# Motivating a supplier to test product quality

by

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***Abstract*:** This paper considers a supplier that offers a buyer a new product of unknown quality. The supplier can run a test that partially reveals unverifiable information concerning the quality, and the buyer can learn the actual quality after agreeing to buy the new product. I identify two main features of a contract for motivating the supplier to run the test. First, the contract may specify an upward or downward quantity distortion. Second, the contract may include slotting allowances, which may be welfare reducing when they discriminate against financially constrained suppliers.

*Keywords*: asymmetric information, information gathering, vertical relations, slotting allowances

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## 1. Introduction

A buyer may sometimes require a supplier to gather information regarding a new and untried product that it is offering. Supermarkets and drugstores, for example, have limited shelf space and may ask a supplier to perform market research for a new product in order to determine whether to place it on the shelf instead of an old one. A manufacturer that considers buying inputs from a new supplier instead of producing them in-house may depend on the supplier to conduct product testing to evaluate the input's durability or safety before deciding whether to use this new input. In some cases, final buyers with bargaining power may also require suppliers to perform product testing. A government, for example, may ask a supplier of a new defense system to test its quality before deciding whether to buy it instead of using existing defense systems.

The buyer may have the ability to learn the actual quality, but only when it starts using the new product, and at the cost of not using an old product of known quality. Supermarkets and drugstores, for example, can learn the actual demand for a new product once they place it on the shelf instead of an old one and observe customers' reactions towards it. A manufacturer that buys an input from a new supplier may learn the actual quality or safety of the input once it is incorporated into the production line instead of an old input. A government may learn the effectives of a defense system, once it is put into use.

Whenever quality is unverifiable, the two informational problems above create an incentive problem for the buyer, because the supplier will always prefer to avoid the costly process of gathering information, while the buyer cannot write a contract based on its ex-post information.

The examples above raise the following research questions. First, what are the features of the buyer's optimal contract for motivating a supplier to test its new product? In particular, will the contract involve the efficient quantity, or may it instead involve an undersupply or oversupply of the new product? What will be the features of the optimal pricing strategy? Will the buyer fully cover the supplier's costs of production or only part of them, or may negative fees even be involved? Also, what is the role of the two informational problems described above in determining the optimal contract? Second, when will the buyer find it optimal to offer a contract that motivates the supplier to test its new product, rather than either buying the new product without testing it first, or continuing to buy the old product instead? Third, what is the total effect of such a contract on welfare? In particular, how does it reflect on the legal and economic debate on whether antitrust authorities should allow retailers to charge slotting allowances: an upfront payment that manufacturers make for securing shelf space? Is such a practice welfare enhancing and does it helps retailers to choose the highest quality supplier? These research questions are of importance both to buyers needing to motivate suppliers to test their new products, and to policy makers for evaluating the effect of such contracts on welfare.

This paper considers a buyer, such as a downstream firm, that motivates an upstream supplier to gather costly information concerning the quality of its new product. I focus on the case where the buyer is an intermediate buyer. But the buyer in this model can alternatively be interpreted as a final buyer with market power to offer the supplier an incentive contract; a government is an example of such a buyer. The supplier can perform a costly test that reveals whether the state is H (L) in which case the quality of the new product is drawn from a more (less) desirable quality distribution. The buyer cannot observe whether the supplier indeed conducted a reliable test. If he chooses to purchase the new product, the buyer privately observes its actual quality, but does not know the state from which the quality was drawn. The buyer can then choose the quantity to be produced based on the actual realization of the quality. In this setting, the buyer has an incentive to motivate the supplier to test its new product even though he learns the true quality ex-post. This is because the buyer decides whether to use the new product before observing its true quality, and therefore relies on the information coming from supplier's product testing.

I find that the equilibrium contract for motivating the supplier to gather information has two main characteristics. First, the buyer distorts the equilibrium quantity away from the vertical integration quantity in a manner that depends on the gap between the cumulative distribution functions in states L and H. The contract can thus involve downward distortion for some values of quality and upward distortion for others. In particular, I show in an example that the contract may involve an upward quantity distortion for low quality and a downward distortion for high quality. This case seems somewhat surprising because it implies that a government, for example, will use the new defense system more than is socially desirable even though product testing indicated low quality, and less than is socially desirable otherwise.

The second main characteristic of the equilibrium contract is that under some realizations of the product's quality, the buyer does not fully compensate the supplier for its total costs, and may ask for negative fees, in which case the supplier pays the buyer.

The intuition for these two results is that the buyer needs to design a contract that solves the two informational problems that my paper considers. The first problem is to motivate the supplier to test its product and reveal the state. To this end, the buyer will set a contract that provides the supplier with high compensation for quality realizations that are more likely to be in state H, and low, possibly negative compensation otherwise. The second informational problem is to motivate the buyer to reveal its ex-post information. Whenever the supplier's compensation is increasing in quality, the buyer will have an ex-post incentive to understate the true quality, and therefore a need to ex-ante distort the quantity downwards. The opposite occurs whenever the supplier's compensation is decreasing in quality, in which case the buyer will distort the quantity upwards. Thus, the combination of the two informational problems results in both above and below cost compensation, combined with downward and upward distortion, respectively.

The result that the contract may include negative fees can provide a new explanation for the use of slotting allowances, the upfront payments that manufacturers make to retailers such as supermarkets or drugstores for reserving shelf space.[1] Indeed, there is some evidence suggesting a link between slotting allowances and market research, as predicted by my model. The report by the Federal Trade Commission (2001), based on the testimonies of selected managers, says that "Some participants stated that a manufacturer's willingness to pay an up-front slotting fee is a tangible, credible statement of confidence … since the manufacturer is the party that has had the best opportunity to study the potential of the new product – for example, as a result of research and test marketing" (p. 13). Sudhir and Rao (2006) investigated the factors that affected the probability of observing slotting allowances. One of their findings is that suppliers that had low levels of credibility for conducting reliable market research supplemented their test market data with slotting allowances. Sudhir and Rao interpreted this result as support for signaling theory: market research indicates that the supplier has private information, which it signals by means of slotting allowances. My paper suggests that in some cases the causality between market research and slotting allowances might be reversed. That is, it is not that market research motivates manufacturers to signal their private information through slotting allowances, but that slotting allowances may motivate manufacturers to perform market research.

Antitrust authorities have investigated the potential effects of slotting allowances on competition, consumers and welfare.[2] On one hand, slotting allowances may have the negative effect of biasing retailers against new products that are offered by financially constrained suppliers that cannot afford to make high upfront payments.[3] A financially constrained supplier may not be able to finance slotting allowances by means of loans, because if the realized demand is low, the supplier will default. At the same time, slotting allowances may enhance social welfare by enabling supermarkets and drugstores to efficiently allocate scarce shelf space between products.

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[1] Slotting allowances are very common in the retail grocery industry. For example, the Federal Trade Commission (2003) found that manufacturers paid slotting allowances for introducing bread, hot dogs, ice cream, pasta and salad dressing. Indeed, introducing a new grocery product requires, on average, paying $1.5 - $2 million in slotting allowances.

