and Hortaçsu and Sareen (2005) provide evidence that

⁸When-issued trading of Treasury securities was prohibited prior to 1970 and again between 1977 and 1981. Restrictions on when-issued trading were removed at the suggestion of the dealers who argued that such trading “would facilitate price discovery and new-issue distribution.” Garbade (2004), p43.

⁹See Garbade and Ingher (2005) for more details.

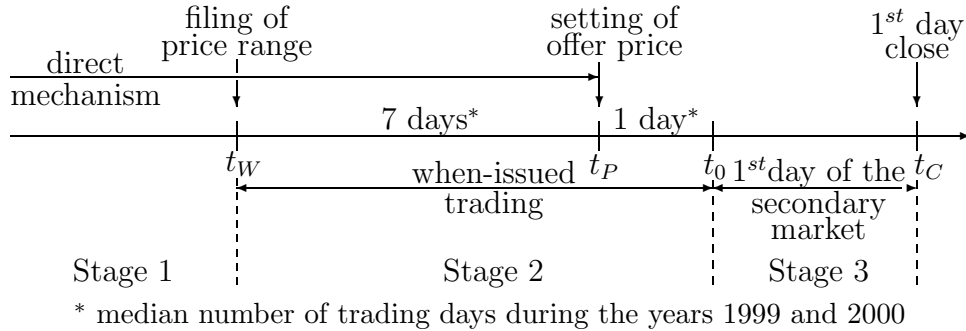


Figure 1: The German IPO Pricing Process
Source: Aussenegg, et al. (2006)

when-issued trading prior to the auction is not very liquid. Thus, it appears that any significant information that is revealed by when-issued trading is revealed after the auction closes.

When-issued trading of IPO shares: When-issued trading also occurs in IPO markets, but (for regulatory reasons) mostly outside the U.S.¹⁰ Cornelli, Goldreich and Ljungqvist (2006) report that most German and Italian IPOs trade in when-issued markets while when-issued trading is less common in other European countries (such as France or Sweden). The market with the highest incidence of when-issued trading is the German IPO market. This market has been separately analyzed in Löffler, Panther and Theissen (2005) and Aussenegg, Pichler and Stomper (2006).

Figure 1 presents a time-line of the IPO pricing process in the German market. There are three stages. During Stage 1 (prior to the posting of the price range), underwriters gather information that is at least partially released when they file the preliminary offering prospectus. When-issued trading opens at time t_W , i.e., after the prospectus has been filed. This aspect of the timeline is typical of when-issued trading in European IPO markets. The trading never opens before the filing of the preliminary offering prospectus.¹¹ As in U.S. Treasury markets, when-issued trading continues up to the issue date.

The empirical evidence suggests that when-issued markets are informative, and that these markets generate information that affects the IPO offering prices. Löffler, Panther

¹⁰U.S. Regulation M, Rule 105, which became effective on March 4, 1997, prohibits the covering of short positions in IPO shares that were created within the last five days before pricing, with allocations received in the IPO. This prohibition effectively prevents when-issued trading. In addition to this rule, there are also restrictions on trading in unregistered shares.

¹¹We thank Gary Beechener of Tullett & Tokyo Liberty (securities) Ltd. for providing this information.

and Theissen (2005) find that the final prices in the when-issued market are unbiased predictors of opening prices in the secondary market. Aussenegg, Pichler and Stomper (2006) and Cornelli, Goldreich and Ljungqvist (2006) present evidence that information revealed through when-issued trading is incorporated into the pricing of bookbuilt issues. The latter evidence is consistent with the word on the street. According to one of the largest market makers in the German when-issued market for IPO shares: “By observing when-issued trading, the underwriter can gauge the market’s interest in an IPO.”¹² Moreover, underwriters can respond to information revealed through when-issued trading since IPOs are not priced according to stringent rules. Underwriters are free to base their pricing decisions on both information that they obtain directly from investors, and information revealed through when-issued trading.

3 The Benchmark: No When-Issued Trading

In this section we present the basic model and we determine the optimal mechanism without when-issued trading. A list of variables and their definitions is given in Table 2 in the Appendix.

3.1 The Basic Model

An issuer wishes to maximize expected proceeds from selling a fixed number of securities. Potential investors are risk neutral, and so are willing to purchase securities as long as the expected return is nonnegative. \tilde{V} is the unknown secondary market value of the *total* offering: per security value times the number of securities sold. An investor who purchases securities obtains a fraction of this value. \tilde{V} is given by:

$$\tilde{V} = v_0 + \tilde{s}w, \tag{1}$$

where v_0 is the prior expected value of \tilde{V} and w is a positive parameter that is strictly smaller than v_0 . \tilde{s} is a random variable that can take on one of two realizations, $s \in \{-1, 1\}$. The prior probability that $s = 1$ is $\pi_0 = 1/2$.

A fraction α ($0 < \alpha < 1/2$) of all potential investors are privately informed. Each informed investor has observed a noisy signal of \tilde{s} . The signal of investor i is a random

¹²This quote was taken from the website of Schnigge AG, [://www.schnigge.de/info/service/pre-ipo-trading.html](http://www.schnigge.de/info/service/pre-ipo-trading.html). The original quote was in German: “Der Emissionsführer kann auf Grund der Handelstätigkeit im Handel per Erscheinen das Interesse des Marktes an der Neuemission messen.”

variable $\tilde{\zeta}_i$ that can take on one of two realizations, $\zeta_i \in \{-1, 1\}$. Conditional on the realization of \tilde{s} , the signals $\tilde{\zeta}_i$ and $\tilde{\zeta}_j$ of any two informed investors i and j are independent of each other and identically distributed. With probability $q > 1/2$, any given informed investor has correctly observed the realization of \tilde{s} . For an investor who sees a positive signal, the probability that $s = 1$ is q and the probability that $s = -1$ is $1 - q$, so that the expected value of \tilde{s} is $q - (1 - q) = 2q - 1 > 0$. For an investor who sees a negative signal, the expected value of \tilde{s} is $1 - 2q < 0$. On average, a fraction $q\alpha$ of investors will have correctly observed the realization of \tilde{s} and $(1 - q)\alpha$ will have observed $-\tilde{s}$. Model (1) and the parameters v_0 , w , α and q are all common knowledge.

We do not distinguish between the issuer and any intermediary, such as an underwriter, who may assist in the security issuance process. We effectively treat these individuals as a single agent, and in what follows we consistently use the term issuer to refer to this agent. We assume that the issuer can identify a number of “regular” investors who are privately informed. In Treasury issues the regular investors are the primary dealers; in equity issues they are typically institutional investors. The issuer can elicit the regular investors’ private information through a mechanism, and then allocate securities to these investors. The issuer may also allocate securities to retail investors. These are investors from whom the issuer does not attempt to elicit information. The offering is, however, restricted to be uniform price, so the issuer cannot price discriminate between regular and retail investors.

It has been shown that including retail investors in the allocation process is beneficial for the issuer, because doing so improves the incentives of informed investors to truthfully reveal their information.¹³ This improvement occurs because the issuer can allocate securities to retail investors if the regular investors report negative information about the value of the securities. But, retail investors include both informed and uninformed investors; as described above, only a fraction α are informed. To ensure that a retail allocation can be successfully placed, the issue may have to be priced at a discount so that uninformed investors are willing to purchase securities. The issue price, p_I , must be less than the expected value of the issue: $p_I \leq E[\tilde{V}] - u_{AS}$, where $u_{AS} > 0$ is the underpricing required to compensate uninformed investors for adverse selection risk that they bear due to the presence of informed investors in the market.¹⁴

¹³See Maksimovic and Pichler (2006) and Bennouri and Falconieri (2008).

¹⁴Fewer informed investors place orders when an issue is overpriced ($s = -1$) than when it is underpriced

Our model of expected underpricing due to adverse selection risk, u_{AS} , is a simplified version of the model in Rock (1986). Underpricing is a function of the information asymmetry that remains between informed and uninformed investors, conditional on the issue price. This quantity is summarized by the parameter π_p , which is the probability that $s = 1$, given all of the information that is used in the primary market pricing process. In our model, this information is summarized by the issue price as a sufficient statistic. The level of underpricing due to adverse selection risk, derived in the Appendix, is:

$$u_{AS} = \frac{q - 2\pi_p(1 - \pi_p) - (2\pi_p - 1)^2q}{1 - ((2\pi_p - 1)q + 1 - \pi_p)\alpha} \alpha w . \quad (2)$$

If π_p is equal to the prior, $\pi_0 = 1/2$, then no new information has been incorporated into the issue price. If $\pi_p = 0$ or $\pi_p = 1$, then perfect information about the realization of \tilde{s} has been incorporated into the issue price, and as can be easily verified from equation (2), $u_{AS} = 0$. This makes sense because incorporating perfect information into the price fully eliminates the informational asymmetry among investors. We show in the Appendix that u_{AS} is decreasing in $|\pi_p - \pi_0|$ which is a measure of the extent to which the pricing process has ameliorated the informational asymmetry. In the remainder of the paper we refer to u_{AS} as underpricing due to “residual adverse selection risk”. The term “residual” is used because this is adverse selection risk that remains after some information has been elicited from a set of regular investors, and used to price the issue. We take the issuer’s desire to minimize u_{AS} as the rationale for the use of a mechanism to elicit information prior to pricing the issue.

3.2 The Benchmark Mechanism

In this section we determine the *benchmark mechanism*. This is the optimal mechanism without when-issued trading. We invoke the Revelation Principle and only consider direct mechanisms, that is mechanisms in which investors submit reports of their signals. In order to obtain our results, some of which depend on our assumption that informed investors have positively, but not perfectly, correlated signals, we need at least two polled investors. To keep the model as simple as possible we assume that information is elicited from exactly two investors.¹⁵ We assume that the issuer is able to ascertain that the two

($s = 1$). Thus, uninformed investors are more likely to receive allocations if the issue is overpriced than if it is underpriced. If the issue were priced at its expected value, $E[\tilde{V}]$, the uninformed investors’ expected return would be negative, and they would refuse to participate.

¹⁵See Maksimovic and Pichler (2006) for a study in which the optimal number of polled investors is determined in a mechanism that is similar to our benchmark.

polled investors are in fact informed. As discussed above, securities may be allocated to these two investors and to a number of retail investors.

There are three possible outcomes for the polled investors' reports: either both report positive information, both report negative information, or one reports positive and the other negative information. We represent these outcomes with the pair $(a, b) \in \{(++), (+-), (-+), (--)\}$, where $(++)$ indicates that both polled investors reported positive information. Information gathered through the mechanism can also be represented with a simple sufficient statistic: the number of reported positive signals minus the number of reported negative signals. We denote this difference with the parameter z , where $z \in \{2, 0, -2\}$. If the polled investors' reports are the only sources of information for pricing the issue, then $\pi_p = \pi(z)$:¹⁶

$$\pi(2) = 1 - \pi(-2) = \frac{q^2}{1 - 2q(1 - q)} \quad \text{and} \quad \pi(0) = \pi_0 = 1/2. \quad (3)$$

A zero value of z indicates that the investors' reports are contradictory ($(+-)$ or $(-+)$) and, hence, overall uninformative. Otherwise: $\pi(2) > 1/2 > \pi(-2)$.

