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Voluntary disclosure and market competition: Theory and evidence from the U.S. services sector

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ABSTRACT

This paper analyses a firm's incentives to disclose private information about market demand and its cost when there is a potential market entrant. A partially pooling disclosure equilibrium exists in which high demand-high cost and low demand-high cost types of firms are nontransparent in the case of risky debt issuance. I use a sample of U.S. service firms to test the theoretical predictions. Consistent with the model's implications, among low-debt service firms those that are high demand-high cost are likely to avoid information disclosure, whereas among high-debt firms those that are high demand-high cost and low demand-high cost are less likely to disclose private information.

1. Introduction

In today's financial system, firms accessing capital markets are required to follow mandatory disclosure rules set by regulatory institutions such as the U.S. Securities and Exchange Commission. In addition to mandatory disclosures, some firms make voluntary disclosures, such as management forecasts and press releases. These actions make sense when one considers the informational asymmetry between managers and other stakeholders regarding value-relevant firm-related information. Thus, these voluntary disclosures could be aimed at minimizing Akerlof's (1970) lemons problem. However, it is a puzzling empirical fact that firms differ greatly in terms of the level and types of voluntary disclosures, with some firms being known for transparency while others are likely to be much more opaque (Lang, 1998; Watson et al., 2002). Understanding the underlying incentives behind these voluntary disclosures is a challenging task for researchers.

This paper studies the voluntary disclosure policy of an incumbent firm when there is a potential market entrant and the incumbent needs financing and issues risky debt. This scenario implies the incumbent is simultaneously signalling in the product and credit markets, while a third party (either the creditors or the financial market) is assessing the incumbent in terms of profitability, in addition to the new competitor. In this case, the incumbent firm holds private information about market demand and its own production costs, both of which can be high or low. The incumbent can choose a different disclosure policy, depending on the combination of the demand and its own cost state. While high (low) market demand increases (decreases) the probability of entry, a low-cost (high-cost) incumbent discourages (encourages) entry.[1] This reasoning implies that the high demand-high cost state is the most favourable state for the entrant and, therefore, the high demand-high cost type has strong incentives to be nontransparent in any equilibrium candidate. Furthermore, the low demand-high cost type would be very cautious about disclosing its type, given risky debt

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[1] Here the model does not consider the possibility of a firm lying about its type, considering the penalties if discovered, or a costless verification mechanism, consistent with the literature.

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financing, because the riskier the incumbent (less profitable) from the viewpoint of debtholders, the more costly the debt issuance.

The model yields an equilibrium in which high demand-high-cost and low demand-high-cost firms do not disclose their type and issue the same amount of debt while the other two types reveal their information. In such an equilibrium, a low demand-high-cost type will prefer to pool with the high demand-high cost type, whose profits are higher, so it can decrease the debt it must repay. On the other hand, a high demand-high cost firm will prefer to disguise its type because of the entrant's higher probability of entry. In other words, the two types of firms pool together because the low demand-high cost type can thus deceive debtholders and issue less costly debt and the high demand-high-cost type can disguise its true state from a potential entrant. Additionally, the other two types (low demand-low cost and high demand-low cost) prefer to remain separate because pooling benefits neither of them in terms of either debt or entry. This model illustrates a second effect influencing disclosure policy in addition to the entry effect, that is, the incumbent's own profitability. This impact of risky debt issuance on disclosure policy in an entry game has not been explored much in the literature as I discuss the most significant contributions of this paper in the next paragraph. Lastly, in addition to the nondisclosure equilibrium described, there exists a fully revealing equilibrium in which every type of incumbent is transparent and has a different amount of debt.

One of the main contributions of this paper is its analysis of the disclosure incentives of an incumbent firm when (industry-wide) market demand and (firm-specific) cost information coexist. The paper's second main contribution is its consideration of the credit market's impact on the voluntary disclosure decision, together with the entrant effect. Basically, the model that I develop presents the situation in which two audiences (the entrant and debtholders) coexist. The model can thus highlight the conflicting incentives to disclose information when firms simultaneously consider the threat of entry and the cost of debt. To the best of my knowledge, no earlier paper has studied the simultaneous disclosure decision of market demand and cost information when these two separate audiences coexist. Many models, beginning with those of Vives (1984) and Gal-Or (1985, 1986), study the optimal disclosure policy of either demand or cost information in Cournot or Bertrand competition settings. As the authors show, in a Bertrand competition setting, the optimal strategy is to disclose private information, whereas, in a Cournot setting, hiding information becomes the dominant strategy. However, the main results of this paper do not depend on the competition structure.

After those first papers, several studies were published on voluntary disclosure decisions (e.g., Darrough and Stoughton (1990), Wagenhofer (1990), Feltham and Xie (1992), Hwang and Kirby (2000), Pae (2002), and Koessler (2008)). The closest to the current paper are those of Darrough and Stoughton (1990), Feltham and Xie (1992), and Pae (2002). While Darrough and Stoughton (1990) and Feltham and Xie (1992)[2] consider the additional effect of the financial market and include both audiences in the picture, they only do so for the voluntary disclosure of market demand information and do not look at cost revelation. The existence of partial disclosure equilibria in the study by Feltham and Xie (1992), who extend the model of Darrough and Stoughton (1990) by considering a potential market demand continuum, depends on whether the entry costs are variable or fixed. This paper's results are independent of the entry costs. On the other hand, while Pae (2002) considers the disclosure of both market demand and cost information in an intertemporal market setting, the author ignores the additional effect of credit or the financial market. In this paper, I therefore aim to show the fundamental trade-off the incumbent could face, that is, becoming less transparent to prevent higher credit market financing costs. This result becomes especially important for those incumbents with the fewest prospects.

Accordingly, this paper considers risky debt issuance to highlight the aforementioned trade-off, which is not covered in earlier studies. This model with risky debt makes clear empirical predictions such as low demand-high-cost incumbent firms having a new incentive to not disclose information and to pool with high demand-high-cost types when the threat of entry and the cost of debt are of simultaneous concern. Another of the paper's biggest contributions is the testing of this simple model's empirical predictions using the panel data of U.S. firms in the service sector.

In addition to these contributions, this paper provides supporting evidence that, in the presence of market imperfections, the financing decisions of firms have real effects, a fundamental issue originally raised by Modigliani and Miller (1958). This paper advances the corporate financing literature on the interaction of product market decisions and firm financing initiated by Brander and Lewis (1986) and furthered by Gertner et al. (1988), Maksimovic (1988), Chevalier and Scharfstein (1996), Campello and Fluck (2006), among others, by highlighting the real effect of capital structure on strategic voluntary disclosures related to the product market. Accordingly, Gertner et al. (1988) study a firm's indirect information revelation to the product market through its capital structure, rather than direct and verifiable information disclosure. By using Myers and Majluf's (1984) prominent result where high-profit firms can distinguish themselves from low-profit ones by issuing more debt, Gertner et al. (1988) illustrate that a separate equilibrium is less likely given simultaneous signalling to the capital and product markets. Their outcome is greatly related and consistent with the current model's implications. Pooling between high demand-high cost and low demand-high-cost types becomes likely when the simultaneous effects of the product and credit markets are taken into account.

As mentioned earlier, the model leads to some testable hypotheses: every incumbent type except high demand-high cost is expected to be transparent when signalling to the credit market is not disregarded, such as for firms with no debt or low levels of debt. This hypothesis stems from the fact that there exists a unique fully revealing equilibrium in which each incumbent type is transparent and the high-demand-high-cost type is indifferent if the incumbent has riskless or no debt. An earlier version of this paper includes the proof of the existence and uniqueness of this full disclosure equilibrium in the case of no or riskless debt and it is available upon request. On the other hand, if risky debt induces signalling to the credit market, partial disclosure is likely in a product market where

[2] Specifically, the authors assume private information to be either favourable/unfavourable for both the entrant and the financial market at the same time, such as market demand information. However, private information on production costs does not apply to their definition, which means their model neglects the simultaneous disclosure decision.

high demand-high-cost and low demand-high-cost types pool together. Signalling to the credit market would be an important concern, especially for firms with high levels of debt.

The empirical section of this paper tests these predictions using panel data on U.S. firms in the service sector from which I generate two subsamples according to firms' debt ratios. The first subsample includes only firms with a debt-to-assets ratio below the 25th percentile in each industry in each year and the second subsample includes firms with a debt-to-assets ratio between the 50th and 100th percentiles in each industry in each year. I proxy for a firm's voluntary disclosure, or level of transparency, with the dispersion of analyst forecasts for the firm in each year by exploiting the documented evidence of a negative relation between a firm's information disclosure policies and the dispersion of individual analyst forecasts (Lang and Lundholm, 1996).

The results of the regression analysis are in accordance with the model's predictions: the dispersion of analyst forecasts is highest for the high demand-high-cost type, which implies that, among low-debt firms, this type is less likely to be transparent. Moreover, the low demand-high cost incumbent together with the high-demand-high-cost type is more likely to avoid voluntary disclosure in the sample of high-debt firms, as implied by the statistically higher dispersion of analyst forecasts. In the literature, the dispersion of analysts' forecasts has been used to proxy for the cost of external financing as well (Lyandres, 2007). Thus, these results also indicate that low demand-high-cost and high demand-high cost incumbents are more financially constrained compared to other types of incumbents in the product market.