[2] See for example the FTC (2001) and the Israeli Antitrust Authority (2003).

[3] The FTC (2001) found that small manufacturers described slotting allowances as "a major stumbling block for us to enter into any large distribution network" (p. 19). They also found that small manufacturers seeking to supply retail grocery markets have difficulties in finding sources of equity capital.

To investigate these two factors, I extend the basic model to two upstream suppliers that differ in their expected qualities. I find that the buyer may prefer to deal with the less efficient supplier simply because this supplier can afford to commit to a contract that offers very low, possibly negative compensation. This result supports the argument that slotting allowances discriminate against small and financially constrained suppliers. The paper provides a condition under which the optimal contract for motivating product testing can reduce social welfare.

My paper is related to previous literature on slotting allowances because of asymmetric information or limited shelf space. Chu (1992), Lariviere and Padmanabhan (1997) and Desai (2000) show that a manufacturer will use slotting allowances to convey private information to a retailer with limited shelf space. There are three main differences between the above literature and my paper. First, these papers assume that the manufacturer already has private information concerning the demand, while my paper explains why manufacturers may perform a costly test to obtain this information. Second, Lariviere and Padmanabhan (1997) and Desai (2000) assume that the manufacturer has the bargaining power to set the slotting allowance and the wholesale price, and Chu (1992) assumes that the manufacturer has the bargaining power to set only the wholesale price. In contrast, my paper focuses on the case where the retailer has full bargaining power to offer a non-linear tariff that may include a payment from the supplier to the buyer. [4] Third, these papers focus on contracts that mitigate an informational problem on the supplier's side, while my paper considers a contract that mitigates an informational problem of both the supplier (ex-ante) and the buyer (ex-post). The results of my model show that the first two differences are crucial because if the buyer has all the bargaining power, and the supplier knows the true demand without testing the product, then the slotting allowance will not emerge in equilibrium. Therefore, this paper contributes to the literature by explaining why retailers use slotting allowances when they have significant bargaining power and manufacturers need to invest in costly information gathering. The third difference is crucial because due to the buyer's ex-post information, the contract may involve upwards quantity distortion for some demand realizations and downwards distortion for others.

Marx and Shaffer (2010) show that a retailer may strategically limit its shelf space in order to induce suppliers to make up-front payments. In my paper, slotting allowances also emerge because of limited shelf space, but since I assume that the buyer has all the bargaining

[4] An alternative explanation for slotting allowances is that they facilitate collusion between competing retailers. This explanation also requires that retailers will have some degree of market power over suppliers. See for example Shaffer (1991), Kim and Staelin (1991), Shaffer (2005), Innes and Hamilton (2006), Kuksov and Pazgal (2007), Marx and Shaffer (2007), Rey, Miklós-Thal and Vergé (2011), Rey and Whinston (2012) and Piccolo and Miklós-Thal (2012).

power, the buyer cannot benefit from strategically limiting its shelf space. Moreover, my paper differs from Marx and Shaffer (2010) in that they focus on full information.

This paper is also closely related to the literature on productive information gathering, where a principal motivates an agent to gather costly information concerning the agent's marginal costs. Contributions in this field include Lewis and Sappington (1997), Crémer, Khalil and Rochet (1998), Dai, Lewis and Lopomo (2006), Shin (2008), Szalay (2009) and Ye (2010). A common feature in this literature is that after the agent invests in the gathering of information, it is the agent that privately observes the costs while the principal observes nothing.[5] When the gathering of information concerns the quality, as in my model, it is reasonable to expect that the buyer (the principal) will ex-post privately observe the actual quality, while the supplier (the agent) can only learn ex-ante the distribution of potential qualities. This difference affects the results in the following way. The above literature finds that information gathering lead to a high-powered incentive, inducing the principal to distort the quantity upwards (downwards) for good (bad) realizations of the marginal costs.[6] This paper adds to their findings by providing conditions under which other patterns of quantity distortion can emerge. In particular, the need to motivate information gathering may have the opposite result: the principal distorts the quantity downward (upward) for good (bad) realizations of the quality. My paper also contributes to this literature by studying the effect of the incentive contract on welfare, and by showing that a principal may deal with the less efficient supplier.

The structure of information in this paper is somewhat similar to Demski and Sappington (1993). They consider an agent that makes an unobservable effort. The principal then privately observes an imperfect signal of the agent's effort and reports it to the agent. Then, a second, publicly observable and contractible signal of the agent's effort is revealed. They find that for some realizations of the public signal, the principal may offer lower compensation for a good private signal than for a bad one. This outcome depends on the joint probability of the private and public signals and the correlation between them. The interpretation of these two signals is similar to the interpretation in my model for the quality variable (privately observable by the principal) and the quantity (publicly observable and contractible). The main contribution of my paper over theirs is that in mine, the public signal, i.e., the quantity, is endogenous and determined by the principal. Consequently, in my model the joint probability does not play a role. Instead, the principal designs a menu of endogenous public signals so as to motivate the principal to later on reveal the private signal. This

[5] In Dai, Lewis and Lopomo (2006) and Szalay (2009), the agent only observes an imperfect signal for the costs, but still the principal does not have any ex-post private information.

[6] Szalay (2009) shows that the opposite case where quantity is distorted downward (upward) for good (bad) realizations occurs only when the principal motivates the agent not to gather information.

difference enables me to identify how the equilibrium quantity is affected by the need to gather information and the resulting effects on welfare.

Matthews and Postlewaite (1985), Shavell (1994) and Polinsky and Shavell (2006) consider firms that can acquire information concerning the quality or safety of their products, and choose whether to credibly reveal it to consumers. This literature focuses on the question of whether mandatory disclosure increases or decreases the incentives of firms to acquire information, and the effect of mandatory disclosure on welfare. The informational structure in my paper differs from that in the above papers in that I assume that the seller, the supplier, cannot credibly disclose its acquired information to the buyer, which is an intermediary between the seller and the final consumer. The paper reveals that if the supplier can credibly disclose information, then the buyer can write a contract that motivates the supplier to do so without having to distort the quantity away from the vertical integration quantity.

The result that the buyer may prefer to deal with a financially unconstrained but inefficient supplier is related to the literature on moral hazard with liquidity constraints. Lewis and Sappington (2000) and Lewis and Sappington (2001) study the optimal contract in a principal-agent problem under moral hazard, when the agent is privately informed about its level of effort and wealth. My paper contributes to this literature by considering liquidity constraints in the context of information gathering when both the principal and the agent gain some unverifiable information. Moreover, Lewis and Sappington (2000) consider the case where the principal deals with one agent, while Lewis and Sappington (2001) consider the case of multiple agents with identical ability. In my paper the principal faces two agents that differ both in their abilities and in their liquidity constraints. However, unlike Lewis and Sappington (2000) and Lewis and Sappington (2001), I focus on the limiting case where the agent's liquidity constraint is common knowledge.