The expected value of the issue, given the reports of the polled investors, is

$$E[\tilde{V}|z] = v_0 + \frac{(z/2)(2q - 1)w}{1 - 2q(1 - q)}. \quad (4)$$

The issue price can be written: $p_I = E[\tilde{V}|z] - u^{ab}$, where u^{ab} is the expected level of underpricing, given that one polled investor reported a and the other reported b . A direct implication of equation (4) is that, if a polled investor misreports her signal, then this action will change $E[\tilde{V}|z]$, by an amount w_L :

$$w_L \equiv \text{“impact of a lie”} = \frac{(2q - 1)w}{1 - 2q(1 - q)} < w. \quad (5)$$

Falsely reporting a negative (positive) signal, instead of positive (negative), will decrease (increase) $E[\tilde{V}|z]$ by an amount w_L . It is important to note that w_L is the impact on the expected value, $E[\tilde{V}|z]$, but not necessarily on the price p_I .

For the benchmark mechanism, many of the variables are subscripted with the symbol N to indicate “No when-issued trading”. The issuer's objective is to:¹⁷

$$\min E[u^{ab}] = \frac{1}{2}(1 - 2q(1 - q))u^{++} + 2q(1 - q)u^{+-} + \frac{1}{2}(1 - 2q(1 - q))u^{--}, \quad (6)$$

$$= Er_N^+ + Er_N^- + Er_N^R \quad (7)$$

¹⁶See the Appendix for the derivation of $\pi(z)$. In Section 4, the value of π_p may also depend on information generated by when-issued trading.

¹⁷Because we assume a fixed quantity of securities to be issued, maximizing issue proceeds is equivalent to minimizing underpricing.

where Er_N^+ = expected return to a polled investor who sees and reports +

$$= (1 - 2q(1 - q))u^{++}h^{++} + 2q(1 - q)u^{+-}h^{+-}, \quad (8)$$

Er_N^- = expected return to a polled investor who sees and reports -

$$= (1 - 2q(1 - q))u^{--}h^{--} + 2q(1 - q)u^{+-}h^{+-}, \quad (9)$$

Er_N^R = expected return to retail investors (investors not polled)

$$= \frac{1}{2}(1 - 2q(1 - q))u^{++}(1 - 2h^{++}) + \frac{1}{2}(1 - 2q(1 - q))u^{--}(1 - 2h^{--})$$

$$+ 2q(1 - q)u^{+-}(1 - h^{+-} - h^{-+}), \quad (10)$$

and where h^{ab} is the fraction of the offering that is allocated to a polled investor who reports a while the other reports b . The objective function is minimized by choosing the values of u^{ab} and h^{ab} subject to the following constraints.

Participation of polled investors: We assume that polled investors will accept allocations if and only if securities are not overpriced, conditional on the information that has been reported in the mechanism:

$$u^{ab} \geq 0 \quad \forall u^{ab} \in \{u^{++}, u^{+-}, u^{--}\}. \quad (PC_N - I)$$

Incentive compatibility: Investors will truthfully report their information, as long as the following incentive compatibility constraints are satisfied:

$$Er_N^+ \geq (1 - 2q(1 - q))(u^{+-} + w_L)h^{+-} + 2q(1 - q)(u^{--} + w_L)h^{--}, \quad (IC_N^+)$$

$$Er_N^- \geq (1 - 2q(1 - q))(u^{+-} - w_L)h^{+-} + 2q(1 - q)(u^{++} - w_L)h^{++}. \quad (IC_N^-)$$

In writing the incentive compatibility constraints we implicitly assume that a polled investor will not refuse an allocation, as long as $(PC_N - I)$ is satisfied.¹⁸ Thus, sending a false positive report exposes an investor to the risk of receiving an over-priced allocation. For this reason, (IC_N^-) will not be binding. This is one aspect of the mechanism design problem that may change in the presence of when-issued trading.

Allocation constraints: The issue must be fully allocated, and cannot be over-allocated. In addition, a minimum fraction of the issue, $h_R \in (0, 1)$, must be allocated to retail

¹⁸In Treasury auctions and in some IPO markets investors are legally bound to purchase allocations. In U.S. IPOs investors are typically not legally bound to purchase allocations, but polled investors and intermediaries who assist in issuing securities are typically engaged in repeated interactions. There are thus reputational reasons for not refusing an allocation.

investors.

$$2h^{--}, 2h^{++}, h^{+-} + h^{-+} \leq 1 - h_R \quad \& \quad h^{ab} \geq 0. \quad (AC_N)$$

Participation of retail investors: In order to ensure sufficient retail participation the issue must be priced to compensate uninformed investors for adverse selection risk:¹⁹

$$u^{++} \geq u_{AS}(2), \quad u^{+-} \geq u_{AS}(0), \quad u^{--} \geq u_{AS}(-2). \quad (PC_N - R)$$

u_{AS} , introduced in Section 3.1, is the expected underpricing due to adverse selection risk. We use the notation $u_{AS}(z)$ to indicate that this expected underpricing is a function of the information obtained through the mechanism. The values for $u_{AS}(0)$, $u_{AS}(2)$ and $u_{AS}(-2)$ are stated in the Appendix, where we also show that $w_L/3 > u_{AS}(0) > u_{AS}(2) > u_{AS}(-2)$.

The benchmark mechanism, the optimal mechanism without when-issued trading, is summarized in the following proposition.²⁰

Proposition 1. The Benchmark Mechanism. *Without when-issued trading the optimal mechanism has the following characteristics:*

1. *Investors who report positive information receive the largest possible allocation. Investors who report negative information receive no allocation.*
2. *Positive expected underpricing is required in each state, due to residual adverse selection risk. The incentive compatibility constraints (IC) are nonbinding, and so no further underpricing is needed in order to induce truthful reporting.*
3. *The expected underpricing is:*

$$Eu_N = 2q(1 - q)u_{AS}(0) + (1 - 2q(1 - q))(u_{AS}(2) + u_{AS}(-2)) / 2 \quad (11)$$

The benchmark mechanism has three key characteristics. First, the allocation policy in the benchmark mechanism is non-decreasing. That is, more securities are allocated to investors who report more positive information about the security value. Second, a direct implication of parts 1 and 2 of Proposition 1 is that a polled investor who has observed positive information expects to earn strictly positive informational rents, while

¹⁹Polled investors do not face an adverse selection risk, because their allocations are based only on the reported information, not on any information that may still reside with other investors. For this reason, the constraint $(PC_N - I)$, requires only nonnegative underpricing.

²⁰This proposition reproduces results from Maksimovic and Pichler (2006). We present these results here in proposition form so that the reader can more easily compare them to our results in the following sections.

an investor who has observed negative information expects to earn zero rents. Third, underpricing in the benchmark mechanism is not determined by the need to pay pooled investors informational rents, but rather by the discount that the uninformed investors require in order to bear adverse selection risk (as discussed at the end of Section 3.1).

4 Optimal Selling Mechanisms with When-Issued Trading

We assume from this point forward that when-issued trading is permitted. Permitting when-issued trading does not, however, ensure that such trading will indeed take place. Primary markets differ substantially in the incidence of when-issued trading. In Treasury markets a complete failure of when-issued trading is virtually unheard of, but the trading sometimes fails in IPO markets. A likely explanation for this difference between IPOs and Treasury markets is based on the fact that it is often quite hard to determine the value of IPO shares based on publicly available information. The issuers of such shares are often relatively small and unknown firms with only a short “track record”. When-issued trading of the shares is therefore easily stifled by the presence of insiders poised to profit from trading with counterparties who only have access to public information.²¹

We capture the possibility of when-issued trading failing to open by assuming that such trading takes place with probability γ , where $\gamma \in [0, 1]$. For now, we assume that this probability is exogenously given.²² The sequence of events is similar to that illustrated in Figure 1. This sequence is typical for IPO markets where when-issued trading does not open until after information has been obtained through a mechanism. When-issued trading of Treasuries typically does open prior to the auction mechanism, and then continues after the bidding in the auction has closed. But, as pointed out by Nyborg and Sundaresan (1996) and Hortaçsu and Sareen (2005), pre-auction trading is often illiquid or even unobservable.²³ In addition, we expect that any information that is revealed by pre-auction trading will be incorporated into the bidders’ prior expectations. We there-

²¹Renneboog and Spaenjers (2008) report that firm size is indeed a significant determinant of the incidence of when-issued trading in the Dutch market. Findings of Cornelli, Goldreich and Ljungqvist (2006) and Dorn (2009) suggest that problems of market failure in the when-issued trading of IPOs are sometimes overcome due to the presence of overly optimistic traders.

²²In Section 5 we model this probability as an endogenous outcome.

²³Hortaçsu and Sareen (2005) report that they couldn’t observe a single trade in the pre-auction when-issued market for Canadian treasuries during their sample period in the years 2001 - 2003.

fore focus on the when-issued trading that takes place after the mechanism, but before the securities are issued.

The sequence of events in our model is as follows. First, the issuer elicits information directly from polled investors (using some type of direct mechanism). After that, publicly observable when-issued trading opens, or doesn't open. If the trading takes place, then it fully reveals all privately held information; i.e., the value of \tilde{s} is revealed.²⁴

4.1 No direct mechanism.

We begin the analysis of this section by defining a second benchmark: the case where the issue is priced without using a direct mechanism for gathering information.²⁵ Without a direct mechanism, the issue is priced based on publicly available information. If when-issued trading reveals the value of the issue, the price can be set equal to this value. Otherwise, the issue is priced according to prior information. In the latter case, the issue must be priced at $v_0 - u_{AS}(0)$ in order to assure retail participation. Thus, the expected underpricing is: $(1 - \gamma)u_{AS}(0)$.

4.2 Two types of direct mechanisms

The benchmark mechanism, described in Section 3.2, is comprised of two components: a pricing rule (u^{ab}) and an allocation rule (h^{ab}). These two rules map polled investors' reports into prices and allocations. If when-issued trading is permitted, then the selling mechanism is comprised of three components: a specification of whether information from when-issued trading may be incorporated into the issue price and allocations, and pricing and allocation rules that are consistent with this specification. If the issuer specifies that the mechanism will be "constrained" (type C), then any investors who want to buy securities in the primary market must submit binding bids, and the investors' bids fully determine the pricing and the allocation of the issue. Post-bidding when-issued trading may reveal information that is not contained in the bids, but such information cannot

²⁴While the assumption of full revelation is a simplification, it is consistent with evidence about both Treasury and IPO markets. There is a broad consensus that publicly observable when-issued trading contributes to price discovery in Treasury markets. A seminal analysis is Nyborg and Sundaresan (1996). Löffler, Panther and Theissen (2005) find that the when-issued market prices are unbiased predictors of the prices at which IPO shares trade on the first day of secondary market trading.