I now briefly review the empirical literature on the effect of product market competition on voluntary disclosure. This literature provides conflicting results regarding the relation between competition and voluntary disclosure (Berger, 2011). These conflicting results are mostly due to problems with the data and the proxy measure for competition, that is, industry concentration. Using industry concentration as the proxy for competition creates limitations due to missing data on private firms and a lack of clarity regarding whether concentrated industries imply less or more competition. However, the mostly widely accepted notion in the earlier literature is that highly concentrated industries are less competitive, with Harris (1998), Botosan and Stanford (2005), and Bamber and Cheon (1998) finding a negative relation between industry concentration and disclosure. Others, however, find either a positive or a statistically insignificant relation (e.g. Botosan and Harris, 2000; Verrecchia and Weber, 2006; Berger and Hann, 2007; Bens et al., 2011). In addition, recent studies, such as those of Ali et al. (2009, 2014), demonstrate that, when missing data on private firms are included to obtain a more accurate measure of industry concentration, the results of Harris (1998) become statistically insignificant and the positive results of Verrecchia and Weber (2006) are reversed. In short, this literature, with its mixed results, has yet to arrive at any conclusions.

More closely related to my work, the paper of Bhojraj et al. (2004) studies the voluntary disclosure decisions of electric utility companies during 1996-1997, when the industry was in transition due to deregulation and competitive pricing. In such a scenario, there are three different target audiences of voluntary disclosures: regulators, capital market participants, and product market competitors. Overall, the authors show that voluntary disclosure decisions are generally consistent with the incentives predicted to affect these three important audiences. They show that (positive) voluntary disclosures decrease with the magnitude of utilities' stranded costs when the stranded cost recovery issue is unresolved. This result is consistent with the incentive to prevent regulators from becoming less inclined to allow the full recovery of stranded costs after hearing positive news about the company. Moreover, Bhojraj et al. (2004) find that, while voluntary disclosures increase with capital market incentives (higher numbers of institutional investors and higher percentages of institutional holdings in the firm's equity), they decrease with product market competition incentives (future market demand). In order to deter new entrants, incumbent firms in high-demand markets would not make voluntary disclosures especially after deregulation, as my paper also confirms.

2. Theoretical analysis

2.1. The model

The model consists of a Bayesian game with signalling. There are two players: the first is an incumbent firm that holds a monopoly position in a product market and the second is an entrant firm wanting to enter this market. In the beginning, nature chooses the type of incumbent. There are four possible types of incumbent that correspond to the combinations of the two different demand and cost levels. After observing its own type, the incumbent determines its disclosure policy, which can disclose its state (both cost and demand state) or withhold all information. The incumbent's profits are affected by its disclosure policy through the potential entrant's decision. While a high (low) market demand increases (decreases) the probability of entry, a low-cost (high-cost) incumbent discourages (encourages) entry. The entrant disburses a random cost K to enter the market with a continuous cumulative distribution function $F(K)$. This means that the entrant always enters into the market with some degree of probability. An important assumption in this setting is that the entrant becomes informed about the state once it enters the market, even if the incumbent has chosen nontransparency.

The states or types of incumbent are denoted ω, where $\omega \in \{1, 2, 3, 4\}$. Each state, from state 1 to state 4, occurs with probability $P(\omega)$, which is common knowledge, and $\sum_{\omega=1}^{4} P(\omega) = 1$. Type 1 corresponds to the high demand-low-cost state (H_D, L_C), whereas type 2 corresponds to the high demand-high cost state (H_D, H_C). Similarly, type 3 refers to the low demand-low-cost state (L_D, L_C), whereas type 4 corresponds to the low-demand-high-cost state (L_D, H_C). The profit of the incumbent in state ω is denoted $\pi_I(\omega)$ when the entrant enters and $\Pi(\omega)$ when the entrant does not. Here, $\Pi(\omega)$ refers to the monopoly profit in state ω. The profit of the entrant in state ω is denoted $\pi_E(\omega)$ when the entrant is in the market. It is clear that the monopoly profit is greater than the duopoly profit for ω, $\Pi(\omega) > \pi_I(\omega)$. Additionally, it is possible to order monopoly (duopoly) profits in different states.

The best possible state for the incumbent is the high demand-low cost state $\omega = 1$, whereas the worst possible state is the low-demand–high-cost state, $\omega = 4$. Thus, the monopoly and duopoly profits of the incumbent can be ordered as $\pi_I(1) \geq \pi_I(2) \geq \pi_I(4)$ ($\Pi(1) \geq \Pi(2) \geq \Pi(4)$) and $\pi_I(1) \geq \pi_I(3) \geq \pi_I(4)$ ($\Pi(1) \geq \Pi(3) \geq \Pi(4)$). However, it is not possible to make comparisons between $\pi_I(2)$ and $\pi_I(3)$ ($\Pi(2)$, and $\Pi(3)$). Similarly, the entrant's profits can be ordered as $\pi_E(2) \geq \pi_E(1) \geq \pi_E(3)$ and $\pi_E(2) \geq \pi_E(4) \geq \pi_E(3)$. The entrant benefits from a high-demand state but suffers from a low-cost competitor. Thus, one cannot compare the profits of $\pi_E(1)$ and $\pi_E(4)$, as in the case of the incumbent with $\pi_I(2)$ and $\pi_I(3)$. The complete ordering of the incumbent's and the entrant's profits depends on the marginal effects of cost and demand.

The incumbent needs to raise external financing, denoted I, in the form of standard debt with a face value of D to start production. Given such borrowing by the incumbent, consider the case of riskless debt. Since the incumbent is prosperous and can pay back the debt in this scenario, the debtholders are not concerned about the incumbent's profitability. That is also why the incumbent does not consider the debtholders when deciding a disclosure policy. One can easily show that the fully revealing equilibrium is the unique equilibrium when the incumbent issues riskless debt. In an earlier and longer version of the paper, the uniqueness of the fully revealing equilibrium with no debt or riskless debt was demonstrated and is available upon request. However, this result changes when debt becomes risky. The debtholders then become concerned about the incumbent's profitability because, in some states, the incumbent can default and, instead of the face value of debt, debtholders obtain the incumbent's profits due to limited liability. The debtholders would then require a higher face value of debt from a riskier incumbent or an incumbent with lower profits. In return, the incumbent would consider the debtholders when determining a disclosure policy. The incumbent type that would be the most concerned about the debtholders would be the one with fewer prospects or the low demand-high cost type.

It is assumed that the incumbent defaults when it does not obtain the monopoly profit ($\Pi(\omega)$) but, rather, the duopoly profit ($\pi_I(\omega)$). In other words, the incumbent defaults when the entrant enters the market and debtholders receive the duopoly profit, $\pi_I(\omega)$, after such default. For such a default scheme, the external financing parameter I should lie in an interval such that $\min\Pi(\omega) = \Pi(4) > I > \max\pi_I(\omega) = \pi_I(1)$.[3]

The timeline of events is as follows. First, nature chooses the incumbent's type and the incumbent becomes informed. Then, the incumbent determines its disclosure policy, which is a binary decision. The variable $t \in \{0, 1\}$ indicates the incumbent's disclosure decision, with $t = 1$ representing full disclosure. After deciding its disclosure policy, the incumbent issues debt D to the investors in return for borrowing I. The investors can say yes or no to D. This issue of debt D can also be observed by the entrant. Thus, D serves as an additional common signal together with the disclosure policy, $t \in \{0, 1\}$. Following the incumbent's moves, the entrant learns its entry cost drawn from $F(K)$ and decides whether or not to enter. Finally, payoffs are realized in the product market. Fig. 1 summarizes the timeline of events.

The property that the entrant can also observe the face value of debt D is natural when the debt in question is public debt. Thus, one can consider the debt here as a corporate bond.

Both players are risk neutral and maximize their expected profits. That is, the incumbent decides on its disclosure policy to maximize its expected payoff and the entrant determines its entry probability such that the entrant enters the market only if it obtains a positive payoff.

Lastly, an important assumption in the model is truthful and costless disclosure. It is reasonable to assume that firms make truthful disclosures, especially if they are subject to auditing.

2.2. Strategic analysis

2.2.1. Disclosure decision

Backwards induction is used to determine the perfect Bayesian-Nash (PBE) equilibrium of the game. First, the entrant's entry decision is determined in terms of probabilities. The entrant knows the type of incumbent with probability one when a transparent incumbent is encountered. In this situation, the entrant enters into the market with probability $F(\pi_E(\omega))$, where $\omega \in \{1, 2, 3, 4\}$. Hence, the entrant enters only when its cost of entry is less than its profit. On the other hand, the entrant forms posterior beliefs according to Bayes' rule with each information set where a nontransparent incumbent is encountered. The posterior beliefs are denoted $q(\omega|t = 0)$, where $t = 0$ indicates a nontransparent disclosure policy. Now, the entrant enters the market with probability $F(\sum_{\omega=1}^{4} q(\omega|t = 0)\pi_E(\omega))$. Accordingly, the entrant considers its expected payoff after encountering a nontransparent incumbent and enters the market when it obtains an expected positive profit.

2.2.2. Risky debt issuance

The debt issuance gives the additional signal that the incumbent preferred nontransparency in the earlier stage. Hence, the entrant and the debtholders form posterior beliefs according to Bayes' rule after observing both the transparency policy and the face value of debt D. I define behaviour strategies ξ_ω and $\sigma_\omega(D)$ for the disclosure policy and the debt offer, respectively. The posterior beliefs are equal to $q(\omega|t = 0, D) = \frac{(1-\xi_\omega)\sigma_\omega(D)P(\omega)}{P(t = 0, D)}$. The face value of debt plays no signalling role given transparency, since the incumbent's type is then revealed.