The rest of the paper is organized as follows. The next section provides several examples of the type of informational problems that motivated this study. Section 3 describes the model and a first-best benchmark. Section 4 considers the contract for motivating the supplier to test the product when the buyer cannot observe whether the supplier has actually done so, and the conditions under which the buyer will use such a contract. Section 5 evaluates the effect of the optimal contract on social welfare in the context of two competing suppliers. Section 6 offers some concluding remarks. All the proofs are in the Appendix.

## 2. Motivating examples

In this section I discuss three important assumptions of my model. The first two assumptions involve two informational problems. First, the supplier can perform a test to gather partial information concerning the quality of the new product, but performing the test and the results of the test are unverifiable, or are the supplier's private information. Second, once the buyer decides to deal with the supplier, the buyer observes the actual quality, which is again unverifiable or the buyer's private information.

This information structure is motivated by several examples. The first example concerns the relationship between suppliers and retailers such as supermarkets and drugstores. In this context, the first informational problem is motivated by the finding of the FTC (2001) that the inability of manufacturers to credibly convey private information on the outcome of market research is one of the reasons that retailers ask for slotting allowances. The FTC didn't provide evidence that a retailer can solve this informational problem by making the contract contingent on the outcome of market research.

Chu (1992) provides several explanations for why market research might be unverifiable. First, a manufacturer may choose to selectively report only positive test market studies. Second, a manufacturer may choose to test the product only in geographical areas (or consumer groups) that are likely to respond positively. Third, a manufacturer may manipulate the data analysis. Finally, Chu (1992) argues that as supermarkets and mass merchants need to assess more than 2,500 new products each year, it is impractical for them to write contingency contracts for each one of them. These arguments are consistent with the literature on market research. Dolan (1991) describes different methods for market research, which are highly sensitive to their design, such as the types of questions asked in a telephone questioner and the sampling method. Klompmaker et al. (1976), Ozer (1999) and Cavusgil, et al. (2009) highlight the need to perform market research throughout the process of introducing a new product, but differ in their perspectives on how to perform a continuous market research. The Harvard Business Essential (2006) highlights the importance of "informal" market research that involves qualitative data, which are naturally more difficult to measure, such as the way participants in test groups respond to a new product. This literature indicates that market research involves such a large set of methods that a retailer may find it difficult to determine whether a supplier conducted a reliable and comprehensive study and to contract on its outcome.

The relationship between suppliers and retailers can involve the second informational problem that my paper considers. The report of the FTC (2001) finds that retailers can acquire ex-post information once they place the product on the shelf. However, it does not provide evidence that contracts can be directly contingent on this information. Instead, contracts can involve buy-back guarantees or failure fees, which are contingent only on actual quantities bought and resold by the retailer. Consistent with this observation, I make a distinction between the actual quantity, which I assume to be verifiable and contractible, and a demand parameter which is unverifiable.[7] It is possible to think of several explanations for why this may be the case. First, the report of the FTC finds that: "the success or failure of a new product depends to some important degree not only on the manufacturer, but also on the support that it receives from the retailer" (pp. 16). In real-life situations, such moral hazard problems, which, for simplicity, I do not explicitly model, could justify my assumption that the actual demand for a new product might be unverifiable. Second, a manufacturer can potentially infer the demand from looking at the quantity that the retailer sells and the price. However, in real-life situations, actual demand is a function of additional factors (prices of substitutes and complements, seasonality, macroeconomic shocks, etc.), which makes it difficult to write a verifiable contract that takes all of these factors into account.

I should note that vertical relations may involve some degree of contractible demand information. The results of my model hold better when the two informational problems are stronger. My model can also suggest how advances in information technology that enhance the ability of firms to share and contract on information can affect market outcome.[8]

Another example of markets that involve the two informational problems that my paper identifies is outsourcing to suppliers in developing markets. Many western manufacturers choose to deal with suppliers from developing markets to produce intermediate and sometime final products. In my model, the buyer can be a manufacturer that needs to motivate a new, but geographically remote supplier to test the durability or safety of its product. The buyer may have the alternative of producing the product in-house, or dealing with a known (perhaps local) supplier (I call this the old product).

Berman and Swani (2010) report that while some western manufacturers rely on safety tests conducted by remote suppliers, the geographical distances make it difficult for these manufacturers to monitor the suppliers' product testing. In extreme cases, suppliers manipulated or concealed the results of safety tests. One unfortunate example is the contaminated milk scandal of 2008. Patrick et al. (2008) report that Cadbury, for example, relied on the external suppliers of its milk products to perform their own tests; "nobody can look for everything", was the claim of the firm's spokesman. Schmit (2008) reports that the toy manufacturer RC2 was accused of not rigorously checking whether its suppliers tested paint for lead and how well the testing was done.

The relationship between manufacturers and their long-distance suppliers also involves the second informational problem that my paper considers. In the above examples,

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[7] As I explain in Section 5, in some cases the contract needs also to rely on the quantity that the buyer sells to final consumers.

[8] Garry (2012), for example, reports that Kroger, a large food retailing company, is planning to adopt a data synchronizing system called Global Data Synchronization Network (GDSN) in early 2013.

manufacturers can learn whether their final product is safe or not. Patrick et al. (2008) report that food manufacturers, including Cadbury, did conduct tests and quality control in their factories on their final products. However, the manufacturer's ex-post information may not be verifiable for the following reasons. First, the tests that manufacturers conduct may lead to inconclusive results. In the example of the contaminated milk scandal, different tests produced different results, making it difficult for manufacturers to prove that these products were indeed contaminated. Second, it is not always possible to contract with suppliers on all ex-post possibilities. Patrick et al. (2008) report that Nestle, for example, conducted 70 different quality tests on its final milk products, but only began looking for melamine after the milk scandal became public. Third, a manufacturer's final product is a combination of many intermediate products, and it is therefore difficult to prove that a particular supplier was the source of contamination.

Berman and Swani (2010) propose several ways in which manufacturers can monitor the product testing of their remote suppliers. These methods are costly, and involve placing the manufacturer's representatives in the suppliers' factory. My model offers the alternative of an incentive contract, which could also help in limiting the scope of the informational problems, though "costly" in that it involves suboptimal quantities.

A third example of markets that involve the two informational problems is to be found in government procurement. In the mid 2000's, the Israeli government had to decide on ways for improving civil defense against ground-to-ground missiles. The two main options were "passive" defense such as bomb shelters, which Israel already has and could be developed further, and an "active" high-tech system for intercepting ground-to-ground missiles in mid-air.

This example has features in common with the first informational problem. The Israeli State Comptroller (2008) reports that in 2006, Refael, an Israeli high-tech firm, started developing the "Iron Dome", an active defense system, following the interest shown in such a system by the Israeli government. The Israeli government signed an agreement with Refael only a year later. The Comptroller reports that the Israeli government didn't test or view tests of the new system before signing the agreement with Refael (p. 6). The agreement didn't specify concrete and measurable requirements from the system, such as a required success rate of intercepting missiles, or a required range (pp. 7, 11 and 13).