²⁵If a mechanism is used but the pricing and allocation rules do not provide incentives for participants to truthfully report their information, then the mechanism is uninformative. From an information gathering perspective, this is equivalent to having no direct mechanism.

be used as an input of the pricing and allocation rules. In this respect, constrained mechanisms resemble Treasury auctions. If the issuer specifies that the mechanism will be “unconstrained” (type U), then investors’ bids are *not* immediately binding. The pricing and allocation of issues may depend not only on the bids, but also on information revealed through when-issued trading. Unconstrained mechanisms are thus similar to what is observed in IPOs.

We first determine the optimal type U mechanism and the optimal type C mechanism. We then determine under what conditions each mechanism type is optimal.

4.3 Optimal Unconstrained Mechanisms

4.3.1 Unconstrained mechanisms with certain when-issued trading

In order to develop our intuition we begin by making the simplifying assumption that publicly observable when-issued trading occurs with probability one, i.e., $\gamma = 1$. This assumption is relaxed below. We impose it for now in order to analyze the effect of when-issued trading on the structure of the optimal mechanism of type U , even though it is clear that, for $\gamma = 1$, the issue should be priced without using a mechanism.

When-issued trading affects the unconstrained mechanism design in a number of ways. First, polled investors who misreport their private information will be able to profit from informed trading in the when-issued market.²⁶ Second, neither the retail investors nor the polled investors commit to accept allocations until after information has been revealed by the when-issued market. Thus, the participation constraints specify that there must be no overpricing conditional on information from both the mechanism and the when-issued market. Third, any pricing errors that could result from polled investors misreporting will be corrected by price discovery in the when-issued market. As a consequence, the term w_L (the impact of a single polled investors’ lie) does not appear in the incentive compatibility constraints. Finally, because the polled investors’ signals are correlated with information that is revealed through when-issued trading, the issuer can discipline polled investors by conditioning the mechanism outcome on information from this market. But, the use of this disciplinary tool is limited by the issuer’s inability to compel investors to accept overpriced allocations.

²⁶We assume that polled investors lose any such trading opportunities if they truthfully report their private information since there is no way to keep the investors’ reports a secret. This assumption is without loss of generality because we could reinterpret a parameter of our model as the *expected* trading profits that the investors lose if they truthfully report their private information.

The new incentive compatibility constraints are:

$$Er_{U1}^+ \geq q^2 u_+^{+-} h_w^{-+} + (1-q)^2 u_-^{+-} h_c^{-+} + q(1-q) u_w^{-+} h_w^{-+} + q(1-q) u_c^{-+} h_c^{-+} + \Psi \quad (IC_{U1}^+)$$

$$Er_{U1}^- \geq q^2 u_-^{+-} h_w^{+-} + (1-q)^2 u_+^{+-} h_c^{+-} + q(1-q) u_w^{+-} h_w^{+-} + q(1-q) u_c^{+-} h_c^{+-} + \Psi \quad (IC_{U1}^-)$$

The above constraints differ from (IC_N^+) and (IC_N^-) in a number of ways. First, we have added subscripts to the underpricing and allocation variables to indicate information learned from when-issued trading. A subscript of c (w) indicates that a polled investor's report is correct (wrong), relative to information from when-issued trading. A subscript of $+$ ($-$) is used for the underpricing variable when the polled investors disagree with each other and the market indicates that $+$ ($-$) is the correct report. Second, as discussed above, the variable w_L , impact of a lie, no longer appears. Third, Ψ represents the expected trading profits that may be obtained after misreporting. We assume that the expected trading profit is the same for investors who misreport positive and negative information. Finally, Er_{U1}^a represents the a priori expected rents to a polled investor who sees and truthfully reports a , given that $\gamma = 1$:

$$Er_{U1}^+ = q^2 u_c^{++} h_c^{++} + (1-q)^2 u_w^{++} h_w^{++} + q(1-q) u_+^{+-} h_c^{+-} + q(1-q) u_-^{+-} h_w^{+-} \quad (12)$$

$$Er_{U1}^- = q^2 u_c^{-+} h_c^{-+} + (1-q)^2 u_w^{-+} h_w^{-+} + q(1-q) u_+^{+-} h_w^{-+} + q(1-q) u_-^{+-} h_c^{-+} \quad (13)$$

The following proposition describes the optimal *incentive-compatible* (IC) pricing and allocation rules. These rules are optimal in the sense that they result in the highest expected proceeds, given that an unconstrained mechanism type has been specified (U) and that the polled investors have incentives to truthfully report their private information. The proposition is written so that it can be contrasted directly with Proposition 1 for the benchmark mechanism. The intuition for the results is discussed following the proposition.

Proposition 2. The IC Unconstrained mechanism if $\gamma = 1$. *If when-issued trading takes place with probability one, $\gamma = 1$, then the optimal unconstrained incentive-compatible pricing and allocation rules have the following characteristics:*

1. *Investors whose reports turn out to be consistent with information revealed by the when-issued market receive the largest possible allocation, regardless of whether their information is positive or negative.*
Investors whose reports are contradicted by the market receive no allocation.
2. *Both incentive compatibility constraints are strictly binding. Rents must be paid in order to induce truthful reporting, both to polled investors with positive and with negative information.*

3. *The expected underpricing is:*

$$Eu_{U1} = \frac{2q\Psi}{(2q-1)(1-h_R)} \quad (14)$$

The results of Proposition 2 are quite different from those of Proposition 1. In the benchmark mechanism, the incentive compatibility constraints are satisfied through the use of a “carrot” and a “stick”. The carrot, the possibility of receiving an underpriced allocation after truthfully reporting positive information, eliminates investors’ incentives to shade their bids. The stick, the possibility of receiving an overpriced allocation after falsely reporting positive information, eliminates investors’ incentives to pad their bids. If when-issued trading is certain to reveal the value of the issue, and the mechanism design is unconstrained, so that it allows information from this market to be incorporated into the issue price, then the stick disappears. The polled investors have incentives to “free-ride” on price discovery in when-issued trading. In addition, the when-issued market affords trading opportunities to polled investors who misreport. As a result, both (IC_{U1}^+) and (IC_{U1}^-) are strictly binding and incentive compatibility requires the issuer to pay informational rents both to polled investors who see positive information and to those who see negative information. The most striking contrast between the two propositions is in the allocation rules. In Proposition 2 the investors who receive the largest allocations are not necessarily those who report the highest valuations. The mechanism in Proposition 2 is in this way very different from a standard auction.

In the following section we expand on Proposition 2 to determine the optimal unconstrained mechanism under the more realistic assumption that when-issued trading may not open: $\gamma \in [0, 1]$.

4.3.2 Unconstrained mechanisms with uncertain when-issued trading

For $\gamma \in (0, 1)$, the optimal unconstrained mechanism must satisfy incentive-compatibility constraints that are weighted averages (weighted by γ and $1 - \gamma$) of the incentive compatibility constraints in Section 4.3.1 (where $\gamma = 1$) and in the benchmark case (where $\gamma = 0$). We denote the resulting incentive compatibility constraints as IC_U^+ and IC_U^- . These constraints, and the participation constraints are stated in the Appendix (in the proof of Proposition 3).

Propositions 1 and 2 indicated that the incentive compatibility constraints are slack in the absence of when-issued trading ($\gamma = 0$), and binding if such trading is certain to take place ($\gamma = 1$). These results are special cases of the following proposition.

Proposition 3. *If the mechanism is unconstrained, then there exist values, $\underline{\gamma}^+$ and $\underline{\gamma}^-$ such that $0 < \underline{\gamma}^+ < \underline{\gamma}^- < 1$, and:*

1. $\forall \gamma \in [0, \underline{\gamma}^+]$ (IC_U^+) is nonbinding, and $\forall \gamma \in (\underline{\gamma}^+, 1]$ (IC_U^+) is strictly binding.
2. $\forall \gamma \in [0, \underline{\gamma}^-]$ (IC_U^-) is nonbinding, and $\forall \gamma \in (\underline{\gamma}^-, 1]$ (IC_U^-) is strictly binding.
3.
$$\underline{\gamma}^+ = \frac{A}{\hat{\Psi} + A} \quad \text{and} \quad \underline{\gamma}^- = \frac{B}{\hat{\Psi} + B} \quad (15)$$

where $\hat{\Psi} = \Psi/(1 - h_R)$, $A = 2q(1 - q)u_{AS}(0) + (1 - 2q(1 - q))u_{AS}(2)/2$ and $B = q(1 - q(1 - q))w_L - (2q - 1)(qu_{AS}(0) + (1 - q)u_{AS}(2)/2) > A$.

The values $\underline{\gamma}^+$ and $\underline{\gamma}^-$ define three distinct parameter regions in which the incentive-compatible mechanism design problem is subject to different sets of binding constraints. The following proposition describes the mechanism and expected underpricing in each of the three parameter regions. Proposition 4 is written so that it can be compared directly to Propositions 1 and 2.

Proposition 4. The optimal Unconstrained mechanism, $\gamma \in [0, 1]$.

1. *If when-issued trading takes place, then investors whose reports are consistent (inconsistent) with information revealed by the market receive the largest possible (zero) allocations.*

If when-issued trading does not take place, then investors who reported positive (negative) signals receive positive (zero) allocations.

2. *Investors who have observed positive signals expect positive informational rents, for all $\gamma \in [0, 1]$. If $\gamma < 1$, then investors who have observed positive signals expect higher informational rents than investors who have observed negative signals. If $\gamma \leq \underline{\gamma}^-$, then investors who have observed negative signals expect zero rents.*

3. *The expected underpricing depends on the value of γ :*

If $\gamma \in [0, \underline{\gamma}^+]$, then $Eu_U = (1 - \gamma)Eu_N$.

If $\gamma \in (\underline{\gamma}^+, \underline{\gamma}^-]$, then $Eu_U = (1 - \gamma)Eu_N + \gamma\hat{\Psi} - (1 - \gamma)A > (1 - \gamma)Eu_N$.

If $\gamma \in (\underline{\gamma}^-, 1]$, then $Eu_U = (1 - \gamma)Eu_N + \frac{\gamma 2q\hat{\Psi} - (1 - \gamma)q(A + C)}{(2q - 1)} > (1 - \gamma)Eu_N$.

where $\hat{\Psi} = \Psi/(1 - h_R)$, $A = 2q(1 - q)u_{AS}(0) + (1 - 2q(1 - q))u_{AS}(2)/2 > 0$ and $C \equiv (1 - 2q(1 - q))(w_L - u_{AS}(0)) + q(1 - q)(w_L - u_{AS}(2))$.