After observing a transparent incumbent, the debtholders accept the debt offer D in state ω if

[3] The first inequality should be satisfied such that I is sufficiently smaller than the left-hand side. The precise threshold is given by the participation constraint of the debtholders, $F(\pi_E(\omega))\pi_I(\omega) + (1 - F(\pi_E(\omega)))\min(D, \Pi(\omega)) \geq I$ from which $I \leq \Pi(\omega)\frac{1}{\upsilon}$, where $\upsilon = \frac{1 - F(\pi_E(\omega))\frac{\pi_I(\omega)}{I}}{1 - F(\pi_E(\omega))} > 1$.

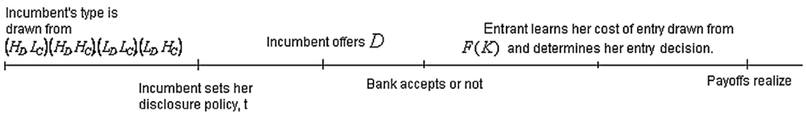

Fig. 1. Timeline with the risky debt.

$$F(\pi_E(\omega))\pi_I(\omega) + (1 - F(\pi_E(\omega)))D \geq I. \tag{1}$$

This equation is the participation constraint of the debtholders and the incumbent would offer the minimum D by pushing the debtholders to the breakeven point. Thus, the face value of debt to be offered by a transparent incumbent in state ω is

$$D(t = 1) = \frac{I - F(\pi_E(\omega))\pi_I(\omega)}{1 - F(\pi_E(\omega))}. \tag{2}$$

On the other hand, the participation constraint of the debtholders after observing a nontransparent incumbent is

$$F\left(\sum_{\omega=1}^{4} q(\omega|t = 0, D)\pi_E(\omega)\right)\left[\sum_{\omega=1}^{4} q(\omega|t = 0, D)\pi_I(\omega)\right] + \left[1 - F\left(\sum_{\omega=1}^{4} q(\omega|t = 0, D)\pi_E(\omega)\right)\right]D \geq I, \tag{3}$$

where $F(\sum_{\omega=1}^{4} q(\omega|t = 0, D)\pi_E(\omega))$ is the entry probability after a nontransparent incumbent is observed. Given that the entrant is in the market, the incumbent defaults and debtholders receive the expected duopoly profit of the incumbent. The debtholders should at least break even in expectation, given their posterior beliefs. Then, the face value of debt to be offered by a nontransparent incumbent becomes

$$D(t = 0) = \frac{I - F(\sum_{\omega=1}^{4} q(\omega|t = 0, D)\pi_E(\omega))[\sum_{\omega=1}^{4} q(\omega|t = 0, D)\pi_I(\omega)]}{[1 - F(\sum_{\omega=1}^{4} q(\omega|t = 0, D)\pi_E(\omega))]} \tag{4}$$

by changing the inequality sign in (3) into an equality.

2.2.3. Equilibria

This section shows that the fully revealing disclosure equilibrium ceases to be unique when risky debt is issued. Risky debt adds a second effect to the original entry effect: the incumbent's profitability. Without risky debt, all incumbent types, except the type in the most profitable state for the entrant (the high demand-high cost type), prefer full disclosure. They avoid being pooled with high demand-high cost type to minimize the probability of entry. Additionally, there is no device to assess the incumbent's profitability. This situation changes once the incumbent needs to borrow from a third party. Then, the incumbent, especially one with the lowest expected profitability (low demand-high cost), will sometimes prefer to be nontransparent and will disguise itself to decrease the penalty from debtholders, even at the cost of being pooled with a high demand-high-cost type.

The following demonstrates the existence of an equilibrium in which high demand-high cost and low demand-high cost types do not disclose their type and issue the same amount of debt while the other two types reveal their information. This yields an additional equilibrium to the fully revealing disclosure equilibrium.

Proposition 1 states the condition that the duopoly profit, $\pi_I(2)$, of the high-demand–high-cost type needs to satisfy for the existence of a fully revealing disclosure equilibrium. This condition is necessary to ensure that low demand-low-cost ($\omega = 3$) and low demand-high-cost ($\omega = 4$) types do not obtain any benefits from being nontransparent. In other words, $\pi_I(2)$ should be small enough so that the gains of these two types due to less costly debt obtained by pooling with the more profitable high demand-high-cost ($\omega = 2$) types are less than the losses due to the more likely presence of the entrant. If the profit ordering of the incumbent is such that $\pi_I(1) \geq \pi_I(3) \geq \pi_I(2) \geq \pi_I(4)$, then the low demand-low cost ($\omega = 3$) type would gain nothing by pooling, since it would become more profitable than the high demand-high cost ($\omega = 2$) type. In this case, the condition on $\pi_I(2)$ stemming from the incentive compatibility (IC) of the low-demand–low-cost ($\omega = 3$) type becomes redundant.

Proposition 1. *There exists a PBE where all the types are transparent and each one holds a different level of debt that is given by Eq. (2) if* $\pi_I(2) \leq \min\left(\left[1 - \frac{F(\pi_E(3))}{F(\pi_E(2))}\right]\Pi(3) + \frac{F(\pi_E(3))}{F(\pi_E(2))}\pi_I(3), \left[1 - \frac{F(\pi_E(4))}{F(\pi_E(2))}\right]\Pi(4) + \frac{F(\pi_E(4))}{F(\pi_E(2))}\pi_I(4)\right)$. *Only type 2 is indifferent between a transparent and a nontransparent disclosure policy. The consistent equilibrium belief is* $q\left(2|t = 0, \frac{I - F(\pi_E(2))\pi_I(2)}{1 - F(\pi_E(2))}\right) = 1$ *for the equilibrium debt level of type 2.*

The next proposition determines the range in which the high demand-high-cost type's profit ($\pi_I(2)$) should be for a PBE to exist where high demand-high cost ($\omega = 2$) and low demand-high cost ($\omega = 4$) types pool together. The conditions on $\pi_I(2)$ derive from the IC constraints of each type, considering both debt and entry effects. For instance, the IC constraint of type 4 imposes the following conditions: $\pi_I(2)$ should be large enough that pooling is optimal for type 4 because its gain from less costly debt is greater than the loss due to a higher likelihood of entry. Depending on the complete profit ordering, the IC constraints of some types (types 1 and 3) could become redundant.

Proposition 2. *A PBE exists where types 2 and 4 are nontransparent and offer the same level of debt* $\overline{D}$ *that is determined by Eq. (4) and equilibrium beliefs, given that* $\pi_I(2)$ *lies in a specific range, determined as follows. The other two types are transparent and their debt levels are given by Eq. (2). The equilibrium beliefs satisfy* $q(2|t = 0, \overline{D}) + q(4|t = 0, \overline{D}) = 1$.

3. Empirical tests

In this section, I use regressions to test the model. Because the voluntary disclosure model is closely related to the study of market information intermediation, the empirical analysis is interpreted as a step towards testing the implications from the general class of market information production and acquisition models, as called for by Healy and Palepu (2001).[4] I begin by stating the empirical implications.

3.1. Empirical implications

The best possible test of my model would compare the behaviour of firms voluntarily disclosing private information about the demand for their products and services and the costs of labour and materials. This comparison could determine whether firms take the same actions as others to reveal their private information given different levels of demand for their products and services and of input costs. Unfortunately, I am not aware of a comprehensive data source containing all firm decisions to voluntarily disclose private information beyond that required by the regulator. Prior studies have attempted to proxy for voluntary disclosure with survey rankings, such as Association for Investment Management and Research (AIMR) scores (e.g. Brown and Hillegeist, 2007; Lang and Lundholm, 1993, 1996; Welker, 1995; Healy et al., 1999; Sengupta, 1998), research-constructed indices of disclosure (e.g. Botosan, 1997; Francis et al., 2008; Shalev, 2009), measures from natural language processing technologies (e.g. Li, 2008, 2010), and the properties of firms' reported earnings (e.g. Dechow and Dichev, 2002; Francis et al., 2004).

However, as Heitzman et al. (2010) and Beyer et al. (2010) point out, these measures capture both voluntary and mandatory disclosures; therefore, interpreting these measures as representing purely voluntary disclosures is problematic. Realistically, the use of an information quality proxy always depends on the underlying characteristics and determinants of these measures; hence, any proxy variable will not necessarily solve this problem, again highlighting the need for an economic definition of earnings/information quality and a direct derivation of measures from that definition.[5]

In this paper, rather than rely on subjective measures of information quality (survey scores, discretionary choices of index members, a word tone dictionary, etc.), I test the model's implications by observing whether there is general agreement among analysts about the firm's future earnings prospects, as reflected in the standard deviation of annual earnings forecasts. Empirical evidence of the negative relation between a firm's information disclosure policies and the dispersion among individual analyst forecasts has been documented by, among others, Lang and Lundholm (1996). Given this relation, a reasonable assumption is that analyst forecast dispersion for a firm is greater when the firm chooses to not be transparent and vice versa. Therefore, the test of my model is to examine whether firms of different types (high demand-high cost, high demand-low-cost, low demand-low cost, or low demand-high cost) are associated with the larger or smaller dispersion of analyst forecasts of annual earnings.

There could be concerns, of course, about how well the dispersion of analyst forecasts proxies for voluntary disclosures or whether other factors are affecting the precision of voluntary disclosures and, in turn, the dispersion of analyst forecasts. However, all the other factors expected to interfere with the dispersion of analyst forecasts will be equally at work in each potential state of the incumbent and not be more pronounced in some states than others. Lastly, these interfering factors will always be prevalent, regardless of the alternative disclosure measure, because no such perfect measure exists and such data are yet to become available. Future research is thus necessary to elaborate on these issues.