This example also has features in common with the second informational problem. According to the Comptroller's report, the agreement gave the government flexibility to choose how many units to order, based on the government's own evaluation of the success of the new system (p. 33). The system was first used in March 2012, during an armed conflict.[9]

[9] See, for example, Cohen and Yagna (2012).

The success rate and other performance measures of the new system during the 2012 conflict were reported in the public media.[10] However, as noted above, these measures were not part of the agreement between the government and Refael. It is possible to think of three explanations for why the system's actual performance may not be fully verifiable. First, it depends on a set of changing factors such as weather conditions and the system's geographic location. Second, as Pecht et al. (2012) note, the Iron Dome is a multi-task system that aims to respond to a variety of threats. Third, the system was operated by the army, and its actual success depended on the ability and performance of the soldiers operating it.[11] These explanations imply that it may be too difficult to contract on the all of the above features.

Another important assumption in my model is that the buyer makes the contract offer before the supplier tests its new product. This assumption implies that the buyer's contract affects the supplier's decision on whether to test the new product.

In the first example of vertical relations between suppliers and retailers, it is possible to think of this timing as representing a situation where a supermarket is already using its shelf space for an old product. The supermarket announces a long-term policy in which new suppliers have to meet its contracting requirements, which may include paying slotting allowances, in order to gain shelf space. A short-sighted supermarket, believing that the supplier has already invested in market research, may have an incentive to change the contract offer. Then, however, future suppliers will not invest in costly market research, as they will anticipate that the supermarket will not maintain its initial offer. This will not be in the long-run interest of the supermarket, and therefore a forward-looking supermarket will have an incentive to maintain its long-run policy. In my second example of manufacturers that deal with external suppliers, suppliers typically conduct product safety testing during and after production, while contracts are negotiated prior to production. Therefore, the contract offer can affect the suppliers' decision to perform product testing. In my third example concerning the "Iron Dome" defense system, the annual report by the Israeli State Comptroller (2008) indicates that the Israeli government proposed to Refael that they develop such a system in 2005 (p. 5). Refael indeed started to develop the system in 2006, but only signed the contract with the Israeli government in 2007. This indicates that long-term commitment is indeed possible when the buyer is a government that needs to establish a reputation for writing contracts to motivate product testing.

[10] See, for example, Katz and Lappin (2012).
[11] See, for example, Cohen (2012).

## 3. The model and vertical integration benchmark

Consider a market with a buyer and a supplier, both risk neutral. The supplier can produce a new intermediate product at cost $c(q)$, where $q$ is the quantity and $c_q(q) \geq 0$, $c_{qq}(q) \geq 0$, $c_q(0) = 0$ and $\lim c_q(q) \to \infty$ for $q \to \infty$. For the most part, I will interpret the buyer as a downstream firm that can transform the new intermediate product into a final product at a one-to-one technology and sell it to final consumers at zero cost. The inverse demand for the new product is $p(q;\theta)$, where $p$ and $q$ are the price and quantity respectively, and $\theta$ measures the new product's actual or perceived quality, from the viewpoint of final consumers, or the product's safety.[12] Suppose that $p_q(q;\theta) < 0$ and $p_\theta(q;\theta) > 0$.

Let $V(q;\theta) \equiv p(q;\theta)q$ denote the buyer's payoff from using the new product, as a function of the quantity, $q$, and the parameter, $\theta$. Suppose that the buyer's marginal payoff is positive for low values of $q$, decreasing with $q$ and increasing with $\theta$: $V_{qq}(q;\theta) < 0$, $V_{q\theta}(q;\theta) > 0$ and $V_q(0;\theta) > 0$.[13] In what follows I will solve the model given $V(q,\theta)$, and therefore my model can also apply to cases where the buyer is a final buyer with utility $V(q,\theta)$. However, as I will explain in section 4, the welfare analysis is meaningful only in cases where the buyer is a downstream firm. Let $q^*(\theta)$ denote the quantity that maximizes vertical integration payoffs given $\theta$, $V(q;\theta) - c(q)$, where $q^*(\theta)$ is the solution to:

$$V_q(q^*(\theta);\theta) - c_q(q^*(\theta)) = 0. \tag{1}$$

It follows from the assumptions above that $q^*(\theta)$, $V(q^*(\theta);\theta)$ and $V(q^*(\theta);\theta) - c(q^*(\theta))$ are increasing with $\theta$.

Suppose that the parameter $\theta$ is initially unknown to both the supplier and the buyer. I consider a game of gathering information that includes two features. First, the supplier can test the potential of the new product, but the test is imperfect: it does not fully reveal $\theta$, and it is unobservable or unverifiable. Second, once the buyer buys the new product, the buyer privately acquires additional information concerning the new product, which is again unverifiable.

I model this scenario as follows. Suppose that $\theta$ is distributed along the interval $[\theta_0, \theta_1]$ according to one of two probability functions. With probability $\gamma$, $0 < \gamma < 1$, the state is "H"

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[12] In the latter interpretation it is reasonable to suspect that $\theta$ affects the buyer's costs and not the actual demand. For example, suppose that each unit of the product can inflict on the buyer a cost $d(\theta)$, where $d_\theta(\theta) < 0$, which measures the expected cost of paying liability in case the product cause damages, or the expected costs of a recall. In this scenario, given a demand function $p(q)$, the buyer earns on each unit $p(q;\theta) = p(q) - d(\theta)$.

[13] Notice that $V_{qq}(q;\theta) = p_{qq}(q;\theta)q + 2p_q(q;\theta)$. Since $p_q(q;\theta) < 0$, $V_{qq}(q;\theta) < 0$ whenever $p_{qq}(q;\theta)$ is either negative, or positive but sufficiently low. Also, $V_{q\theta}(q;\theta) = p_{q\theta}(q;\theta)q + p_\theta(q;\theta) > 0$ requires that $p_{q\theta}(q;\theta)$ is positive, or negative but sufficiently low in absolute terms because $p_\theta(q;\theta) > 0$. Finally, $V_q(0;\theta) > 0$ only requires that $p(0;\theta) > 0$.

and $\theta$ is drawn from a "high" probability distribution function, $f_H(\theta)$. With probability $1 - \gamma$, the state is "L" and $\theta$ is drawn from a "low" probability distribution function, $f_L(\theta)$.[14] Suppose that $f_k(\theta) > 0$, $\forall\theta\in[\theta_0, \theta_1]$, $\forall k = \{H,L\}$. This assumption implies that any $\theta\in[\theta_0, \theta_1]$ can be drawn from both $f_H(\theta)$ and $f_L(\theta)$, and the buyer cannot learn the state by observing $\theta$. The cumulative distribution function for $f_k(\theta)$, $k = H,L$, is $F_k(\theta)$, where $F_k(\theta_0) = 0$ and $F_k(\theta_1) = 1$.