Part 1 of Proposition 4 shows that the optimal allocation policy specifies allocations that are conditional on the occurrence and the outcome of price discovery in when-issued trading. If the trading takes place, then investors are “rewarded” with an allocation if their reports turn out to be consistent with information revealed through the trading. If the trading doesn’t take place, then investors are “rewarded” for reporting positive signals, like in the benchmark mechanism.

Part 2 of the proposition indicates that investors’ informational rents depend on the a priori probability with which when-issued trading takes place. Investors with positive private information generally receive higher informational rents than those with negative private information. If $\gamma \leq \underline{\gamma}^-$, then the latter investors receive zero rents, like in the benchmark mechanism.

Part 3 of Proposition 4 shows how the possibility of when-issued trading affects the expected underpricing of the issue, relative to the benchmark case. An unambiguous decrease in expected underpricing occurs only if it is sufficiently unlikely that the trading will actually take place, i.e., if $0 < \gamma \leq \underline{\gamma}^+$. In contrast, if $\gamma > \underline{\gamma}^-$, then the expected underpricing may exceed that in the benchmark case, for the following reasons: the polled investors will truthfully report their private information only if they are compensated for the expected trading profits thus lost, and if they are given incentives to abstain from free-riding on price discovery in when-issued trading. Since these “hurdles” increase in γ , so do the informational rents that the investors require to disclose their private information.

4.4 Optimal Constrained Mechanisms

We now consider the class of constrained mechanisms, inspired by the rules in Treasury auctions: investors commit to accept allocations when they submit their reports (bids), and the pricing and allocation rules are functions only of the polled investors’ reports. The constrained mechanism design problem shares features with the benchmark case and the unconstrained mechanism design problem. Like in the benchmark case, polled investors may receive overpriced allocations if they falsely report positive information. The similarities with the unconstrained mechanism design problem are due to the trading opportunities that the investors forego in the when-issued market if they truthfully disclose their private information.

Proposition 5 characterizes the optimal constrained pricing and allocation rules. The incentive compatibility constraints for this problem (presented in the proof of Proposition

5) are a cross between those for the unconstrained problem and the benchmark case. The participation constraints are the same as in the benchmark case.

Proposition 5. The optimal Constrained mechanism, $\gamma \in [0, 1]$.

If $\Psi \leq (3/8)(1 - h_R)w_L$,²⁷ then:

1. *Investors who report positive information receive the largest possible allocation. Investors who report negative information receive no allocation.*
2. *Positive expected underpricing is required, due to residual adverse selection risk and the possibility of trading profits. If expected trading profits are high enough, then the incentive compatibility (IC) constraint is binding for investors with positive information. The IC constraint is nonbinding for investors with negative information.*
3. *The expected underpricing is:*

$$Eu_C = Eu_N + \max[0, \gamma \hat{\Psi} - A]$$

where $\hat{\Psi} = \Psi/(1 - h_R)$ and $A = 2q(1 - q)u_{AS}(0) + (1 - 2q(1 - q))u_{AS}(2)/2 > 0$.

Comparing the optimal constrained (C) mechanism with the optimal unconstrained (U) mechanism reveals that the former mechanism type (C) avoids a problem that can make it costly to obtain truthful reports from the polled investors using an unconstrained mechanism, i.e. the investors' incentive to free-ride on price discovery in the when-issued market. With a constrained mechanism, the polled investors know that the pricing of the issue depends solely on their bids. For reasonable parameter values, it is therefore always incentive compatible for the investors to truthfully report negative private information about the value of the issue. Since the investors need not be rewarded for reporting negative signals, the optimal allocation rule is similar to that of a "standard" auction: investors who report higher valuations receive larger allocations. In addition, polled investors earn zero expected informational rents if they have negative information about the value of the issue.

The unconstrained mechanism type is, however, superior to the constrained type on another account: polled investors can be motivated to reveal their private information by giving them allocations if their reports turn out to be consistent with information revealed

²⁷As can be seen in the proof of the proposition, we impose this restriction so that we can focus on what we consider to be the most reasonable case, rather than presenting two different cases. To get an intuitive sense of the restriction: If a polled investor misreports *and* then receives the entire nonretail allocation *and* then is able to trade this entire allocation at the expected value that is determined by the investor's lie, then this polled investor will obtain a trading profit of $(1 - h_R)w_L$. This is the highest possible outcome. Any expected trading profit that is consistent with both our model and existing models of market microstructure will result in expected trading profits that are a fraction of $(1 - h_R)w_L$.

Mechanism type	Probability market opens	Expected underpricing
no direct mechanism	$\gamma \in [0, 1]$	$(1 - \gamma)u_{AS}(0)$
unconstrained (U)	$\gamma \in [0, \underline{\gamma}^+]$	$(1 - \gamma)Eu_N$
unconstrained (U)	$\gamma \in (\underline{\gamma}^+, \underline{\gamma}^-]$	$(1 - \gamma)Eu_N + \gamma\hat{\Psi} - (1 - \gamma)A$
unconstrained (U)	$\gamma \in (\underline{\gamma}^-, 1]$	$(1 - \gamma)Eu_N + \frac{\gamma 2q\hat{\Psi} - (1-\gamma)q(A+C)}{(2q-1)}$
constrained (C)	$\gamma \in [0, 1]$	$Eu_N + \max[0, \gamma\hat{\Psi} - A]$

Table 1: Expected Underpricing for three different specifications: no direct mechanism, an unconstrained direct mechanism, and a constrained direct mechanism

through when-issued trading. In the next section, we examine the trade-off between mechanism types more extensively and derive conditions that describe this trade-off.

4.5 The Optimal Mechanism

We now consider which type of mechanism is overall optimal by comparing the optimal constrained and the optimal unconstrained mechanisms. Table 1 presents a summary of the expected underpricing for the two types of mechanisms. Proposition 6 shows that the optimal choice of mechanism type depends on the probability γ with which when-issued trading takes place.

Proposition 6: The optimal direct mechanism.

1. If $\gamma \leq \underline{\gamma}^-$, then the optimal unconstrained direct mechanism, U , results in higher expected issue proceeds than the optimal constrained direct mechanism, C .
2. If $\gamma > \underline{\gamma}^-$, then there exist parameter values such that the optimal constrained direct mechanism, C , results in strictly higher expected issue proceeds than the optimal unconstrained direct mechanism, U . In the limit as $\gamma \rightarrow 1$, $w_L/4 < \hat{\Psi} \leq 3w_L/8$ is a sufficient condition such the optimal C -type mechanism results in strictly higher issue proceeds than the optimal U -type mechanism.

Proposition 6 tells us that if the probability of when-issued trading is low enough, $\gamma \leq \underline{\gamma}^-$, then the unconstrained mechanism is unambiguously optimal. That is, the issuer should employ a mechanism that allows information from the when-issued market to affect the issue price. If, however, $\gamma > \underline{\gamma}^-$, then the results are not as clear cut. In this case the optimal choice between the two mechanism types depends on the relative values of expected trading profits (Ψ), the expected cost to the issuer of pricing the issue without

any when-issued trading information (Eu_N), and the probability that informed investors have correct information (q). If, for example, γ is high and the expected trading profits are high, then the constrained mechanism type is optimal.

These results are consistent with observed phenomena. When-issued trading is permitted in both European IPOs and in Treasury issues, but the likelihood that such trading will actually take place is much higher for Treasury issues than for IPOs. Our results thus predict that IPO mechanisms should be unconstrained, consistent with evidence presented in Section 2 of this paper. To rationalize the use of constrained mechanisms in Treasury issues, we consider the case in which $\gamma > \gamma^-$. The latter condition is not in itself sufficient for the optimal mechanism to be of the constrained type. However, as is indicated in Proposition 6, a constrained mechanism is optimal if both γ and the expected trading profit, Ψ , that a polled investor can earn by misrepresenting her private information are sufficiently high. The latter requirement is consistent with evidence that bidders in Treasury auctions are monopolists, or near monopolists, with regard to their private information.²⁸ This evidence suggests that Ψ takes a high value in Treasury markets because we know from trading models that the more closely private information is held, the higher the expected trading profits from this information.²⁹ In addition, some primary dealers may have very valuable information regarding their own (individual) plans to engage in a “squeeze” which will affect the market price.

Our analysis also implies that if the Treasury were to change its policy and use an unconstrained mechanism, instead of a constrained mechanism, then the allocation policy that is currently used in Treasury auctions (bidders whose bids are above the clearing price receive allocations) may not be optimal. This is because the bidders would have incentives to “free-ride” on price discovery in the when-issued market. Rather than conditioning their bids on their private information, they would simply bid in a way that maximizes their expected allocations.

The focus of our work has been on the design of the optimal pricing mechanism, but our analysis also provides insight into the value of permitting when-issued trading. These results are summarized in the following corollary.

Corollary 1. *If $\gamma \leq \underline{\gamma}^+$, then the expected issue proceeds are higher than in the absence*

²⁸Hortaçsu and Sareen (2005) provide evidence that bidders in government treasury auctions have private information regarding demand that has been submitted only to the individual bidder.

²⁹Compare, for example, Kyle (1985) and Holden and Subrahmanyam (1992).

of when-issued trading. If $\gamma > \underline{\gamma}^+$, then the expected issue proceeds may be lower than in the absence of when-issued trading.

Corollary 1 and Proposition 6 present some results that seem rather counterintuitive. Allowing when-issued trading is most clearly beneficial to the issuer when there is a sufficiently low probability ($\gamma \leq \underline{\gamma}^+$) that such trading will actually take place. And, if the probability of when-issued trading is higher than this, then even though the trading, if it opens, will generate information about the value of the issue, it may be optimal for the issuer to precommit to ignore such information when setting the issue price, i.e., to specify a constrained mechanism.

We have up to this point ignored the possibility that the opening of when-issued trading may depend on the mechanism itself. A natural extension of our analysis is suggested by an institutional regularity in European IPO markets. In these markets, when-issued trading never starts before the issuer releases a preliminary offering prospectus that includes a price range. It is our understanding that this price range is based on information that the underwriters obtain in the course of discussions with regular investors. Thus, it appears that these investors report information that then allows when-issued trading to open. This idea certainly makes sense if traders in the when-issued market fear losing from trading with insiders, and the insiders' informational advantage is reduced once the price range is published.³⁰ It is, however, at odds with an assumption in our analysis up to this point: that when-issued trading takes place with an exogenous probability. This assumption is relaxed in the next section.