If the incumbent holds riskless debt or no debt, a PBE exists in which all types of firms have incentives to be transparent, except the type 2 firm (high demand-high cost), which is indifferent to the voluntary disclosure policy. Thus, the model implies, for example, that, for incumbents, the dispersion among analyst forecasts of the annual earnings of a firm that is either high demand-low cost, low demand-low cost, or low demand-high cost will not depend on the firm's disclosure practices, whereas it could for a high demand-high cost type of firm. By examining the dispersion of analyst forecasts for different firm types, I might find significant dispersion among high demand-high cost firms but not among the other types.

Similarly, Proposition 2 derives the PBE in which, when debt is used for financing, type 1 (high demand-low cost) and type 3 (low-demand-low-cost) firms will disclose private information, whereas type 2 (high demand-high cost) and type 4 (low-demand-high-cost) firms will not. I summarize the hypotheses as follows.

HYPOTHESES:

H1: All else being equal, greater dispersion of analyst earnings forecasts is observed for firms with *low* levels of debt that are associated with *high demand–high cost* type.

H2: All else being equal, greater dispersion of analyst earnings forecasts is observed for firms with *high* levels of debt that are associated with *high demand–high cost* and *low demand–high cost* types.

3.2. Sample data

Implications of the theoretical model are tested with a collection of analyst forecasts of annual earnings from 1982 to 2012 from the Institutional Brokers' Estimate System (I/B/E/S) database. I study the relation between the voluntary disclosure of private information and firm type by examining whether the dispersion of analysts forecast in a given industry is associated with firms'

[4] See also the discussion of the empirical evidence of Core (2001).

[5] See also the more detailed discussion of these issues, among others, of Core (2001) and Dechow et al. (2010).

production and labour costs. Implicitly, I assume an efficient market in terms of information production and acquisition, in the sense that there will be no disagreement among financial analysts if the firm they are covering are transparent.

The I/B/E/S database contains the earnings estimates for U.S. companies from 1976 on and the I/B/E/S History database covers the historical estimate records of over 45,000 companies across 70 markets. There are two versions of the I/B/E/S earnings estimate history (Summary and Detail) and, this paper focuses on the annual earnings estimates among firms in the service sector from the Summary History dataset. The challenge of studying firms' strategic decisions here is the identification and measurement of the costs of production and labour. It is therefore helpful to focus on a single sector, rather than compare manufacturers to business service providers. In other words, I can thus better control for the impact of sector characteristics on the perceptions of strategic issues (Yasai-Ardekani, 1986). In addition, a narrowed focus on a single sector can ensure a high level of internal validity. For example, Burks et al. (2018) examine the empirical relation between market competition and voluntary disclosure in the banking industry but their research focuses on identifying the causal effect rather than disentangling the underlying economic factors contributing to this relation.

I define service firms in the United States based on the 49 industry portfolios on Kenneth French's website and I list all the industry descriptions of the service sector in Table 1.[6]

3.3. Empirical specification

The dependent variable is the dispersion of analyst forecasts for firm *i* in year *t*. The standard deviation of annual earnings estimates is used to proxy for the forecast dispersion. I standardize the dispersion measure by dividing the standard deviation by the mean of all the estimates for firm *i* in year *t*. The explanatory variables are described next. At the end of this section, I discuss regressions that correct for the bias caused by residuals that could be correlated across industries and thereby verify that the correlation within an industry cluster does not distort the coefficient estimates of the ordinary least squares (OLS) regressions.

The model assumes two factors that can influence a firm's decision to voluntarily disclose its private information: cost and demand. I estimate a firm's cost, *cost*, as the sum of its cost of goods sold (COGS) and selling, general, and administrative expenses (SG &A), both available from the firm's annual financial statements. To make the cost measure comparable across companies, I standardize it by dividing it by the firm's total revenue (sales) that year. Similarly, I use the revenue divided by total assets to proxy for the demand, *demand*, for the firm's products and services. In addition, within each industry and year, I rank all firms by *cost* and *demand* separately and create two dummy variables *hi-cost* and *hi-demand* that equal one if the firm is ranked above the mean value of *cost* and *demand*, respectively, and zero otherwise.

By matching the I/B/E/S Summary History dataset to the Compustat Annual dataset, I construct a set of variables to control for firm characteristics. The standard measure of firm size in this article and in most of the relevant literature is total assets, which is reported in the balance sheet of a firm's financial statements. To avoid problems of a skewed firm size distribution and potential outliers that could bias the regression results, I use a natural logarithm transformation of total assets to normalize the distribution.

The use of debt is measured by the ratio of total debt (Compustat item *dlc* plus *dltt*) to total assets. In the corporate finance literature, the use of debt increases in earnings during periods of rising operating income due to the tax benefits of debt but adds significant risks for stockholders and creditors because of added interest obligations. I also control for firm growth potential and innovation capabilities by adding the ratio of the market value to the book value and the ratio of research and development (R&D) expenses to total assets to the regression. Lastly, I add the Herfindahl–Hirschman (HHI) index to control for market concentration. Table 2 presents descriptive statistics of those variables: the mean, the standard deviation, and the minimum and maximum values.

An examination of the correlation matrix in Table 3 indicates that the correlations between independent variables are generally smaller than 0.5, except the interaction terms *cost* × *demand*, *hi-cost* × *hi-demand*, and *lo-cost* × *hi-demand*. The low correlation among the independent covariates helps avoid the problem of multicollinearity with high standard errors and low significance levels when both variables are included in the same regression. Further diagnostics indicate no obvious evidence of serious multicollinearity among the covariates.

In the first sample, I include only firms with a debt-to-assets ratio below the 25th percentile in each industry in each year. In other words, these low-debt firms are in the first quartile (first to 25th percentile) of the debt-to-assets ratio of their industry each year. I estimate the effect of market competition on the dispersion of analyst forecasts by fitting the following OLS regression equation that take the form and control various firm characteristics:

$$\begin{aligned}\text{Dispersion}_{i,t} = \; & \beta_0 + \beta_1 \text{Assets}_{i,t} + \beta_2 M2B_{i,t} + \beta_3 \text{Debt}_{i,t} + \beta_4 R\&D_{i,t} + \beta_5 \text{HHI}_{i,t} + \beta_6 \text{Cost}_{i,t} \\ & + \beta_7 \text{Demand}_{i,t} + \beta_8 \text{Cost}_{i,t} \times \text{Demand}_{i,t} + \text{IndustryFE}_i + \text{YearFE}_t + \epsilon_{i,t} \end{aligned} \tag{5}$$

The dependent variable is the standard deviation of analyst forecasts of firms' annual earnings divided by the mean of earnings forecasts. The independent variables include the natural logarithm of total assets, the market-to-book ratio, financial leverage (debt-to-assets ratio), the R&D-to-assets ratio, the Herfindahl–Hirschman index (HHI), cost (COGS + SG&A-to-revenue ratio), demand (revenue-to-assets ratio), and the interaction term of cost and demand. I include a full set of industry fixed effects to control for unobservable (within groups) heterogeneity and a full set of time (year) dummies to control for macroeconomic shocks that affect all firms in a given year.

Similarly, I use a sample of (high-debt) firms whose debt-to-assets ratios are in the third and fourth quartiles (50th to 100th

[6] Retrieved from http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/Data_Library/changes_ind.html.

Table 1
All industries in the service sector.

Industry	SIC (Low)	SIC (High)
Rooming and boarding houses	7020	7021
Camps and recreational vehicle parks	7030	7033
Services – personal	7200	7200
Services – laundry, cleaners	7210	7212
Services – diaper service	7214	7214
Services – coin-op cleaners, dry cleaners	7215	7216
Services – carpet, upholstery cleaning	7217	7217
Services – laundry, cleaners	7219	7219
Services – photo studios, portrait	7220	7221
Services – beauty shops	7230	7231
Services – barber shops	7240	7241
Services – shoe repair	7250	7251
Services – funeral	7260	7269
Services – misc	7270	7290
Services – tax return	7291	7291
Services – misc	7292	7299
Services – photofinishing labs (School pictures)	7395	7395
Services – auto repair, services	7500	7500
Services – automobile parking	7520	7529
Services – auto repair shops	7530	7539
Services – auto services, except repair (car washes)	7540	7549
Services – Misc repair services	7600	7600
Services – Electrical repair shops	7620	7620
Services – Radio and TV repair shops	7622	7622
Services – Refridge and air conditioner repair	7623	7623
Services – Electrical repair shops	7629	7629
Services – Watch, clock and jewelry repair	7630	7631
Services – Reupholster, furniture repair	7640	7641
Services – Misc repair shops	7690	7699
Services – legal	8100	8199
Services – educational	8200	8299
Services – social services	8300	8399
Services – museums, galleries, botanic gardens	8400	8499
Services – membership organizations	8600	8699
Services – private households	8800	8899
Services – truck, auto rental and leasing	7510	7515
Commercial printing	2750	2759
Signs, advertising specialty	3993	3993
Services – industrial launderers	7218	7218
Services – business services	7300	7300
Services – advertising	7310	7319
Services – credit reporting agencies, collection services	7320	7329
Services – mailing, reproduction, commercial art	7330	7339
Services – services to dwellings, other buildings	7340	7342
Services – cleaning and builging maint	7349	7349
Services – misc equip rental and leasing	7350	7351
Services – medical equip rental	7352	7352
Services – heavy construction equip rental	7353	7353
Services – equip rental and leasing	7359	7359
Services – personnel supply services	7360	7369
Services – computer programming and data processing	7370	7372
Services – computer processing, data prep	7374	7374
Services – information retrieval services	7375	7375
Services – computer facilities management service	7376	7376
Services – computer rental and leasing	7377	7377
Services – computer maintanence and repair	7378	7378
Services – computer related services	7379	7379
Services – misc business services	7380	7380
Services – security	7381	7382
Services – news syndicates	7383	7383
Services – photofinishing labs	7384	7384
Services – telephone interconnections	7385	7385
Services – misc business services	7389	7390
Services – R&D labs	7391	7391
Services – management consulting &P.R.	7392	7392
Services – detective and protective (ADT)	7393	7393
Services – equipment rental &leasing	7394	7394
Services – trading stamp services	7396	7396