The difference between the two states is that

$$E_H\big(V(q^*(\theta);\theta) - c(q^*(\theta))\big) > E_L\big(V(q^*(\theta);\theta) - c(q^*(\theta))\big), \tag{2}$$

where

$$E_k\left(V(q^*(\theta);\theta) - c(q^*(\theta))\right) = \int_{\theta_0}^{\theta_1}\left(V(q^*(\theta);\theta) - c(q^*(\theta))\right)f_k(\theta)d\theta, \quad k = \{H, L\}, \tag{3}$$

denotes the expected vertical integration payoff that can be obtained from the new product in state $k = \{H,L\}$, given that a vertically integrated firm can observe the realization of $\theta$ before setting $q^*(\theta)$. Condition (2) implies that from the viewpoint of maximizing the vertical integration profit, the new product is more profitable (in expectation) when the state is H.

Suppose that the supplier can perform a test, at cost $C$, that reveals to the supplier the state $k = \{H,L\}$, but not $\theta$. Notice that this modeling of imperfect product testing is a generalization of special cases in which the test only reveals some statistical parameter (such as the average quality or the dispersion of potential qualities), in which case the two distribution functions differ only with respect to a particular statistical dimension. In my analysis below, I do not make any restrictions on the difference between the two distortions other than condition (2), in order to keep the discussion as general as possible. In section 3.2, I consider an example in which the two distributions differ in one statistical parameter and discuss the economic interpretation of the results.

Suppose that the buyer has a reservation utility $V^*$ from buying an old product of known quality, where $E_H(V(q^*(\theta);\theta) - c(q^*(\theta))) > V^* > E_L(V(q^*(\theta);\theta) - c(q^*(\theta)))$. This assumption implies that the buyer benefits from knowing the true state because it can then choose the new product if the state is H and the old product if the state is L. In deciding whether to ask the supplier to test its product, the buyer will compare this benefit with the cost of the test.

Consider the following three-stage game, which I illustrate in Figure 1. In the first stage, the buyer offers a take-it-or-leave-it contract to the supplier. There are many potential contracts that the buyer can offer to the supplier. A general form of a contract is a payment scheme, $T(q)$, such that if the supplier accepts the contract, the buyer commits to substituting

[14] I discuss the robustness of the results to more than two states in the Conclusion.

the old product with the new one, and then after observing $\theta$, buying a certain $q$ from the supplier for the price of $T(q)$. In this case, the buyer will buy ex-post the quantity $q(\theta)$ that maximizes $V(q;\theta) - T(q)$ given $\theta$, and pay to the seller $T(\theta) = T(q(\theta))$. For simplicity, it would be convenient to solve the model for a direct menu, $\{q(\tilde{\theta}), T(\tilde{\theta})\}$, such that the buyer reports some $\tilde{\theta}$ and receives the line $(q(\tilde{\theta}), T(\tilde{\theta}))$, where $\tilde{\theta}$ denote the buyer's report while $\theta$ denote the true quality. I allow for both positive or negative $T(\tilde{\theta})$. Moreover, $(q(\tilde{\theta}), T(\tilde{\theta}))$ can represent a linear or non-linear $T(q)$. In section 5, I study the equivalence between this menu and the original contract.

Notice that if the buyer motivates product testing, the buyer does not want to offer a menu that is accepted in state L. To see why, suppose that the buyer offers a menu $\{((q(\tilde{\theta}|H), T(\tilde{\theta}|H)), (q(\tilde{\theta}|L), T(\tilde{\theta}|L))\}$ that motivates the supplier to test the new product and choose $(q(\tilde{\theta}|i), T(\tilde{\theta}|i))$ in state $i \in \{H, L\}$. Since the menu that maximizes the vertical integration profit given $\theta$ is $(q(\tilde{\theta}), T(\tilde{\theta})) = (q^*(\tilde{\theta}), c(q^*(\tilde{\theta}))$, the buyer cannot earn from this option more than $\hat{V}^* \equiv \gamma E_H(V(q^*(\theta);\theta) - c(q^*(\theta))) + (1 - \gamma)E_L(V(q^*(\theta);\theta) - c(q^*(\theta)))$. However, the buyer can always earn $\hat{V}^*$ by offering a contract that does not induce product testing, by offering $(q(\tilde{\theta}), T(\tilde{\theta})) = (q^*(\tilde{\theta}), c(q^*(\tilde{\theta}))$ and using the new product without any product testing. As I will show in Proposition 2, the menu $\{((q(\tilde{\theta}|H), T(\tilde{\theta}|H)), 0\}$, in which the buyer does not deal with the supplier if the state is L, can provide the buyer with higher profit than $\hat{V}^*$. I can therefore write the menu $\{((q(\tilde{\theta}|H), T(\tilde{\theta}|H)), 0\}$ as $\{(q(\tilde{\theta}), T(\tilde{\theta})\}$.[15]

In the second stage, the supplier observes the menu $\{q(\tilde{\theta}), T(\tilde{\theta})\}$ and chooses whether to perform the test or not. The buyer cannot verify the results of the test and write a contract contingent on whether the supplier has performed a reliable test. After either observing the results of the test or not performing it, the supplier decides whether to accept the contract or not. The supplier's reservation profit from rejecting the contract is zero. In the third stage, if the supplier has rejected the contract, or if the buyer has chosen in the first stage not to make an offer to begin with, then the buyer remains with the old intermediate product and earns $V^*$. If the buyer has made an offer that the supplier has accepted, then the buyer carries the new product, and a learning process begins in which the buyer learns $\theta$. Following Chu (1992) in the context of the retail industry, I assume that the buyer learns $\theta$ immediately after the supplier agreed to the contract, though the buyer cannot learn $\theta$ without forgoing the potential profit from the old intermediate product, $V^*$. For example, many supermarkets use a barcode system that provides accurate, up-to-date data on actual sales. Notice that it is possible to

[15] It is straightforward to show that there is no loss of generality in considering contracts that do not include payment if there is no trade.

interpret $V^*$ as the cost or the length of the process of learning θ, because while the buyer is trying out the new product, it loses $V^*$. As $V^*$ increases, the buyer's learning process becomes more costly, in that a supermarket, for example, has more to lose by placing the new product on the shelf, in terms of the profit forgone from the old product. In this interpretation, if $V^* < E_L(V(q^*(\theta);\theta) - c(q^*(\theta)))$, the process of learning θ, after the new product is on the shelf, is either very short, or inexpensive, such that the buyer will always try out the new product without asking the seller to test it. If $V^* > E_H(V(q^*(\theta);\theta) - c(q^*(\theta)))$, the learning process is too long and the buyer will never ask the supplier to test the new product. Only for intermediate values of θ such that $E_H(V(q^*(\theta);\theta) - c(q^*(\theta))) > V^* > E_L(V(q^*(\theta);\theta) - c(q^*(\theta)))$, can motivating the supplier to test the new product be potentially profitable for the buyer, depending on the value of $C$.

The buyer then reports $\tilde{\theta}$. The buyer's ex-post information is also unverifiable and cannot be part of the contract. Notice that since by assumption $f_k(\theta) > 0$, $\forall k$ = H,L, $\forall\theta\in[\theta_0, \theta_1]$, even though the buyer observes θ ex-post, the buyer cannot infer from θ if the test has been made. Intuitively, if low (high) values of θ are possible only in state L (H)—so that the buyer can learn the state from observing any realization of $\theta\in[\theta_0, \theta_1]$—the buyer could use this ex-post information to write a contract that motivates the supplier to test the new product without any quantity distortion.