5 Endogenous When-Issued Trading

In this section we assume that the probability of when-issued trading is endogenous and depends on the outcome of the mechanism. We assume that trading will take place if and only if the mechanism is informative, i.e., if and only if $z \in \{2, -2\}$, where z is the sum of the polled investors' reports. If the polled investors submit conflicting reports, then the mechanism is uninformative ($z = 0$) and when-issued trading will not take place. As long as both polled investors truthfully report, then the probability that when-issued trading takes place is $1 - 2q(1 - q)$ which is greater than $1/2$. If one polled investor lies, then this

³⁰In an earlier version of this paper we included a simple market microstructure model that was based on that of Glosten and Milgrom (1985) and that illustrated this point. We have removed this model as it is not central to the mechanism design problem.

probability is $2q(1 - q)$ which is less than $1/2$. Thus, misreporting lowers the probability that when-issued trading will take place.³¹

Proposition 7. *If the opening of when-issued trading depends on information obtained in the mechanism, then*

1. *In the unconstrained mechanism, U , IC^- is nonbinding; IC^+ may be binding.*
2. *The optimal mechanism is the optimal unconstrained direct mechanism.*

Proposition 7 indicates that the optimal mechanism design and the expected proceeds in the case with an endogenous probability of market opening are qualitatively the same as in the case where $\gamma \leq \underline{\gamma}^-$: the constrained mechanism is not optimal. As discussed above, the constrained mechanism involves a commitment on the part of the issuer to ignore when-issued trading as a source of information when pricing the issue. Such a commitment discourages investors from free-riding on information discovery in when-issued trading. If, however, the opening of when-issued trading depends on the investors' reports, then free-riding is no longer a concern. Lying to take advantage of informed trading opportunities is self-defeating, because doing so lessens the probability that such opportunities will be available, and may also increase the likelihood of being awarded an overpriced allocation. As a result, the cost to the issuer of inducing truth-telling is low enough that the unconstrained pricing mechanism is optimal for all parameter values. That is, it is optimal for the issuer to incorporate information both from the direct mechanism and from when-issued trading when pricing the securities.

These results are consistent with what we observe in European IPOs: unconstrained mechanisms are employed and information from the mechanisms seems to be necessary for when-issued trading to open. It is only in the case such that when-issued trading is very likely to open, regardless of the polled investors' reports, that a constrained mechanism may be optimal.

³¹We also considered relaxing the assumption that only two investors are polled in the mechanism. With only two polled investors, our model exaggerates the impact that each has on the informativeness of the mechanism, and, thus, on the probability of when-issued trading. However, the model also exaggerates the impact (and thus personal benefit) that each can have by misreporting. Since these two effects are counteracting, it does not seem that a model with more than two polled investors would yield results that are qualitatively different from those in Proposition 7.

6 Conclusion

We analyze mechanisms for pricing unseasoned securities. Rather than examine the mechanism design problem within a vacuum, we place this problem in a setting in which price discovery may occur in when-issued trading. We thus extend the mechanism design problem in order to allow for pricing and allocation rules based on both information contained in investors' bids, and information revealed through when-issued trading.

Our results provide an explanation of why pricing mechanisms for new issues of Treasury securities differ in a key qualitative aspect from mechanisms for pricing unseasoned corporate equity securities. Treasury auctions are designed so that the issue price depends only on the bids that are submitted in the auction, and not on information from outside sources, such as post-auction when-issued trading. In contrast, the most commonly used method for issuing equity securities, bookbuilding, allows the pricing of such issues to depend both on participants' indications of interest and on information revealed through when-issued trading.

We show that the key explanatory variable for this difference in primary market design is the likelihood that when-issued trading will actually take place. In Treasury markets it is virtually certain that when-issued trading will occur after the close of bidding in the auction. In equity markets such trading sometimes fails to open, and empirical evidence suggests that the reasons are common causes of market failure, such as a lack of publicly available information about the value of equity issues.

Our analysis reveals general advantages and disadvantages of allowing the pricing of a securities issue to depend on when-issued market prices. We show that, if polled investors (those who are invited to submit bids or report indications of interest) are almost certain that when-issued trading will take place, then these investors have incentives to "free-ride" on the price discovery that occurs during the trading and to conceal their private information about the value of an issue. To avoid such free-riding, it may be optimal to price a securities issue based just on the information contained in the investors' reports. This result provides a rationale for pricing U.S. Treasury issues solely on the basis of the auction bids. If, however, the likelihood of when-issued trading is relatively low, then there is no need to discourage free-riding. As a consequence, it is optimal to allow the trading to affect the primary market pricing and allocation of issues. In the latter case, the optimal mechanism incorporates two sources of information: information that investors report

within the mechanism and information revealed through when-issued trading. This result is consistent with evidence that both types of information indeed determine the pricing of European IPOs.

While our analysis has been inspired by existing institutions, such as those for pricing unseasoned Treasury and equity securities, we expect that our results are more generally applicable. For example, there has recently been much discussion about the pricing of financial assets under the TARP program. Suggestions for pricing mechanisms have included auctions or reverse auctions (in which participants submit offers to sell), i.e., “constrained” mechanisms for pricing securities based solely on information contained in the participants’ reports. Our analysis suggests that the optimality of such a policy depends on the liquidity of the financial markets that may contribute to price discovery.

Appendix

Random variables:

\tilde{V} = secondary market value $\in \{v_0 + w, v_0 - w\}$

$\tilde{s} \equiv \frac{\tilde{V} - v_0}{w} \in \{-1, 1\}$

$\tilde{\varsigma}_i$ = informed trader i 's signal of \tilde{s} .

Exogenous parameters: (The exogenous parameters are all common knowledge)

v_0 = prior expected value of \tilde{V}

π_0 = prior probability that $s = 1$

w = constant (See above for \tilde{V})

q = probability that $\varsigma_i = s$, i.e., that an informed investor has correct information,
 $1/2 < q < 1$

α = fraction of investors who are informed. $0 < \alpha < 1/2$

γ = probability that when-issued trading opens

h_R = minimum fraction of the offering that must be allocated to retail investors

Other variables:

N : used as a subscript to indicate No when-issued trading

T : used as a subscript to indicate when-issued Trading takes place and trading information is incorporated into price and allocations

δ = zero if mechanism precludes when-issued trading information from price and allocations; one, otherwise

p_I = issue price

π_p = probability that $s = 1$, given all info known by issuer at time of setting price

z = sum of signals reported by polled investors

$\pi(z)$ = probability that $s = 1$, given z

$u_{AS}(z)$ = expected underpricing due to residual adverse selection risk

w_L = impact of a lie on the expected value of the security

u^{ab} = underpricing, given one polled investor reports a and one reports b

h^{ab} = fraction allocated to polled investor who reports a when other reports b

u_x^{ab} = underpricing, given the polled investors reports ab and the market reveals x

h_x^{ab} = allocation to investor who reports a when other reports b & the market reveals x

Ψ = expected trading profit for polled investor who misreports $\leq (3/8)(1 - h_R)w_L$

$\hat{\Psi} = \Psi / (1 - h_R)$

Table 2: Notation

Underpricing due to adverse selection risk.

$$E[\tilde{V} | \pi_p] = v_0 + (2\pi_p - 1)w \tag{16}$$

Informed investor i has observed a signal of \tilde{s} : $\tilde{\varsigma}_i \in \{-1, 1\}$.

$$prob\{s = 1 | \pi_p, \varsigma_i = 1\} = \frac{q\pi_p}{q\pi_p + (1-q)(1-\pi_p)} > \pi_p,$$

$$prob\{s = 1 | \pi_p, \varsigma_i = -1\} = \frac{(1-q)\pi_p}{(1-q)\pi_p + q(1-\pi_p)} < \pi_p.$$

Given these probabilities, an informed investor values the issue as follows:

$$E[\tilde{V} | \pi_p, \varsigma_i = 1] = v_0 + \frac{q\pi_p - (1-q)(1-\pi_p)}{q\pi_p + (1-q)(1-\pi_p)} w > E[\tilde{V} | \pi_p] \quad (17)$$

$$E[\tilde{V} | \pi_p, \varsigma_i = -1] = v_0 + \frac{(1-q)\pi_p - q(1-\pi_p)}{(1-q)\pi_p + q(1-\pi_p)} w < E[\tilde{V} | \pi_p] \quad (18)$$

Investors arrive randomly in the retail market. Allocations are given on a first-come first-served basis until the issue is sold. An investor who “participates in the offering” joins the queue for an allocation. If $s = 1$, then on average a fraction q of the informed investors will participate; if $s = -1$, then on average a fraction $1 - q$ will participate. Table 2 presents the expected value and the expected relative allocations to each group of investors (informed and uninformed), for each realization of \tilde{s} . The table is written assuming that $p_I > E[\tilde{V} | \pi_p, \varsigma_i = -1]$, so that investors who have observed negative signals do not participate; this is checked below.³² Because $q > 1/2$, the uninformed will on average receive more securities if the value of these securities is low ($s = -1$).

Realization of \tilde{s}	$s = -1$	$s = 1$
Probability of this realization	$1 - \pi_p$	π_p
Expected secondary market value \tilde{V}	$v_0 - w$	$v_0 + w$
Allocation to informed investors	$\frac{(1-q)\alpha}{1-q\alpha}$	$\frac{q\alpha}{1-(1-q)\alpha}$
Allocation to uninformed investors	$\frac{1-\alpha}{1-q\alpha}$	$\frac{1-\alpha}{1-(1-q)\alpha}$

Table 2: Expected Value and Allocations

Uninformed investors will participate in the offering only if their expected return is nonnegative. When underpricing is minimized, this expected return is zero:

$$0 = (1 - \pi_p)(v_0 - w - p_I) \frac{1 - \alpha}{1 - q\alpha} + \pi_p(v_0 + w - p_I) \frac{1 - \alpha}{1 - (1 - q)\alpha}, \quad (19)$$

Solving equation (19) for p_I yields:

$$p_I = v_0 + \left(\frac{2\pi_p - 1 - (\pi_p + q - 1)\alpha}{1 - ((2\pi_p - 1)q + 1 - \pi_p)\alpha} \right) w. \quad (20)$$

³²The number of investors who reveal their information through a mechanism is small relative to the total number of informed investors. Thus, the fraction of informed investors is not affected by information gathering.

The above expression is $> E[\tilde{V}|\pi_p, \varsigma_i = -1]$, so those who have observed negative signals do not participate. The expected underpricing due to adverse selection risk is:

$$u_{AS}(\pi_p) = E[\tilde{V}|\pi_p] - p_I = \frac{q - 2\pi_p(1 - \pi_p) - (2\pi_p - 1)^2q}{1 - ((2\pi_p - 1)q + 1 - \pi_p)\alpha} \alpha w. \quad (21)$$

Define the following variable:

$$\begin{aligned} \bar{u}_{AS} &\equiv \frac{u_{AS}(\pi)}{w\alpha} = \frac{q - 2\pi(1 - \pi) - (2\pi - 1)^2q}{1 - ((2\pi - 1)q + 1 - \pi)\alpha} \\ \frac{\partial \bar{u}_{AS}}{\partial \pi} &= \\ (2q - 1) &\left(\frac{2(1 - 2\pi)(1 - (1 - q)\alpha - (2q - 1)\pi\alpha) + \alpha(q - 2\pi(1 - \pi) - (2\pi - 1)^2q)}{(1 - ((2\pi - 1)q + 1 - \pi)\alpha)^2} \right) \\ &= (2q - 1) \left(\frac{2(1 - 2\pi) - 2(1 - \pi)^2\alpha + (1 - 2\pi)^2q\alpha + q\alpha}{(1 - ((2\pi - 1)q + 1 - \pi)\alpha)^2} \right) \end{aligned} \quad (22)$$

The denominator of (22) is strictly positive. The numerator is strictly decreasing in π and strictly positive if $\pi = 1/2$. Thus, (22) is strictly positive $\forall \pi \leq 1/2 \implies$

a) For all $\pi_p \leq 1/2$, u_{AS} is strictly increasing in π_p .