(*continued on next page*)

Table 1 (*continued*)

Industry	SIC (Low)	SIC (High)
Services – commercial testing labs	7397	7397
Services – business services	7399	7399
Services – trailer rental and leasing	7519	7519
Services – engineering, accounting, research, management	8700	8700
Services – engineering, accounting, surveying	8710	8713
Services – accounting, auditing, bookkeeping	8720	8721
Services – research, development, testing labs	8730	8734
Services – management, public relations, consulting	8740	8748
Services – misc	8900	8910
Services – engineering &architect	8911	8911
Services – misc	8920	8999
Depository institutions	6000	6000
Federal reserve banks	6010	6019
Commercial banks	6020	6020
National commercial banks	6021	6021
State banks – Fed Res System	6022	6022
State banks – not Fed Res System	6023	6024
National banks – Fed Res System	6025	6025
National banks – not Fed Res System	6026	6026
National banks, not FDIC	6027	6027
Banks	6028	6029
Savings institutions	6030	6036
Banks	6040	6059
Credit unions	6060	6062
Foreign banks	6080	6082
Functions related to deposit banking	6090	6099
Nondepository credit institutions	6100	6100
Federal credit agencies	6110	6111
FNMA	6112	6113
S&Ls	6120	6129
Agricultural credit institutions	6130	6139
Personal credit institutions (Beneficial)	6140	6149
Business credit institutions	6150	6159
Mortgage bankers	6160	6169
Finance lessors	6170	6179
Financial services	6190	6199

Table 2
Summary statistics. The sample include firms in the U.S. services sector as defined in Table 1.

Name	Variable	Mean	Std. Dev.	Minimum	Maximum
Forecast Dispersion	disp	0.097	0.172	0.009	1.255
log(Total Assets)	lat	7.759	2.156	3.423	13.82
Market/Book	m2b	2.581	2.691	0.310	17.790
Debt/Assets	debt	0.186	0.151	0.001	0.691
R&D/Assets	xrd	0.013	0.041	0	0.217
Herfindahl-Hirschman Index	hhi	0.293	0.262	0.052	1
Cost	cost	0.742	0.157	0.341	1.173
Demand	demand	0.515	0.683	0.039	3.229
Cost × Demand	c × d	0.443	0.641	0.013	3.262
Hi-cost	hi_cost	0.458	0.498	0	1
Hi-demand	hi_demand	0.458	0.498	0	1
Hi-cost × Hi-demand	hc × hd	0.241	0.428	0	1
Hi-cost × Lo-demand	hc × ld	0.202	0.402	0	1
Lo-cost × Hi-demand	lc × hd	0.202	0.401	0	1
Lo-cost × Lo-demand	lc × ld	0.242	0.428	0	1

percentiles) of the debt-to-assets ratio in each industry in each year to fit the following OLS regression equation:

$$\begin{aligned}\text{Dispersion}_{i,t} = {} & \beta_0 + \beta_1\text{Assets}_{i,t} + \beta_2 M2B_{i,t} + \beta_3\text{Debt}_{i,t} + \beta_4 R\&D_{i,t} + \beta_5\text{HHI}_{i,t} + \beta_6\text{Hi\_}C\text{ost}_{i,t} \\ & + \beta_7\text{Hi\_}D\text{emand}_{i,t} + \beta_8\text{Hi\_}C\text{ost}_{i,t} \times \text{Hi\_}D\text{emand}_{i,t} + \beta_9\text{Hi\_}C\text{ost}_{i,t} \times \text{Lo\_}D\text{emand}_{i,t} \\ & + \beta_{10}\text{Lo\_}C\text{ost}_{i,t} \times \text{Hi\_}D\text{emand}_{i,t} + \beta_{11}\text{Lo\_}C\text{ost}_{i,t} \times \text{Lo\_}D\text{emand}_{i,t} + \text{IndustryFE}_i \\ & + \text{YearFE}_t + \epsilon_{i,t}\end{aligned} \tag{6}$$

Again, the dependent variable is the standard deviation of analyst forecasts for firm annual earnings divided by the mean of

Table 3

Cross-correlation matrix. The sample include firms in the U.S. services sector as defined in Table 1.

Variables	disp	lat	m2b	debt	xrd	hhi	cost	demand	c*times*d	hi_cost	hi_demand	hc × hd	hc × ld	lc × hd	lc × ld
disp	1.000														
lat	−0.149	1.000													
m2b	−0.029	−0.251	1.000												
debt	−0.053	0.139	0.067	1.000											
xrd	0.150	−0.372	0.340	−0.196	1.000										
hhi	0.087	−0.443	0.254	0.209	0.199	1.000									
cost	0.273	−0.433	0.067	−0.133	0.266	0.400	1.000								
demand	0.058	−0.516	0.289	−0.040	0.193	0.446	0.570	1.000							
c × d	0.076	−0.501	0.251	−0.060	0.185	0.419	0.600	0.994	1.000						
hi_cost	0.178	−0.059	−0.124	−0.067	0.030	−0.154	0.406	0.063	0.103	1.000					
hi_demand	−0.003	0.034	0.053	−0.072	0.038	−0.152	0.026	0.174	0.178	0.127	1.000				
hc × hd	0.108	−0.092	−0.028	−0.027	0.033	−0.026	0.285	0.246	0.269	0.614	0.614	1.000			
hc × ld	0.105	0.035	−0.121	−0.065	−0.000	−0.165	0.177	−0.201	−0.176	0.548	−0.463	−0.284	1.000		
lc × hd	−0.113	0.157	0.086	−0.070	0.014	−0.166	−0.285	−0.079	−0.097	−0.462	0.547	−0.284	−0.253	1.000	
lc × ld	−0.089	0.012	0.014	0.051	−0.021	−0.028	−0.245	−0.107	−0.123	−0.519	−0.519	−0.319	−0.285	−0.284	1.000

Table 4

Low-debt Firms. This sample contains all firms in the first quartile (0 to 25 percentile) of debt-to-assets ratio in each industry in each year. The dependent variable is the standard deviation of analyst forecasts for firms' annual earnings divided by the mean earnings forecasts. The independent variables include the natural log of total assets, market-to-book ratio, financial leverage (debt-to-assets ratio), R&D-to-assets ratio, cost (COGS + SG&A-to-revenue ratio), demand (revenue-to-assets ratio), and the interaction term of cost and demand. All specifications use OLS regression with industry fixed-effects. In addition, specifications (2), (4), (6), and (8) use year fixed-effects, and specifications (7) and (8) use robust cluster SE on industry. *z*-Statistics are shown in the parentheses with ***, ** and * indicating its statistical significant level of 1%, 5% and 10% respectively.

Dependent variable: dispersion	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
log(Total Assets)	−0.0018	−0.0068	0.0056	0.0010	0.0066	0.0017	0.0066	0.0017
	(−0.37)	(−1.40)	(1.20)	(0.21)	(1.44)	(0.38)	(0.91)	(0.32)
Market/Book	−0.0156***	−0.0108***	−0.0055**	−0.0032	−0.0023	−0.0005	−0.0023	−0.0005
	(−5.61)	(−3.84)	(−2.02)	(−1.19)	(−0.83)	(−0.18)	(−0.63)	(−0.32)
Debt/Assets	−0.3529**	−0.1051	−0.4387***	−0.1689	−0.4739***	−0.2026	−0.4739	−0.2026
	(−2.25)	(−0.67)	(−2.97)	(−1.14)	(−3.22)	(−1.36)	(−1.47)	(−1.85)
R&D/Assets	0.4891**	0.4944***	0.1837	0.2345	0.1107	0.1671	0.1107	0.1671*
	(2.46)	(2.58)	(0.98)	(1.29)	(0.59)	(0.91)	(1.79)	(2.49)
HHI	0.2403***	0.2492***	0.1314*	0.1620**	0.1124*	0.1465**	0.1124*	0.1465*
	(3.36)	(3.42)	(1.94)	(2.34)	(1.67)	(2.12)	(2.31)	(2.17)
Cost			0.5660***	0.5528***	0.4765***	0.4733***	0.4765***	0.4733***
			(12.46)	(11.58)	(9.49)	(8.83)	(24.18)	(17.59)
Demand			−0.0296	−0.0250	−0.4567***	−0.3619***	−0.4567***	−0.3619***
			(−1.59)	(−1.39)	(−4.26)	(−3.39)	(−9.88)	(−4.72)
Cost × Demand					0.4600***	0.3622***	0.4600***	0.3622***
					(4.05)	(3.20)	(8.21)	(4.33)
Constant	0.0261	−0.0310	−0.4276***	−0.5607***	−0.3097	−0.4386***	−0.3097***	−0.4386***
	(0.38)	(−0.21)	(−5.29)	(−3.66)	(−3.63)	(−2.79)	(−12.80)	(−6.31)
Industry Fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed-effects	No	Yes	No	Yes	No	Yes	No	Yes
Industry Robust Cluster	No	No	No	No	No	No	Yes	Yes
Observations	1154	1154	1154	1154	1154	1154	1154	1154
Adj. R-squared	0.078	0.163	0.189	0.253	0.200	0.260	0.224	0.301

earnings forecasts. The independent variables include the natural logarithm of total assets, the market-to-book ratio, financial leverage (debt-to-assets ratio), the R&D-to-assets ratio, the Herfindahl–Hirschman index (HHI), cost (COGS + SG&A-to-revenue ratio), a high-demand dummy variable *Hi-Demand* (equal to one when a firm's demand is above the median of its industry in each year and zero otherwise), a high-cost dummy variable *Hi-Cost* (equal to one when a firm's costs are above the median of its industry in each year and zero otherwise), and the four interaction terms of all the demand and cost dummy variables, that is, *Hi-Cost* × *Hi-Demand*, *Hi-Cost* × *Lo-Demand*, *Lo-Cost* × *Hi-Demand*, and *Lo-Cost* × *Hi-Demand*. All specifications use OLS regression with industry fixed effects.