From the viewpoint of maximizing total profits, a vertically integrated firm can choose between three options: first, performing the test and using the new (old) product in state H (L), and earning: $-C + \gamma E_H(V(q^*(\theta);\theta) - c(q^*(\theta))) + (1-\gamma)V^*$; second, selling the new product without testing it first and earning $\hat{V}^*$; third, selling the old product and earning $V^*$. To compare between these three options, notice that if the vertically integrated firm does not test the new product, it will use the old product if $V^* > \hat{V}^*$, and the new product if $V^* \leq \hat{V}^*$. Therefore, if $V^* > \hat{V}^*$, the firm compares between the first and the third options. If $V^* \leq \hat{V}^*$, the firm makes a comparison between the first and the second options. Comparing these options reveals that there is a cutoff,

$$C^* = \begin{cases} \gamma\left(E_H\left(V(q^*(\theta);\theta) - c(q^*(\theta))\right) - V^*\right), & if\ V^* > \hat{V}^*, \\ (1-\gamma)\left(V^* - E_L\left(V(q^*(\theta);\theta) - c(q^*(\theta))\right)\right), & if\ V^* \leq \hat{V}^*, \end{cases} \tag{4}$$

such that the vertically integrated firm performs the test if and only if $C < C^*$.

If the supplier and the buyer are vertically separated, but the buyer can observe whether the supplier tested the new product and the results of the test, then the buyer will implement the vertical integration outcome and earn the vertical integration payoff by offering a menu

$(q(\theta),T(\theta)) = (q^*(\theta), C/\gamma + c(q^*(\theta)))$ contingent on observing the result that the state is H. The supplier's expected payoffs are zero, though the supplier earns positive payoff in state H. Notice that the buyer will truthfully report θ because by setting $T(\theta)) = C/\gamma + c(q^*(\theta))$ the buyer fully internalizes the supplier's production cost.

## 4. Vertical separation and asymmetric information

This section describes the case of vertical separation, in which the supplier has to perform the costly test in order to learn the state, the results of the test cannot be verified and it cannot be verified that the test has been carried out. Once the buyer replaces the old product with the new one, the buyer learns θ, which is again unverifiable. The main conclusion of this section is that under such an informational structure, the optimal contract for motivating the supplier to test the new product includes downward or upward distortion in the quantity, depending on the two distribution functions.

I will proceed as follows. First, I characterize and solve the buyer's optimal contract that induces the supplier to perform the test. Then, I characterize the features of the contract. Then, I move to the question of whether the buyer will indeed find it optimal to use such a contract. Finally, I show how the buyer can implement this contract using slotting allowances.

### *3.1. The optimal contract for motivating the supplier to gather information*

Because the buyer cannot observe whether the supplier has performed the test and the results of the test, the buyer faces the problem of moral hazard and adverse selection: the buyer needs to motivate the supplier to perform the test, and to reveal its outcome. The buyer's problem is therefore:

$$\max_{(q(\theta),T(\theta))} E_H\left(V(q(\theta);\theta)-T(\theta)\right), \tag{5}$$

s.t.

$$(IC_B) \qquad \forall\theta\in[\theta_0,\theta_1],\quad \theta=\arg\max_{\tilde\theta}\left(V(q(\tilde\theta);\theta)-T(\tilde\theta)\right),$$

$$(IC_S^{ex-post}) \qquad E_L\big(T(\theta)-c(q(\theta))\big)\le 0,$$

$$(IR_S^{ex-post}) \qquad E_H\big(T(\theta)-c(q(\theta))\big)\ge 0,$$

$$(IC_S^{ex-ante}) \quad -C+\gamma E_H\big(T(\theta)-c(q(\theta))\big)\ge \gamma E_H\big(T(\theta)-c(q(\theta))\big)+(1-\gamma)E_L\big(T(\theta)-c(q(\theta))\big),$$

$$(IR_S^{ex-ante}) \quad -C+\gamma E_H\big(T(\theta)-c(q(\theta))\big)\ge 0.$$

Notice that the buyer's profit is derived under the assumption that the buyer truthfully reports: $\tilde\theta = \theta$. Therefore, the first constraint, $IC_B$, is the buyer's incentive compatibility, which ensures that given that the supplier has accepted the contract and the buyer has observed the realization of θ, the buyer will choose the corresponding line from the menu by truthfully reporting θ. This first constraint emerges because of the buyer's ex-post private information and the inability to contract on the actual realization of θ. The next two constraints relate to the supplier's ex-post behavior. After performing the test, $IC_S^{ex-post}$ ensures that the supplier prefers not to accept the contract if the state is L, while $IR_S^{ex-post}$ ensures that the supplier accepts the contract if the state is H. The last two constraints relate to the supplier's ex-ante behavior. The $IC_S^{ex-ante}$ constraint ensures that the supplier prefers to perform the test, given that afterwards it will accept the contract only if the state is H (which occurs with probability γ), over accepting the contract without testing the new product first. The $IR_S^{ex-ante}$ constraint ensures that the supplier prefers to perform the test over not interacting with the buyer.

To solve this problem, notice that $IC_S^{ex-post}$ and $IR_S^{ex-post}$ are not binding, as they are satisfied whenever $IC_S^{ex-ante}$ and $IR_S^{ex-ante}$ are satisfied. Next I turn to rewriting $IC_B$. Let $U(\theta;\tilde{\theta}) = V(q(\tilde{\theta});\theta) - T(\tilde{\theta})$ and let $U(\theta) = U(\theta;\theta)$ denote the buyer's ex-post payoff given that it truthfully reports: $\tilde{\theta} = \theta$. As is well known (see for example Laffont and Martimort (2001)), necessary and sufficient conditions for $IC_B$ are that $q(\theta)$ is non-decreasing with θ and the buyer earns:

$$U(\theta) = U(\theta_0) + \int_{\theta_0}^{\theta} V_\theta(q(\hat{\theta});\hat{\theta})d\hat{\theta}. \tag{6}$$

Intuitively, if the buyer is to be induced to ex-post report θ, it needs to specify its ex-post "information rents", defined in (6). These information rents differ from the usual information rents in the principal-agent literature in that here, the principal, the buyer, leaves them not to the agent, but to itself. Using (6), $IC_B$ requires that:

$$T(\theta) = V(q(\theta);\theta) - \int_{\theta_0}^{\theta} V_\theta(q(\hat{\theta});\hat{\theta})d\hat{\theta} - U(\theta_0). \tag{7}$$

Substituting (7) into (5), $IC_S^{ex-ante}$, $IR_S^{ex-ante}$ and rearranging, I can rewrite the buyer's problem as: [16]

$$\max_{q(\theta)} E_H\left(V(q(\theta);\theta) - c(q(\theta)) - \frac{C}{\gamma}\right), \tag{8}$$

s.t.