The numerator of (22) is strictly negative if $\pi = (1 - \alpha)/2 + \alpha q$. (This result can be obtained by setting $q = 1/2 + \varepsilon$, where $0 < \varepsilon < 1/2$.) Thus, (22) is negative $\forall \pi \geq (1 - \alpha)/2 + \alpha q$. In addition,

$$\bar{u}_{AS} \Big|_{z=0} = \frac{2q - 1}{2 - \alpha} > \bar{u}_{AS} \Big|_{z=1} = \frac{(2q - 1)2q(1 - q)}{1 - ((2q - 1)q + 1 - q)\alpha} \implies$$

b) for all $\pi_p \geq q$, u_{AS} is strictly decreasing in π_p , and $u_{AS}(\pi_p) < u_{AS}(\pi_0)$.

Points a) and b) together imply that, if the issue is priced after obtaining information that is at least as good as that of one informed investor, then underpricing due to adverse selection risk will be lower than without the information. And, as more information is learned, underpricing due to adverse selection risk decreases.

Derivation of $\pi(z)$: We know that

$$\pi(0) = 1/2, \quad \pi(1) = q, \quad \text{and} \quad \pi(-1) = 1 - q = 1 - \pi(1).$$

We can define $\pi(z)$ as a function of all signals obtained, except i 's signal, together with i 's signal ς_i . For $z \geq 1$, we let $\varsigma_i = 1$:

$$\begin{aligned} \pi(z) &= \frac{\text{prob}\{\varsigma_i = 1|s = 1\}\pi(z - 1)}{\text{prob}\{\varsigma_i = 1|s = 1\}\pi(z - 1) + \text{prob}\{\varsigma_i = 1|s = -1\}(1 - \pi(z - 1))} \\ &= \frac{q\pi(z - 1)}{q\pi(z - 1) + (1 - q)(1 - \pi(z - 1))} \end{aligned} \quad (23)$$

For $z \leq -1$, we let $\varsigma_i = -1$:

$$\begin{aligned}\pi(z) &= \frac{\text{prob}\{\varsigma_i = -1|s = 1\}\pi(z+1)}{\text{prob}\{\varsigma_i = -1|s = 1\}\pi(z+1) + \text{prob}\{\varsigma_i = -1|s = -1\}(1 - \pi(z+1))} \\ &= \frac{(1-q)\pi(z+1)}{(1-q)\pi(z+1) + q(1 - \pi(z+1))}\end{aligned}\quad (24)$$

Using these equations and the above values for $\pi(1)$ and $\pi(-1)$, we obtain equation (3).

Underpricing due to residual adverse selection risk. From equations (2) and (3):

$$\frac{u_{AS}(0)}{w\alpha} = \frac{2q-1}{2-\alpha} \quad (25)$$

$$\begin{aligned}\frac{u_{AS}(2)}{w\alpha} &= \frac{q - \frac{2q^2(1-q)^2}{(q^2+(1-q)^2)^2} - \left(\frac{2q-1}{q^2+(1-q)^2}\right)^2 q}{1 - \left(\frac{2q-1}{q^2+(1-q)^2}\right) q\alpha - \left(\frac{(1-q)^2}{q^2+(1-q)^2}\right) \alpha} \\ &= \frac{(2q-1)2q^2(1-q)^2}{(q^2+(1-q)^2)(q^2+(1-q)^2 - \alpha(1-3q(1-q)))}\end{aligned}\quad (26)$$

$$\begin{aligned}\frac{u_{AS}(-2)}{w\alpha} &= \frac{q - \frac{2q^2(1-q)^2}{(q^2+(1-q)^2)^2} - \left(\frac{2q-1}{q^2+(1-q)^2}\right)^2 q}{1 + \left(\frac{2q-1}{q^2+(1-q)^2}\right) q\alpha - \left(\frac{q^2}{q^2+(1-q)^2}\right) \alpha} \\ &= \frac{(2q-1)2q^2(1-q)^2}{(q^2+(1-q)^2)(q^2+(1-q)^2 - \alpha q(1-q))}\end{aligned}\quad (27)$$

$$q > 1/2 \implies 1 - 3q(1-q) > q(1-q) \implies u_{AS}(2) > u_{AS}(-2).$$

$u_{AS}(0)$ is strictly increasing in q . When q is close to $1/2$, $\partial u_{AS}(2)/\partial q$ and $\partial u_{AS}(-2)/\partial q$ are positive; when q is close to one, $\partial u_{AS}(2)/\partial q$ and $\partial u_{AS}(-2)/\partial q$ are negative.

From equations (25) and (5):

$$u_{AS}(0) = \left(\frac{\alpha}{2-\alpha}\right) (1 - 2q(1-q))w_L < \frac{w_L}{3}. \quad (28)$$

Proof of Proposition 1. The benchmark mechanism. Rearranging the incentive compatibility constraints, (IC_N^+) and (IC_N^-) :

$$\begin{aligned}(1 - 2q(1-q)) (u^{++}h^{++} - (w_L + u^{+-})h^{-+}) + \\ 2q(1-q) (u^{+-}h^{+-} - (w_L + u^{--})h^{--}) \geq 0\end{aligned}\quad (29)$$

$$\begin{aligned}(1 - 2q(1-q)) (u^{--}h^{--} + (w_L - u^{+-})h^{+-}) + \\ 2q(1-q) (u^{+-}h^{-+} + (w_L - u^{++})h^{++}) \geq 0\end{aligned}\quad (30)$$

It is optimal to set $h^{+-} = 2h^{++} = 1 - h_R$, $h^{-+} = 0$, and $h^{--} = 0$.

$(PC_N - R)$ is binding and the IC constraints are nonbinding for all values of z . Thus:

$u^{--} = u_{AS}(-2)$, $u^{+-} = u_{AS}(0)$ and $u^{++} = u_{AS}(2)$, and the expected underpricing is thus given by equation (11). \blacksquare

Proof of Proposition 2. Because $q > 1 - q$, it is optimal to set $u^{ab}h_w^{ab} = 0 \forall$ pairs of (a, b) . The *IC* constraints can thus be written:

$$q(qu_c^{++}h_c^{++} + (1-q)u_+^{+-}h_c^{+-}) - (1-q)((1-q)u_-^{+-}h_c^{+-} + qu_c^{--}h_c^{--}) \geq \Psi \quad (31)$$

$$q(qu_c^{--}h_c^{--} + (1-q)u_-^{+-}h_c^{+-}) - (1-q)((1-q)u_+^{+-}h_c^{+-} + qu_c^{++}h_c^{++}) \geq \Psi \quad (32)$$

Because $\Psi > 0$ and residual adverse selection risk is zero, the above are strictly binding:

$$qu_c^{++}h_c^{++} + (1-q)u_+^{+-}h_c^{+-} = qu_c^{--}h_c^{--} + (1-q)u_-^{+-}h_c^{+-} = \Psi/(2q-1). \quad (33)$$

Equation (33) gives the expected rents for an investor who truthfully reports and turns out to be correct. Thus, the a priori expected rents for an investor who truthfully reports are as follows, regardless of whether the information is positive or negative:

$$Er_{U1}^+ = Er_{U1}^- = q\Psi/(2q-1). \quad (34)$$

In the optimal mechanism $h_c^{++} = h_c^{--} = (1-h_R)/2$ and $h_c^{+-} = h_c^{-+} = 1-h_R$. Combining this allocation rule with equation (33) and the result that $u_w^{ab} = 0$, we can calculate the expected underpricing:

$$Eu_{U1} = \frac{q^2}{2}(u_c^{++} + u_c^{--}) + q(1-q)(u_+^{+-} + u_-^{+-}) = \frac{2q\hat{\Psi}}{(2q-1)} \quad (35)$$

where $\hat{\Psi} = \Psi/(1-h_R)$. \blacksquare

Proof of Proposition 3. $\gamma \in [0, 1]$, $R = U$, and mechanism is IC.

Each constraint IC_U^a , $a \in \{+, -\}$, is the weighted average of the constraints (IC_N^a) and (IC_{U1}^a) . More specifically, the LHS of (IC_U^+) is given by: $Er_U^+ = (1-\gamma)Er_N^+ + \gamma Er_{U1}^+$ and the RHS is $(1-\gamma)$ times the RHS of (IC_N^+) plus γ times the RHS of (IC_{U1}^+) . The LHS of (IC_U^-) is given by: $Er_U^- = (1-\gamma)Er_N^- + \gamma Er_{U1}^-$ and the RHS is $(1-\gamma)$ times the RHS of (IC_N^-) plus γ times the RHS of (IC_{U1}^-) .

We first solve the mechanism design problem as far as we can for a general value of γ .

We then show the existence of and determine the values of $\underline{\gamma}^+$ and $\underline{\gamma}^-$.

As in Proposition 2, the issuer will optimally set $u^{ab}h_w^{ab} = 0 \forall$ pairs of (a, b) . We can thus write the *IC* constraints by combining equations (29) and (31) to obtain equation

(IC_U^+) , and combining equations (30) and (32) to obtain equation (IC_U^-) :

$$\begin{aligned} \gamma q^2 u_c^{++} h_c^{++} - \gamma(1-q)^2 u_c^{+-} h_c^{+-} + \gamma q(1-q) (u_+^{+-} h_c^{+-} - u_c^{--} h_c^{--}) + \\ (1-\gamma)(1-2q(1-q)) (u^{++} h^{++} - (w_L + u^{+-}) h^{-+}) + \\ 2(1-\gamma)q(1-q) (u^{+-} h^{+-} - (w_L + u^{--}) h^{--}) \geq \gamma \Psi \quad (IC_U^+) \end{aligned}$$

$$\begin{aligned} \gamma q^2 u_c^{--} h_c^{--} - \gamma(1-q)^2 u_+^{+-} h_c^{+-} + \gamma q(1-q) (u_-^{+-} h_c^{+-} - u_c^{++} h_c^{++}) + \\ (1-\gamma)(1-2q(1-q)) (u^{--} h^{--} - (u^{+-} - w_L) h^{+-}) + \\ 2(1-\gamma)q(1-q) (u^{+-} h^{+-} - (u^{++} - w_L) h^{++}) \geq \gamma \Psi \quad (IC_U^-) \end{aligned}$$

The participation constraints require that:

$$u_c^{aa}, u_w^{aa}, u_+^{+-}, u_-^{+-} \geq 0, \quad u^{++} \geq u_{AS}(2), \quad u^{--} \geq u_{AS}(-2), \quad u^{+-} \geq u_{AS}(0) \quad (36)$$

(In pricing regime U participation must be ex post rational. I.e., investors observe all of the available information and the offer price, then they decide whether to invest.)