It is well known that OLS standard errors are unbiased when the residuals are independent and identically distributed. When the residuals are correlated across observations, OLS standard errors can be biased and either over- or underestimate the true variability of the coefficient estimates.[7] I run additional regressions with clustered (Rogers) standard errors that produce White standard errors which are robust to within-cluster (within-industry) correlation. In addition, because the regression model includes the dummy variables *Hi-Cost* and *Hi-Demand* and the four interaction terms *Hi-Cost*, *Lo-Cost*, *Hi-Demand*, and *Lo-Demand*, there is a concern of multicollinearity. To overcome this potential problem, four regression routines were run, each one with one size variable. This enables me to examine the effects of the four types of firms (high demand-high cost, low demand-high cost, high demand-low cost, and low demand-low cost) separately.

3.4. Empirical results

The estimation results of Eq. (5) using low-debt firms in the U.S. services sector are presented in Table 4. In this longitudinal dataset, each firm's cost of labour and materials and the market demand for its products and services are measured by continuous variables.

As a robustness check, I exclude *cost* and *demand* as the explanatory variables in specifications (1) and (2). The adjusted R^2 values of 7% without the year fixed effects and 16.3% with the year fixed effects indicate that *assets M2B*, *debt*, *R & D*, and *HHI* are reasonable control variables. The negative coefficients of *M2B* and *debt* and the positive coefficients of *R & D* and *HHI* suggest that firms with greater growth opportunities, higher financial leverage, lower innovation capabilities, and less market power tend to be more transparent. When I add the scale variables *cost* and *demand* to the regressions in specifications (3) and (4), the statistical significance of the coefficient estimates for *M2B*, *Debt*, *R & D*, and *HHI* is reduced, whereas firms with lower costs of labour and materials are more likely to disclose information, as are those with a higher market demand for their products and services. The positive coefficient of the

[7] See Petersen and Mitchell (2009) for a more technical discussion.

Table 5

High-debt Firms. This sample contains all firms in the third and forth quartiles (50 to 100 percentile) of debt-to-assets ratio in each industry in each year. The dependent variable is the standard deviation of analyst forecasts for firms' annual earnings divided by the mean earnings forecasts. The independent variables include the natural log of total assets, market-to-book ratio, financial leverage (debt-to-assets ratio), R&D-to-assets ratio, Herfindahl-Hirschman index, cost (COGS + SG&A-to-revenue ratio), hi-demand dummy variable (with 1 for a firm's demand above the median of its industry in each year and 0 otherwise), hi-cost dummy variable (with 1 for a firm's cost above the median of its industry in each year and 0 otherwise), and the four interaction terms of the demand and cost dummy variables: Hi-cost × Hi-demand, Hi-cost × Lo-demand, Lo-cost × Hi-demand, and Lo-cost × Lo-demand. All specifications use OLS regression with industry fixed-effects. In addition, specifications (5) to (6) use year fixed-effects, and specifications (7) and (8) use robust cluster SE on industry. *z*-Statistics are shown in the parentheses with ***, ** and * indicating its statistical significant level of 1%, 5% and 10% respectively.

Dependent variable: dispersion	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
log(Total Assets)	−0.0030	−0.0036*	−0.0030	−0.0037**	−0.0030	−0.0036	−0.0030	−0.0037
	(−1.63)	(−1.94)	(−1.63)	(−1.98)	(−0.38)	(−0.41)	(−0.38)	(−0.41)
Market/Book	−0.0040***	−0.0022*	−0.0039***	−0.0021*	−0.0040	−0.0022	−0.0039	−0.0021
	(−3.21)	(−1.76)	(−3.16)	(−1.74)	(−1.06)	(−0.96)	(−1.07)	(−0.97)
Debt/Assets	−0.0736**	−0.0484	−0.0733**	−0.0483	−0.0736	−0.0484**	−0.0733	−0.0483**
	(−2.37)	(−1.57)	(−2.36)	(−1.57)	(−1.39)	(−3.08)	(−1.38)	(−2.98)
R&D/Assets	0.2821***	0.3062***	0.2832***	0.3117***	0.2821*	0.3062**	0.2832*	0.3117**
	(2.59)	(2.83)	(2.60)	(2.88)	(2.16)	(2.72)	(2.15)	(2.70)
HHI	0.0453	0.0293	0.0426	0.0266	0.0453	0.0293	0.0426	0.0266**
	(1.57)	(0.99)	(1.48)	(0.90)	(1.90)	(1.20)	(1.84)	(1.14)
Hi-cost	0.0470***	0.0538***	−0.0372	−0.0419	0.0470***	0.0538***	−0.0372	−0.0419
	(7.68)	(8.92)	(−1.25)	(−1.43)	(7.22)	(11.59)	(−1.32)	(−1.34)
Hi-demand	0.0056	0.0031	−0.0364	−0.0432	0.0056	0.0031	−0.0364	−0.0433*
	(0.94)	(0.54)	(−1.17)	(−1.42)	(0.65)	(0.52)	(−1.52)	(−2.41)
Hi-cost × Hi-demand			0.0868**	0.1030***			0.0868**	0.1030**
			(2.17)	(2.62)			(2.72)	(3.80)
Hi-cost × Lo-demand			0.0390	0.0545**			0.0390	0.0545**
			(1.53)	(2.17)			(1.88)	(3.04)
Lo-cost × Hi-demand			−0.0058	0.0018			−0.0058	0.0018
			(−0.22)	(0.07)			(−0.91)	(0.17)
Lo-cost × Lo-demand			−0.0444**	−0.0441**			−0.0444*	−0.0441*
			(−2.45)	(−2.46)			(−2.13)	(−2.03)
Constant	0.0619*	0.2132***	0.1019***	0.2542***	0.0619	0.2132***	0.1019	0.2542**
	(1.89)	(3.03)	(2.80)	(3.52)	(1.70)	(3.84)	(1.96)	(3.47)
Industry Fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed-effects	No	Yes	No	Yes	No	Yes	No	Yes
Industry Robust Cluster	No	No	No	No	Yes	Yes	Yes	Yes
Observations	2689	2689	2689	2689	2689	2689	2689	2689
Adj. R-squared	0.102	0.145	0.104	0.148	0.118	0.170	0.121	0.174

interaction term *cost* × *demand* in specifications (5) and (6) implies that type 2 (high cost-high demand) firms actually avoid voluntary disclosure rather than being indifferent to the disclosure policy.

As discussed above, I repeat the analysis of (5) and (6) using the robust cluster estimator and the results reported in columns (7) and (8) in Table 4 are similar to those of columns (5) and (6). The adjusted R^2 values of 20% and 22.4% in columns (5) and (7) and the adjusted R^2 values of 26% and 30% in columns (6) and (8), respectively, suggest that these specifications explain the data reasonably well.

The estimation results of Eq. (6) for the high-debt firms in the U.S. services sector are presented in Table 5. In this panel data, each firm's costs of production and labour and the market demand for its products and services are measured by dummy variables (*Hi-Cost*, *Lo-Cost*, *Hi-Demand*, and *Lo-Demand*) and their interaction terms (*Hi-Cost* × *Hi-Demand*, *Hi-Cost* × *Lo-Demand*, *Lo -Cost* × *Hi-Demand*, and *Lo-Cost* × *Lo-Demand*) are included in the specifications.

The coefficient estimates in specifications (1) and (2) in Table 5 are similar to those in Table 4. The overall fit of these regressions is measured by adjusted R^2 values of 10.2% and 14.5%, respectively. Except for the statistical insignificance of *Hi-Cost* × *Lo-Demand* in specification (3), the positive coefficients of the interaction terms of both high cost-high demand and high cost-low demand, as reported in columns (3) and (4), are consistent with the hypothesis (H2) that these two types of firms are more likely to avoid voluntary disclosure. It is interesting to note that the coefficient estimates of *Lo-Cost* × *Lo-Demand* are statistically significant in both cases, suggesting that, inline with the model's predictions, low cost-low demand type of firms are willing to reveal more of their private information to the market. As indicated before, these results also imply that high cost-high demand and high cost-low demand type of firms are more financially constrained, since the dispersion of analyst forecasts is used to also proxy for the cost of external financing (Lyandres, 2007).