[16] In the Appendix I show that this reduced maximization problem is equivalent to the original maximization problem.

$$E_H\left(T(\theta)-c(q(\theta))\right)-E_L\left(T(\theta)-c(q(\theta))\right)\geq\frac{C}{\gamma(1-\gamma)}, \tag{9}$$

$$q_\theta(\theta) \geq 0 \text{ and } (7).$$

Therefore, the buyer's problem is to maximize the vertical integration profit, subject to the constraint that the gap between the supplier's expected payoffs in states H and L is sufficiently wide in comparison with the cost of the test. This constraint is binding, as the following lemma shows:

**Lemma 1:** *The full information quantity,* $q^*(\theta)$, *does not satisfy* (7) *and* (9).

I therefore maximize (8) given that (7) and (9) are binding, and then verify that the solution satisfies $q_\theta(\theta) \geq 0$. Let $q^{**}(\theta)$ and $T^{**}(\theta)$ denote the equilibrium contract. Substituting (7) into (9), the first-order condition with respect to $q(\theta)$ is:

$$V_q(q(\theta);\theta)-c_q(q(\theta))=\lambda V_{q\theta}(q(\theta);\theta)\frac{F_L(\theta)-F_H(\theta)}{\left(f_H(\theta)+\lambda(f_H(\theta)-f_L(\theta))\right)}, \tag{10}$$

where the left-hand side set equal to zero is the first-order condition under vertical integration (see (1)), and $\lambda$ is the Lagrange multiplier. For $\lambda = 0$, the right-hand side of (10) equals zero and therefore the solution is identical to the vertical integration quantity. If $\lambda > 0$ but not too high, then the term in the denominator in the right-hand side of (10) is positive because by assumption $f_H(\theta) > 0$, $\forall\theta\in[\theta_0, \theta_1]$. Moreover, recalling that by assumption $V_{\theta q}(q;\theta) > 0$, the sign of the quantity distortion is negatively affected by the sign of the gap $F_L(\theta) - F_H(\theta)$. The first Proposition shows that this is indeed the case:

**Proposition 1:** *There is an interior solution to the buyer's problem if C is sufficiently small and* $\gamma$ *is intermediate. In this solution, for a given* $\theta$, $q^{**}(\theta) < ( > )\ q^*(\theta)$ *if* $F_L(\theta) > ( < )\ F_H(\theta)$. *The gap* $|q^*(\theta) - q^{**}(\theta)|$ *equals 0 if* $C = 0$ *and is increasing with C, and decreasing (increasing) with* $\gamma$ *for* $\gamma < (>)\ 1/2$. *The supplier's payoff,* $T^{**}(\theta) - c(q^{**}(\theta))$ *is increasing* (*decreasing*) *with* $\theta$ *if* $F_L(\theta) > ( < )\ F_H(\theta)$.

Proposition 1 indicates that the distortion in the equilibrium quantity at a given $\theta$ depends on the gap between the two cumulative distribution functions.

The intuition for this result is the following. The buyer needs to design a contract that achieves two goals. The first is to motivate the supplier to test the new product and reveal the state, and the second is to provide itself with the motivation to reveal its own ex-post information. To achieve the first goal, the buyer needs to set a contract such that the supplier will gain low (and in some cases negative) payoff in realizations of θ that are more likely in state L, and high payoff in realizations of θ that are more likely in state H. The supplier will indeed find it profitable to agree to the contract only after testing the new product and realizing that it has a high potential, because otherwise it incurs negative expected payoff. To achieve the second goal, however, the buyer needs to distort the quantity, because otherwise it will have an ex-post incentive to report a θ that is more likely to emerge in state L. By distorting the quantity, the buyer can increase its own ex-post profit at the expense of the supplier, but the supplier is aware of this and will not agree to the contract to begin with. Now, for realizations of θ such that an increase in θ increases the supplier's payoff, the buyer has an ex-post incentive to understate θ. To counterbalance this incentive, the buyer will ex-ante distort the quantity downwards, such that understating θ involves buying a small quantity. Likewise, for realizations of θ such that an increase in θ decreases the supplier's payoff, the buyer has an ex-post incentive to overstate θ. To counterbalance this incentive, now the buyer will ex-ante distort the quantity upwards, such that overstating θ involves buying a larger quantity.

To conclude, under asymmetric information the buyer distorts the supplier's payoff, such that it will depend on θ, in order to motivate the supplier to test the new product. At the same time, the buyer distorts the equilibrium quantity to provide itself with the motivation to truthfully report θ. The optimal solution balances between these two considerations.

As for the effect of $C$ on the contract, the result that the buyer can implement the vertical integration outcome if $C = 0$ indicates that the assumption that the supplier needs to engage in costly information gathering is crucial in this model. As $C$ increases, a higher gap between the supplier's expected payoff in the two states is needed to motivate the supplier to test the new product, which in turn forces the buyer to increase the distortion in the quantity (either upwards or downwards). The effect of γ on the equilibrium distortion is however non-monotone. For low values of γ, the supplier has a strong incentive not to perform the test and to reject the contract because it is most likely that the state will turn out to be L anyway, making $IR_S^{ex-ante}$ more restrictive. For high values of γ, the supplier has a strong incentive to accept the contract without performing the test because the state is most likely to be H anyway, making $IC_S^{ex-ante}$ more restrictive.

Notice that an interior solution to the buyer's problem can only be ensured if $C$ is not too high and γ is intermediate. Intuitively, if $C$ is high enough or γ is either close to zero or one, then the resulting distortion in $q(\theta)$ can potentially be too significant, such that there will be some realizations of θ in which $q_\theta^{**}(\theta) < 0$, in violation of the condition that $q^{**}(\theta)$ is non-decreasing. Also, the proof of Proposition 1 shows that the second-order condition for the buyer's problem can be ensured only if $C$ is low or $\gamma$ is close to 1/2. Otherwise, the buyer's problem as defined above does not have an interior solution. The critical values of $C$ and $\gamma$ that can give rise to such a problem, if at all, depend on the specification of the two distribution functions. To avoid making additional assumptions on the distribution functions, I will focus the discussion on the case where $C$ is low and $\gamma$ is intermediate, for which Proposition 1 ensures that there is an interior solution.

The results of Proposition 1 are consistent with Dai, Lewis and Lopomo (2006) and Szalay (2009), where the information that the agent gathers is an imperfect signal of the actual marginal costs. These authors, who focus on distribution functions that satisfy versions of a mean-preserving, stochastic dominance, find that the quantity distortion is affected by the ranking of the distribution functions of the potential signal. Thus, the equilibrium quantity is distorted upward (downward) for good (bad) realizations of the signal (in Szalay (2009), and the opposite pattern occurs if the principal motivates the agent not to gather information. In my model the structure of information is different in that it is the principal that observes the actual realization of quality and chooses the quantity based on this information. This enables me to consider a boarder range of distribution functions, and generate richer results in terms of the quantity distortion. I explore these possibilities in the next subsection.