The allocation constraints are the same as in the earlier problems. The objective is to minimize the expected value of underpricing. The optimal value of $u_w^{aa}, a \in \{+, -\}$ is 0, so the expected underpricing is:

$$\begin{aligned} \gamma \left(q^2 (u_c^{++} + u_c^{--}) / 2 + q(1-q) (u_+^{+-} + u_-^{+-}) \right) + \\ (1-\gamma) \left((1-2q(1-q)) (u^{++} + u^{--}) / 2 + 2q(1-q) u^{+-} \right) \quad (37) \end{aligned}$$

With the problem written as above we can state the following: i) It is optimal to give the largest possible allocations to investors whose reports are confirmed if the market opens, and to those who report + if the market doesn't open: $2h_c^{++} = 2h_c^{--} = h_c^{+-} = h_c^{-+} = 2h^{++} = h^{+-} = (1-h_R)$. And, to award the smallest possible allocation to those who report - if the market doesn't open: $h^{-+} = h^{--} = 0$. ii) It's clearly optimal to set u^{--} to its lowest feasible value: $u^{--} = u_{AS}(-2)$.

At this point we define: $U^+ \equiv qu_c^{++}/2 + (1-q)u_+^{+-}$ and $U^- \equiv qu_c^{--}/2 + (1-q)u_-^{+-}$. ($qU^a(1-h_R)$ is the expected rent received by a polled investor who observes and reports a , if $\gamma = 1$.) We can now write the problem as follows:

Choose $u_c^{++}, u_c^{--}, u_+^{+-}, u_-^{+-}, u^{++}$ and u^{+-} to:

$$\begin{aligned} \min Eu_U = \gamma q (U^+ + U^-) + \\ (1-\gamma) (Eu_N + (1-2q(1-q))(u^{++} - u_{AS}(2))/2 + 2q(1-q)(u^{+-} - u_{AS}(0))) \quad (38) \end{aligned}$$

subject to:

$$u_c^{++}, u_c^{--}, u_+^{+-}, u_-^{+-} \geq 0, \quad u^{++} \geq u_{AS}(2), \quad u^{+-} \geq u_{AS}(0) \quad (39)$$

$$\begin{aligned} &\gamma(qU^+ - (1-q)U^-) + \\ &\quad (1-\gamma)\left((1-2q(1-q))u^{++}/2 + 2q(1-q)u^{+-}\right) \geq \gamma\hat{\Psi} \end{aligned} \quad (40)$$

$$\begin{aligned} &\gamma(qU^- - (1-q)U^+) + \\ &\quad (1-\gamma)\left((1-2q(1-q))(w_L - u^{+-}) + q(1-q)(w_L - u^{++})\right) \geq \gamma\hat{\Psi} \end{aligned} \quad (41)$$

where $\hat{\Psi} = \Psi/(1-h_R)$. Equation (39) is $(PC-R)$, (40) is (IC_U^+) and (41) is (IC_U^-) . We know from Propositions 1 and 2 that if $\gamma = 0$, both (40) and (41) are nonbinding; and if $\gamma = 1$, both are binding. But, because $w_L - u_{AS}(0) > 2u_{AS}(0) > 2u_{AS}(2)$ and $1 - 2q(1-q) > 2q(1-q)$, (40) binds at a lower value of γ , than does (41).

Suppose that both (40) and (41) ((IC_U^+) and (IC_U^-)) are nonbinding. Then, all of the constraints in (39) are binding: $u^{++} = u_{AS}(2)$, $u^{+-} = u_{AS}(0)$, $u_c^{++} = u_+^{+-} = u_c^{--} = u_-^{+-} = 0$, and $U^+ = U^- = 0$. Putting these values into (40) we see that (IC_U^+) is satisfied with equality, but not strictly binding, when:

$$\begin{aligned} (1 - \underline{\gamma}^+)Eu_N &= \underline{\gamma}^+\hat{\Psi} + (1 - \underline{\gamma}^+)(1 - 2q(1 - q))u_{AS}(-2)/2 \implies \\ \underline{\gamma}^+ &= \frac{A}{\hat{\Psi} + A} \end{aligned} \quad (42)$$

where $A \equiv Eu_N - (1 - 2q(1 - q))u_{AS}(-2)/2$.

If $\gamma \leq \underline{\gamma}^+$, then (IC_U^+) is nonbinding; if $\gamma > \underline{\gamma}^+$, then (IC_U^+) is strictly binding.

As stated above, if $\gamma \leq \underline{\gamma}^+$, then (41) is nonbinding.

Suppose now that (40) is binding and (41) is satisfied with equality, but not strictly binding. Then $U^- = 0$ and (40) and (41) can be written:

$$\gamma qU^+ + (1-\gamma)\left((1-2q(1-q))u^{++}/2 + 2q(1-q)u^{+-}\right) = \gamma\hat{\Psi} \quad (43)$$

$$\begin{aligned} &-\gamma(1-q)U^+ + \\ &\quad (1-\gamma)\left((1-q(1-q))w_L - (1-2q(1-q))u^{+-} - q(1-q)u^{++}\right) = \gamma\hat{\Psi} \end{aligned} \quad (44)$$

To satisfy (43) the issuer must set U^+ , u^{++} and/or u^{+-} strictly above what is required by (39), the participation constraint.

As long as γ is low enough so that (41) is strictly nonbinding, then in the optimal mechanism these parameters can be set to any values that satisfy equations (43) and (39).

(Note that the coefficients for these parameters in the objective function (38) are identical to those in (43).) However, when we take into account constraint (41), then it becomes optimal to set u^{++} and u^{+-} to their lowest feasible values, so that all rents are paid by setting a higher value of U^+ . (This is simply because $q > 1/2$, so that $q/(1-q) > (1-2q(1-q))/(2q(1-q)) > (2q(1-q))/(1-2q(1-q))$.)

The constraints (43) and (44) are now written as:

$$\underline{\gamma}^- qU^+ = \underline{\gamma}^- \hat{\Psi} - (1 - \underline{\gamma}^-)A \quad (45)$$

$$-\underline{\gamma}^-(1-q)U^+ = \underline{\gamma}^- \hat{\Psi} - (1 - \underline{\gamma}^-)C \quad (46)$$

where $C \equiv (1 - 2q(1 - q))(w_L - u_{AS}(0)) + q(1 - q)(w_L - u_{AS}(2))$.

Subtracting (46) from (45):

$$\underline{\gamma}^- U^+ = (1 - \underline{\gamma}^-) (C - A) \quad (47)$$

Putting (47) into (46) and solving for $\underline{\gamma}^-$:

$$\underline{\gamma}^- = \frac{qC + (1 - q)A}{\hat{\Psi} + qC + (1 - q)A} = \frac{B}{\hat{\Psi} + B} \quad (48)$$

where $B \equiv qC + (1 - q)A = q(1 - q(1 - q))w_L - (2q - 1)(qu_{AS}(0) + (1 - q)u_{AS}(2)/2)$.

If $\gamma \leq \underline{\gamma}^-$, then (IC_U^-) is nonbinding; if $\gamma > \underline{\gamma}^-$, then (IC_U^-) is binding. We know that $C > A$. (Actually $C > 2A$.) Thus, $\underline{\gamma}^- > \underline{\gamma}^+$. ■

Proof of Proposition 4. The proof for part 1 is given above in the proof of Proposition 3. The proof for part 2 follows directly from Proposition 1 and the proof of Proposition 3: Conditioned on the market not opening, those with positive signals expect positive informational rents and those with negative signals expect zero rents. qU^+ and qU^- are the respective rents expected by these investors, conditioned on the market opening. We've already shown that $U^+ = 0$ (> 0) if $\gamma \leq \underline{\gamma}^+$ ($\gamma > \underline{\gamma}^+$), and $U^- = 0$ if $\gamma \leq \underline{\gamma}^-$.

If $\gamma > \underline{\gamma}^-$, then we can replace (45) and (46) with

$$\gamma(qU^+ - (1 - q)U^-) = \gamma\hat{\Psi} - (1 - \gamma)A \quad (49)$$

$$\gamma(qU^- - (1 - q)U^+) = \gamma\hat{\Psi} - (1 - \gamma)C \quad (50)$$

Solving the above:

$$U^+ = \frac{\hat{\Psi}}{(2q - 1)} - \frac{(1 - \gamma)(qA + (1 - q)C)}{\gamma(2q - 1)} \quad (51)$$

$$U^- = \frac{\hat{\Psi}}{(2q - 1)} - \frac{(1 - \gamma)(qC + (1 - q)A)}{\gamma(2q - 1)} \quad (52)$$

Because $C > A$ and $q > 1 - q$, $U^+ > U^-$.

The proof for part 3 also follows from the proof of Proposition 3:

If $\gamma \in [0, \underline{\gamma}^+]$, then neither IC constraint is binding and $(PC - R)$ is binding. Thus, $Eu_U(\gamma \leq \underline{\gamma}^+) = (1 - \gamma)Eu_N$.

If $\gamma \in (\underline{\gamma}^+, \underline{\gamma}^-]$, then (40) is binding, but (41) is not, and expected underpricing is given by inserting (43) into (38):

$$Eu_U = \gamma \hat{\Psi} + (1 - \gamma)(1 - 2q(1 - q))u_{AS}(-2)/2 = (1 - \gamma)Eu_N + \gamma \hat{\Psi} - (1 - \gamma)A.$$

(Note: If $\gamma = \underline{\gamma}^+$, then $\gamma \hat{\Psi} = (1 - \gamma)A$; if $\gamma > \underline{\gamma}^+$, then $\gamma \hat{\Psi} > (1 - \gamma)A$.)