I repeat the analysis of specifications (1) to (4) using the robust cluster estimator and the inference does not change qualitatively, as indicated by the results in specifications (5) to (8). Note that, across eight specifications, four report negative coefficients for the

Table 6

Robustness Check. This sample contains all firms in the third and forth quartiles (50 to 100 percentile) of debt-to-assets ratio in each industry in each year. The dependent variable is the standard deviation of analyst forecasts for firms' annual earnings divided by the mean earnings forecasts. The independent variables include the natural log of total assets, market-to-book ratio, financial leverage (debt-to-assets ratio), R&D-to-assets ratio, Herfindahl-Hirschman index and four interaction terms of the demand and cost dummy variables: Hi-cost × Hi-demand, Hi-cost × Lo-demand, Lo-cost × Hi-demand, and Lo-cost × Lo-demand. The value of the Hi-demand dummy variable is 1 for a firm whose demand is above the median demand of its industry in each year and 0 otherwise and the value of the Hi-cost dummy variable is 1 for a firm whose cost is above the median cost of its industry in each year and 0 otherwise. Similarly, the value of the Lo-demand dummy variable is 1 for a firm whose demand is below the median demand of its industry in each year and 0 otherwise and the value of the Lo-cost dummy variable is 1 for a firm whose cost is below the median cost of its industry in each year and 0 otherwise. All specifications use OLS regression with year and industry fixed-effects with robust cluster SE on industry. *z*-Statistics are shown in the parentheses with ***, ** and * indicating its statistical significant level of 1%, 5% and 10% respectively.

Dependent variable: dispersion	(1)	(2)	(3)	(4)
log(Total Assets)	−0.0054	−0.0051	−0.0048	−0.0057
	(−0.59)	(−0.54)	(−0.52)	(−0.61)
Market/Book	−0.0031	−0.0027	−0.0024	−0.0035
	(−1.16)	(−0.95)	(−0.86)	(−1.28)
Debt/Assets	−0.0387*	−0.0517	−0.0541	−0.0386*
	(−2.04)	(−1.94)	(−1.96)	(−2.02)
R&D/Assets	0.311*	0.309*	0.307*	0.298*
	(2.52)	(2.27)	(2.27)	(2.27)
HHI	0.0262	0.0264	0.0267	0.0273
	(0.98)	(0.93)	(0.97)	(1.02)
Hi-cost × Hi-demand	0.0424***			
	(13.60)			
Hi-cost × Lo-demand		0.0333**		
		(3.59)		
Lo-cost × Hi-demand			−0.0356***	
			(−6.54)	
Lo-cost × Lo-demand				−0.0396***
				(−10.84)
Constant	0.229***	0.248**	0.246***	0.2716***
	(4.23)	(4.13)	(4.11)	(4.60)
Observations	2689	2689	2689	2689
Adj. R-squared	0.156	0.151	0.149	0.155

debt variable with 5% statistical significance. This evidence suggests that debt plays a disciplinary role on firm behaviour, creating incentives for firms to reveal more information.[8]

3.5. Robustness checks

It is worth noting that the value of the *Hi-Demand* dummy variable is set to one for a firm whose demand is above the industry median of the entire sample in each year, whereas the value of *Lo-Demand* is one for a firm whose demand is below the median of the entire sample in the same year. Similarly, the values of *Hi-Cost* and *Lo-Cost* are set based on the median cost of the industry in the entire sample. In the regression of Eq. (6), I use the subsample of only firms with a high debt-to-assets ratio, rather than the entire sample, to run cross-sectional tests of the factors (a combination of *Hi-Demand*, *Lo-Demand*, *Hi-Cost*, and *Lo-Cost*) to determine the dispersion of analyst forecasts. Because the threshold values for high and low demand and cost are based on the entire sample, whereas the analysis including the interaction terms of *Hi-Demand*, *Lo-Demand*, *Hi-Cost*, and *Lo-Cost* in the same specification is conducted on the subsample, multicollinearity is not a serious concern. Nevertheless, I still want to address the potential problem of multicollinearity and I therefore run four additional regression routines, each one with one size variable. This robustness check allows me to examine the effect of each type of firm (*high demand-high cost*, *low demand-high cost*, *high demand-low cost*, and *low demand-low cost*) separately. The positive coefficient estimates of *Hi-Cost* × *Hi-Demand* and *Hi-Cost* × *Lo-Demand* are positive and statistically significant at the 1% and 5% levels in specifications (1) and (2) of Table 6, respectively. This positive relation between these two types of firms and the level of disagreement among analysts suggests that *high demand-high cost* and *low demand-high-cost* firms do not want to reveal more information to the market, supporting the hypothesis of the pooling equilibrium. On the contrary, both *high demand-low cost* and *low demand-low cost* firms are associated with a lower degree of information asymmetry between the firm and the market, as suggested by the negative and statistically significant (at the 1% level) coefficient estimates of *Lo-Cost* × *Hi-Demand* and *Lo-C ost* × *Lo-Demand* in specifications (3) and (4), respectively.

A further complication arises when the industry structure remains consistent. I need to emphasize the assumption of the existence of new firms entering the industry that is inherent in my theoretical model. However, some industries do not have many potential entrants, perhaps because these industries have consolidated and incumbent firms have responded to heightened competition by

8 This view is similar to Jensen's (1986), but with a different kind of outcome.

Table 7
IT Service Industry. This sample contains all Information Technology (IT) service firms in the third and forth quartiles (50 to 100 percentile) of debt-to-assets ratio in the IT industry in each year. The dependent variable is the standard deviation of analyst forecasts for firms' annual earnings divided by the mean earnings forecasts. The independent variables include the natural log of total assets, market-to-book ratio, financial leverage (debt-to-assets ratio), R&D-to-assets ratio, and four interaction terms of the demand and cost dummy variables: Hi-cost × Hi-demand, Hi-cost × Lo-demand, Lo-cost × Hi-demand, and Lo-cost × Lo-demand. The value of the Hi-demand dummy variable is 1 for a firm whose demand is above the median demand of its industry in each year and 0 otherwise and the value of the Hi-cost dummy variable is 1 for a firm whose cost is above the median cost of its industry in each year and 0 otherwise. Similarly, the value of the Lo-demand dummy variable is 1 for a firm whose demand is below the median demand of its industry in each year and 0 otherwise and the value of the Lo-cost dummy variable is 1 for a firm whose cost is below the median cost of its industry in each year and 0 otherwise. All specifications use OLS regression with year and industry fixed-effects with robust cluster SE on industry. *z*-Statistics are shown in the parentheses with ***, ** and * indicating its statistical significant level of 1%, 5% and 10% respectively.

Dispersion	(1)	(2)	(3)	(4)
log(Total Assets)	−0.0218	−0.0227	−0.0205	−0.0233
	(−0.68)	(−1.00)	(−0.78)	(−0.80)
Market/Book	−0.00013	−0.00003	0.0011	−0.0009
	(−0.09)	(−0.02)	(0.67)	(−0.40)
Debt/Assets	0.148	0.1904	0.1378	0.185
	(0.89)	(1.20)	(0.84)	(1.25)
R&D/Assets	0.272	0.4004	0.384	0.275
	(1.40)	(1.97)	(1.59)	(1.35)
HHI	0.0393***	0.0306***	0.0499***	0.0327
	(3.77)	(7.26)	(20.43)	(4.16)
Hi-cost × Hi-demand	0.079***			
	(2.65)			
Hi-cost × Lo-demand		0.116***		
		(4.39)		
Lo-cost × Hi-demand			−0.109***	
			(−16.59)	
Lo-cost × Lo-demand				−0.0737***
				(−46.13)
Constant	0.183	0.185	0.195	0.2458
	(1.11)	(1.77)	(1.60)	(1.67)
Observations	499	499	499	499
R-squared	0.101	0.119	0.112	0.099

improving service quality or by specializing in certain service areas. If this is the case, the incentive effects encouraging or discouraging firms to disclose private information about market demand and costs will be weak. Therefore, I need to focus on those industries in which new entrants arrive on a continuous basis. In the next robustness check, I construct a subsample consisting only of information technology (IT) firms providing computer programming and data processing services (Standard Industrial Classification, or SIC, code 7370) and repeat my previous regressions. Again, the coefficient estimates reported in Table 7 confirm a positive association between high-cost firms and information asymmetry and a negative relation between low-cost firms and information disclosure.

A number of additional tests are performed to validate the aforementioned results. First, I split the sample into financial services and nonfinancial services firms and conduct the regressions separately. Second, I add more explanatory variables to control for firm characteristics such as the current ratio, the cash-to-assets ratio, industry size, chief executive officer ownership, and institutional ownership. Third, I use forecast error (the difference between analyst estimates and actual earnings realized in the next year) to proxy for information quality. In all three cases, the results hold, with only minor changes in coefficient size.[9]

4. Conclusion

This paper examines a monopolistic firm's incentives to disclose private information on market demand and the firm's cost when there is a potential entrant to the market. If only product market-related incentives are considered, there exists a unique fully revealing disclosure equilibrium in which every type of incumbent, except the high demand-high cost type, is transparent. The high demand-high cost type is in the most favourable state for the entrant. This type of firm therefore tries to decrease the probability of entry by committing to a nontransparent disclosure policy. This would have worked if any other incumbent type also preferred to be nontransparent. However, it is not optimal for any other type to pool together with the high demand-high cost firm, since that would increase the likelihood of entry. Nonetheless, the pooling of some types could occur when the incumbent needs external financing in the form of risky debt. In other words, a partial disclosure equilibrium is observed once credit market-related incentives are also taken into account. In this case, since the riskiness of the incumbent from the viewpoint of the debtholders affects the costliness of the debt issuance, the incumbent type with the fewest prospects (low demand-high cost type) will not always prefer to reveal its type. This

[9] For the sake of brevity, the results of these additional tests are not tabulated but are available upon request.

means that there exists an equilibrium in which high demand-high-cost and low demand-high cost types do not disclose their type and issue the same amount of debt while the other two types reveal their information. The existence of this second type of equilibrium depends on the duopoly profit of the high demand-high-cost type, which should lie in a specific range. The model with risky debt that I develop provides one possible explanation for the empirical fact that two different kinds of firms are usually observed, transparent versus opaque, by analysing firms' simultaneous signalling to the product and credit markets.