If $\gamma \in (\underline{\gamma}^-, 1]$, then both (40) and (41) are binding. Expected underpricing is determined by setting $u^{++} = u_{AS}(2)$ and $u^{+-} = u_{AS}(0)$, and by inserting (51) and (52) into (38):

$$\begin{aligned} Eu_U &= (1 - \gamma)Eu_N + \gamma q(U^+ + U^-) \\ &= (1 - \gamma)Eu_N + \frac{\gamma 2q \hat{\Psi}}{(2q - 1)} - \frac{(1 - \gamma)q(A + C)}{(2q - 1)}. \end{aligned} \quad (53)$$

From the proof of Proposition 3 we know that if $\gamma > \underline{\gamma}^-$, then $\gamma \hat{\Psi} > (1 - \gamma)(qC + (1 - q)A)$. It follows (because $C > A$ and $q > 1 - q$) that if $\gamma > \underline{\gamma}^-$, then $\gamma \hat{\Psi} > (1 - \gamma)((1 - q)C + qA)$. Thus, if $\gamma > \underline{\gamma}^-$, then $\gamma 2q \hat{\Psi} > (1 - \gamma)q(A + C)$. \blacksquare

Proof of Proposition 5. The IC constraints are the same as in the benchmark case, (29) and (30), except that an investor who lies expects to make trading profits if the market opens:

$$\begin{aligned} (1 - 2q(1 - q)) (u^{++}h^{++} - (w_L + u^{+-})h^{-+}) + \\ 2q(1 - q) (u^{+-}h^{+-} - (w_L + u^{--})h^{--}) \geq \gamma \Psi \end{aligned} \quad (54)$$

$$\begin{aligned} (1 - 2q(1 - q)) (u^{--}h^{--} + (w_L - u^{+-})h^{+-}) + \\ 2q(1 - q) (u^{+-}h^{-+} + (w_L - u^{++})h^{++}) \geq \gamma \Psi \end{aligned} \quad (55)$$

Because of the factor w_L , it is optimal to set $h^{-+} = 0$ and $2h^{++} = h^{+-} = (1 - h_R)$. It is also optimal to set $u^{+-} = u_{AS}(0)$. The above constraints can thus be written:

$$(1 - 2q(1 - q)) \frac{u^{++}}{2} + 2q(1 - q) \left(u_{AS}(0) - \frac{(w_L + u^{--})h^{--}}{(1 - h_R)} \right) \geq \gamma \hat{\Psi} \quad (56)$$

$$(1 - 2q(1 - q)) \left(\frac{u^{--}h^{--}}{(1 - h_R)} + w_L - u_{AS}(0) \right) + q(1 - q)(w_L - u^{++}) \geq \gamma \hat{\Psi} \quad (57)$$

where $\hat{\Psi} = \Psi/(1 - h_R)$. It is clear that (56) will bind before (57). We start by assuming that (57), (IC^-) , is nonbinding. (We check this at the end of the proof.) It is thus optimal

to set $h^{--} = 0$ and $u^{--} = u_{AS}(-2)$. If (56) is nonbinding, then expected underpricing is Eu_N , the same as in the benchmark case. If (56) is binding, then

$$u^{++} = \frac{2}{1 - 2q(1 - q)} \left(\gamma \hat{\Psi} - 2q(1 - q)u_{AS}(0) \right). \quad (58)$$

The expected underpricing is thus:

$$Eu_C = \max \left[Eu_N, \gamma \hat{\Psi} + (1 - 2q(1 - q)) u_{AS}(-2)/2 \right] \quad (59)$$

$$= Eu_N + \max \left[0, \gamma \hat{\Psi} - A \right] \quad (60)$$

where A is defined in Proposition 3.

As a final step we check that (57) is nonbinding. Inserting (58) into (57):

$$\gamma \hat{\Psi} \leq (1 - 2q(1 - q))(1 - q(1 - q))w_L - (1 - 4q(1 - q))u_{AS}(0) \quad (61)$$

Noting that $u_{AS}(0) = (1 - 2q(1 - q)) \left(\frac{\alpha}{2 - \alpha} \right) w_L$, (61) can be written:

$$\frac{\gamma \hat{\Psi}}{w_L} \leq (1 - 2q(1 - q)) \left(1 - q(1 - q) - (1 - 4q(1 - q))\alpha/(2 - \alpha) \right) \quad (62)$$

The RHS of (62) is $> 3/8$. (This can be seen by allowing q to go to its lower limit of $1/2$.)

Thus, $\hat{\Psi} \leq (3/8)(1 - h_R)w_L$ is sufficient to ensure that (57) is nonbinding. ■

Proof of Proposition 6. This proposition follows from Propositions 4 and 5 (as summarized in Table 1), and:

Part 1: $Eu_C \geq Eu_N - A + \gamma \hat{\Psi} > (1 - \gamma)(Eu_N - A) + \gamma \hat{\Psi}$.

Part 2: From the proof of Proposition 4, if $\gamma > \underline{\gamma}$, then $\gamma 2q \hat{\Psi} > (1 - \gamma)q(A + C)$.

As $\gamma \rightarrow 1$, $Eu_U \rightarrow (2q/(2q - 1))\hat{\Psi}$.

From equations (25) to (28), we know that $w_L > 3u_{AS}(0)$ and $u_{AS}(0) > u_{AS}(2) > u_{AS}(-2)$. Thus, $\hat{\Psi} > w_L/4$ (and $\hat{\Psi} \leq 3w_L/8$, as in Proposition 5) is sufficient so that, as

$\gamma \rightarrow 1$, $Eu_C \rightarrow \hat{\Psi} + u_{AS}(-2)/2$.

$(2q/(2q - 1))\hat{\Psi} - \hat{\Psi} - u_{AS}(-2)/2 > 0$ for $\hat{\Psi} > w_L/4$.

Thus, $w_L/4 < \hat{\Psi} \leq 3w_L/8$ is sufficient such that as $\gamma \rightarrow 1$, $Eu_C < Eu_U$. ■

Proof of Corollary 1. $Eu_N =$ expected underpricing with no when-issued trading $> (1 - \gamma)Eu_N$. But, $\gamma \hat{\Psi} - (1 - \gamma)A > 0$. ■

Proof of Proposition 7. The market opens if the mechanism is $++$ or $--$, but doesn't if the outcome is $+-$. Thus, in the *IC* constraints for pricing regime U, w_L appears only

in the outcome $+ -$:

$$Er^+ = q^2 u_c^{++} h_c^{++} + (1-q)^2 u_w^{++} h_w^{++} + 2q(1-q) u^{+-} h^{+-} \quad (63)$$

$$Er^- = q^2 u_c^{--} h_c^{--} + (1-q)^2 u_w^{--} h_w^{--} + 2q(1-q) u^{+-} h^{-+} \quad (64)$$

$$\begin{aligned} Er^+ &\geq (q^2 + (1-q)^2) (u^{+-} + w_L) h^{-+} + \\ &\quad q(1-q) (u_c^{--} h_c^{--} + u_w^{--} h_w^{--}) + 2q(1-q) \Psi_1 \quad (IC^+) \end{aligned}$$

$$\begin{aligned} Er^- &\geq (q^2 + (1-q)^2) (u^{+-} - w_L) h^{+-} + \\ &\quad q(1-q) (u_c^{++} h_c^{++} + u_w^{++} h_w^{++}) + 2q(1-q) \Psi_1 \quad (IC^-) \end{aligned}$$

Note on expected trading profits, Ψ_1 : Suppose that polled investor i lies and the market still opens. This means that polled investor j reported a signal that agrees with i 's report and thus disagrees with i 's actual signal. Investor i does have private information that she can trade on, but this information is arguably of lower quality than in the case without endogenous market opening. We can assume that $0 < \Psi_1 < \Psi$.

As in the earlier proofs, it is optimal to set $u_w^{--} = h_w^{--} = 0$ and $h^{-+} = 0$. We thus write the problem as follows: The objective is to minimize:

$$Eu = q^2 (u_c^{++} + u_c^{--})/2 + (1-q)^2 u_w^{++}/2 + 2q(1-q) u^{+-} \quad (65)$$

Subject to the following IC constraints:

$$\begin{aligned} q^2 u_c^{++} h_c^{++} + (1-q)^2 u_w^{++} h_w^{++} + 2q(1-q) u^{+-} h^{+-} &- q(1-q) u_c^{--} h_c^{--} \\ &\geq 2q(1-q) \Psi_1 \end{aligned} \quad (66)$$

$$\begin{aligned} q^2 u_c^{--} h_c^{--} - (q^2 + (1-q)^2) (u^{+-} - w_L) h^{+-} &- q(1-q) (u_c^{++} h_c^{++} + u_w^{++} h_w^{++}) \\ &\geq 2q(1-q) \Psi_1 \end{aligned} \quad (67)$$

and the following participation constraints:

$$u_c^{++}, u_w^{++}, u_c^{--} \geq 0, \quad u^{+-} \geq u_{AS}(0) \quad (68)$$

The allocation constraints are the same as in the earlier problems.

Because $q > 1/2$, the optimal solution calls for the maximum feasible allocation to polled investors whose reports are verified when the market does open: $2h_c^{++} = 2h_c^{--} = 1 - h_R$, and the minimum allocation those whose reports are contradicted: $h_w^{++} = 0$.

Part 1: Either (66) and (67) are both nonbinding, or (66) is binding and (67) is non-binding, or both are binding. For the moment we'll assume that (67) is nonbinding; we'll check this below. It is thus optimal to set u^{+-} to its lowest feasible value of $u_{AS}(0)$. From equation (28) we know that $u_{AS}(0) < w_L/3$. Thus, it is optimal to set h^{+-} to the largest feasible amount: $h^{+-} = 1 - h_R$, and to set $u_c^{--} = 0$ and $qu_c^{++}/2 = \max \left[2(1 - q) \left(\hat{\Psi}_1 - u_{AS}(0) \right), 0 \right]$. This results in the following expected underpricing:

$$Eu_U = 2q(1 - q) \max \left[u_{AS}(0), \hat{\Psi}_1 \right]. \quad (69)$$

We now need to check if (67) is nonbinding. We know that (67) can only bind if (66) is also binding. Thus, necessary and sufficient for (??) to be nonbinding is:

$$\begin{aligned} (1 - 2q(1 - q))(w_L - u_{AS}(0)) - 2(1 - q)^2 \left(\hat{\Psi}_1 - u_{AS}(0) \right) &\geq 2q(1 - q)\hat{\Psi}_1 \implies \\ (1 - 2q(1 - q))w_L - (2q - 1)u_{AS}(0) &\geq 2(1 - q)\hat{\Psi}_1 \end{aligned} \quad (70)$$

As stated above, $u_{AS}(0) < w_L/3$. So sufficient for (70) is:

$$\left(1 - 2q(1 - q) - \frac{(2q - 1)}{3} \right) w_L \geq 2(1 - q)\hat{\Psi}_1 \quad (71)$$

Keeping in mind that $q > 1/2$, it is easy to show that $\hat{\Psi}_1 \leq w_L/2$ is sufficient for (71). Thus, for all reasonable parameter values, (67) is nonbinding.

Part 2: We now consider pricing regime C. This problem is identical to that of Proposition 5, except that after a lie the market opens with probability $2q(1 - q)$. Following from equation (60):

$$Eu_C = Eu_N + \max \left[0, 2q(1 - q)\hat{\Psi}_1 - A \right] \quad (72)$$

where A is defined in Proposition 3.

$Eu_N > 2q(1 - q)u_{AS}$ and $A < Eu_N$, so $Eu_U < Eu_C$. ■

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