In addition, I test the model with the data. I carry out empirical tests to verify the theoretical predictions using the panel data of service firms in the United States, since a narrowed focus on a single sector can ensure a high level of internal validity. The main econometric finding is that both high demand-high cost and low demand high-cost firms avoid information disclosure while issuing debt for long-term financing, as my model implies. I also observe that, among low-debt firms, high demand-high cost incumbents have the greatest incentives to hide information. This observation is in accordance with the full disclosure equilibrium that would occur if signalling to the credit market were not the main concern, as in the case of low-debt firms. Lastly, by incorporating my results and earlier work, I conclude that high demand-high-cost and low demand-high cost firms are also the most financially constrained.

Appendix A

Proof of Proposition 1. I first check whether the proposed equilibrium strategies form best responses for each type. The plausible out-of-equilibrium beliefs are given by $q(2|t=0, D)=1$ for any offered debt amount, D.

Starting with type 1, the payoff that this type gets when it is transparent is given as: $[1-F(\pi_E(1))]\left[\Pi(1)-\frac{I-F(\pi_E(1))\pi_I(1)}{1-F(\pi_E(1))}\right]$. Realize that when the entrant is in the market, which occurs with probability $F(\pi_E(1))$, the incumbent goes bankrupt and obtains a zero payoff. The alternative payoff when type 1 is nontransparent and offers the equilibrium debt level of type 2, which is $\frac{I-F(\pi_E(2))\pi_I(2)}{1-F(\pi_E(2))}$, is given as: $[1-F(\pi_E(2))]\left[\Pi(1)-\frac{I-F(\pi_E(2))\pi_I(2)}{1-F(\pi_E(2))}\right]$. Notice that the equilibrium belief is at work in this payoff. Then, type 1 prefers to be transparent if the following inequality holds:

$$[1-F(\pi_E(1))]\left[\Pi(1)-\frac{I-F(\pi_E(1))\pi_I(1)}{1-F(\pi_E(1))}\right]\geq[1-F(\pi_E(2))]\left[\Pi(1)-\frac{I-F(\pi_E(2))\pi_I(2)}{1-F(\pi_E(2))}\right]\Leftrightarrow \tag{7}$$

$$F(\pi_E(2))[\Pi(1)-\pi_I(2)]\geq F(\pi_E(1))[\Pi(1)-\pi_I(1)] \tag{8}$$

The left hand side of the inequality (7) is always strictly bigger than the right hand side implying that type 1 prefers to disclose. Given the out-of equilibrium beliefs, there is also no better deviation for type 1. If it was nontransparent and offered a debt level which is less than the equilibrium debt level of type 2, the debtholders would not accept the offer and type 1 would obtain a zero payoff. If it was nontransparent and offered a larger debt level than the equilibrium level of type 2, this would decrease the right hand side of the inequality (7).

$$[1-F(\pi_E(2))]\left[\Pi(2)-\frac{I-F(\pi_E(2))\pi_I(2)}{1-F(\pi_E(2))}\right]=[1-F(\pi_E(2))]\left[\Pi(2)-\frac{I-F(\pi_E(2))\pi_I(2)}{1-F(\pi_E(2))}\right] \tag{9}$$

Like type 1, it has also no better deviation with the given out-of-equilibrium beliefs.

$$[1-F(\pi_E(3))]\left[\Pi(3)-\frac{I-F(\pi_E(3))\pi_I(3)}{1-F(\pi_E(3))}\right]\geq[1-F(\pi_E(2))]\left[\Pi(3)-\frac{I-F(\pi_E(2))\pi_I(2)}{1-F(\pi_E(2))}\right]\Leftrightarrow \tag{10}$$

$$F(\pi_E(2))[\Pi(3)-\pi_I(2)]\geq F(\pi_E(3))[\Pi(3)-\pi_I(3)] \tag{11}$$

Realize that the above inequality always holds if the complete profit ordering is given as $\pi_I(1)\geq\pi_I(3)\geq\pi_I(2)\geq\pi_I(4)$. Otherwise, it holds if $\pi_I(2)\leq\left[1-\frac{F(\pi_E(3))}{F(\pi_E(2))}\right]\Pi(3)+\frac{F(\pi_E(3))}{F(\pi_E(2))}\pi_I(3)$.

$$[1-F(\pi_E(4))]\left[\Pi(4)-\frac{I-F(\pi_E(4))\pi_I(4)}{1-F(\pi_E(4))}\right]\geq[1-F(\pi_E(2))]\left[\Pi(3)-\frac{I-F(\pi_E(2))\pi_I(2)}{1-F(\pi_E(2))}\right]\Leftrightarrow \tag{12}$$

$$F(\pi_E(2))[\Pi(4)-\pi_I(2)]\geq F(\pi_E(4))[\Pi(4)-\pi_I(4)] \tag{13}$$

This inequality holds when $\pi_I(2)\leq\left[1-\frac{F(\pi_E(4))}{F(\pi_E(2))}\right]\Pi(4)+\frac{F(\pi_E(4))}{F(\pi_E(2))}\pi_I(4)$. □

Proof of Proposition 2. I first check again whether the proposed equilibrium strategies are the best responses for each type. The out-of-equilibrium beliefs are given by $q(2|t=0, D)=q(2|t=0,\overline{D})$, $q(4|t=0, D)=q(4|t=0,\overline{D})$ and $q(2|t=0, D)+q(4|t=0, D)=1$ for any other offered debt amount, D.

For type 1, the payoff of transparency versus the payoff of nontransparency when it offers the equilibrium debt level $\overline{D}$ of types 2 and 4 is represented with the following inequality:

$$[1-F(\pi_E(1))]\left[\Pi(1)-\frac{I-F(\pi_E(1))\pi_I(1)}{1-F(\pi_E(1))}\right]\geq[1-F(E\pi_E)]\left[\Pi(1)-\frac{I-F(E\pi_E)E\pi_I}{1-F(E\pi_E)}\right]\Leftrightarrow \tag{14}$$

$$F(E\pi_E)[\Pi(1)-E\pi_I]\geq F(\pi_E(1))[\Pi(1)-\pi_I(1)] \tag{15}$$

where $E\pi_E=q(2|t=0,\overline{D})\pi_E(2)+q(4|t=0,\overline{D})\pi_E(4)$ and $E\pi_I=q(2|t=0,\overline{D})\pi_I(2)+q(4|t=0,\overline{D})\pi_I(4)$ which are the expected profits of the incumbent and the entrant with the equilibrium beliefs. This equilibrium always holds if the complete profit ordering of the entrant is such that $\pi_E(2) \geq \pi_E(4) \geq \pi_E(1) \geq \pi_E(3)$ because then $E\pi_E \geq \pi_E(1)$ and $E\pi_I \leq \pi_I(1)$. In other words, type 1 has no incentives to become nontransparent either from the entry or debt side with such a profit ordering. Otherwise (if $\pi_E(2) \geq \pi_E(1) \geq \pi_E(4) \geq \pi_E(3)$), it needs to hold that $\pi_I(2) \leq \pi_I(4) + \frac{F(E\pi_E)[\Pi(1) - \pi_I(4)] - F(\pi_E(1))[\Pi(1) - \pi_I(1)]}{F(E\pi_E)q(2 \mid t = 0, \overline{D})} = C_1$. Realize that there is also no better deviation with the given out-of-equilibrium beliefs which is also valid for all other types.

$$[1 - F(E\pi_E)]\left[\Pi(2) - \frac{I - F(E\pi_E)E\pi_I}{1 - F(E\pi_E)}\right] \geq [1 - F(\pi_E(2))]\left[\Pi(2) - \frac{I - F(\pi_E(2))\pi_I(2)}{1 - F(\pi_E(2))}\right] \Leftrightarrow \tag{16}$$

$$F(\pi_E(2))[\Pi(2) - \pi_I(2)] \geq F(E\pi_E)[\Pi(2) - E\pi_I] \tag{17}$$

$$[1 - F(\pi_E(3))]\left[\Pi(3) - \frac{I - F(\pi_E(3))\pi_I(3)}{1 - F(\pi_E(3))}\right] \geq [1 - F(E\pi_E)]\left[\Pi(3) - \frac{I - F(E\pi_E)E\pi_I}{1 - F(E\pi_E)}\right] \Leftrightarrow \tag{18}$$

$$F(E\pi_E)[\Pi(3) - E\pi_I] \geq F(\pi_E(3))[\Pi(3) - \pi_I(3)] \tag{19}$$

This inequality always holds given that the incumbent's complete profit ordering is such that $\pi_I(1) \geq \pi_I(3) \geq \pi_I(2) \geq \pi_I(4)$. This is because $E\pi_E \geq \pi_E(3)$ and $E\pi_I \leq \pi_I(3)$ in this case. Otherwise, $\pi_I(2)$ needs to satisfy that $\pi_I(2) \leq \pi_I(4) + \frac{F(E\pi_E)[\Pi(3) - \pi_I(4)] - F(\pi_E(3))[\Pi(3) - \pi_I(3)]}{F(E\pi_E)q(2 \mid t = 0, \overline{D})} = C_3$.

$$[1 - F(E\pi_E)]\left[\Pi(4) - \frac{I - F(E\pi_E)E\pi_I}{1 - F(E\pi_E)}\right] \geq [1 - F(\pi_E(4))]\left[\Pi(4) - \frac{I - F(\pi_E(4))\pi_I(4)}{1 - F(\pi_E(4))}\right] \Leftrightarrow \tag{20}$$

$$F(\pi_E(4))[\Pi(4) - \pi_I(4)] \geq F(E\pi_E)[\Pi(4) - E\pi_I] \tag{21}$$

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