### *3.2. The characteristics of the optimal contract*

As I have explained above, I allow for any arbitrary distribution functions that satisfy (2). Therefore, cases in which the test only reveals some statistical measure of $\theta$ are special cases of my model. In this section, I consider an example in which the test reveals one statistical parameter concerning potential qualities. This example enables me to provide an economic interpretation of my results, and in particular to identify how the two informational problems affect the equilibrium contract. [17]

To this end, suppose that the two distributions are unimodal along the interval [0, 1] of the form:

$$f_t(\theta) = \begin{cases} 1-\alpha_t + 2\dfrac{\alpha_t}{\beta_t}\theta, & if\ \theta \le \beta_t, \\ 1-\alpha_t + 2\dfrac{\alpha_t}{1-\beta_t}(1-\theta), & if\ \theta > \beta_t, \end{cases} \quad t \in \{H, L\}. \tag{11}$$

[17] In a supplementary note, I provide more general statements on how the relationship between the two distribution functions affects the quantity. The note is available at http://www.tau.ac.il/~yehezkel/. In this section I illustrate the main points of this example, and discuss their implications for product testing.

where $\alpha_t \in [0,1]$ and $\beta_t \in [0,1]$. Figure 2 illustrates a probability distribution as a function of $\alpha$ and $\beta$. Fixing $\alpha$, the parameter $\beta$ is the single mode of the distribution that identifies whether a distribution is skewed to the left ($\beta < 1/2$), in which case $\theta$ is more likely to be low, or to the right ($\beta > 1/2$), in which case $\theta$ is more likely to be high. Fixing $\beta$, the parameter $\alpha$ identifies whether a distribution is dispersed (low $\alpha$) or concentrated (high $\alpha$). To see the economic interpretations of $\alpha$ and $\beta$, and how they affect the features of the contract, I distinguish between two polar cases:

***Case 1 - The test reveals the mode:*** Suppose that $\alpha_L = \alpha_H$, and that the test identifies whether the mode is $\beta_L$ or $\beta_H$, where $\beta_H > \beta_L$.[18] Intuitively, for a given $\alpha_L = \alpha_H$, the gap $\beta_H - \beta_L$ measures the quality of the supplier's ex-post information from performing the test. For $\beta_H - \beta_L \to 0$, the two distribution functions become very similar, and therefore the test provides little new information to the supplier. As $\beta_H - \beta_L$ increases, the supplier obtains more valuable information from testing the new product. As the following corollary shows, in this case the equilibrium contract involves a downward quantity distortion for all levels of qualities other than the two extremes, 0 and 1. This distortion is more significant the more valuable is the information that the supplier obtains from conducting the test, i.e., the higher is $\beta_H - \beta_L$.

**Corollary 1:** *Consider the distribution functions defined in* (11), *and suppose that* $\beta_H > \beta_L$ *and* $\alpha_L = \alpha_H$. *Then, if* $\beta_H - \beta_L \to 0$, *there is no quantity distortion:* $q^*(\theta) - q^{**}(\theta) \to 0$. *As* $\beta_H - \beta_L$ *increases, there is a stronger downward quantity distortion:* $q^*(\theta) - q^{**}(\theta)$ *increases for all* $\theta \in (0, 1)$.

The intuition for this result follows from the intuition to Proposition 1. Here, it is always more likely that $\theta$ will be high (low) in state H (L). Therefore, the contract will reward the supplier for high $\theta$'s, which in turn forces the buyer to distort the quantity downwards, to prevent the buyer from ex-post understating $\theta$.

Notice that in the above case, since $\alpha_L = \alpha_H$, the value of the buyer's ex-post information, from observing $\theta$, is the same for both states. In the second case I relax this assumption:

***Case 2 – The test reveals the dispersion of potential qualities:*** Now suppose that the test also reveals new information on the dispersion of potential $\theta$ in state H. Suppose that $\beta_H \geq \beta_L$, and the test also reveals whether $\alpha \in (\alpha_L, \alpha_H)$, where I allow $\alpha_H$ to be higher or lower than

[18] Notice that in this case, $f_H(\theta)$ dominates $f_L(\theta)$ by first-order stochastic dominance.

$\alpha_L$.[19] It is possible to allow for the case of $\beta_H = \beta_L$, in which case the two distributions differ only in $\alpha$.[20] Now, given $\alpha_L$, if $\alpha_H$ is high, the buyer does not have significant ex-post private information concerning $\theta$. The reason is the following. Recall that the buyer buys the new product only in state H. Therefore, if the distribution in state H is concentrated ($\alpha_H$ is close to 1), then the buyer is not expected to gain significant ex-post information from selling the new product, given that the supplier revealed that the state is H, because the test provides the supplier with an (almost) accurate prediction of $\theta$ in state H. As the distribution in state H becomes more dispersed ($\alpha_H$ decreases), the buyer's ex-post information concerning $\theta$ becomes more of a problem. As the following corollary shows, in this case the equilibrium contract involves downward distortion for some values of $\theta$, and upward distortion for others. In particular, if the test reveals that the new product is risky and therefore the buyer has valuable ex-post information ($\alpha_H$ is close to 0), then the contract has the somewhat counterintuitive feature of the buyer distorting the quantity upwards if demand turns out to be low, and downwards if demand turns out to be high. Otherwise, the contract involves downward distortion for low demand and upward distortion for high demand.

**Corollary 2:** *Consider the distribution functions defined in* (11), *and suppose that* $\beta_H \geq \beta_L$.

(i) *If* $\alpha_H < \alpha_L$, *then there is a cutoff,* $\overline{\theta}$, *such that the contract involves upward quantity distortion,* $q^*(\theta) < q^{**}(\theta)$, *for* $\theta \in (\theta_0, \overline{\theta})$ *and downward quantity distortion,* $q^*(\theta) > q^{**}(\theta)$, *for* $\theta \in (\overline{\theta}, \theta_1)$.

(ii) *If* $\alpha_H > \alpha_L$, *then there is a cutoff,* $\underline{\theta}$, *such that the contract involves downward quantity distortion,* $q^*(\theta) > q^{**}(\theta)$, *for* $\theta \in (\theta_0, \underline{\theta})$ *and upward quantity distortion,* $q^*(\theta) < q^{**}(\theta)$, *for* $\theta \in (\underline{\theta}, \theta_1)$.

The first part of Corollary 2 indicates that a government, for example, may actually use a new defense system more than is socially desirable if after trying out the system, its actual quality turns out to be low, and less than is socially desirable otherwise. Likewise, a supermarket or a manufacturer will sell more than the monopoly quantity of the new product for low realizations of quality and less than the monopoly quantity otherwise. The opposite is true for the second part of Corollary 2.

[19] Notice that in this case, the two distribution functions satisfy the definition of Diamond and Stiglitz (1974) for the single-crossing condition.

[20] The case of $\beta_H = \beta_L$ may still satisfy condition (2). In the supplementary note, I provide a condition under which this case is possible under the assumptions of my model.

The intuition for this result again follows from Proposition 1 and Corollary 1. In part (i), θ is significantly dispersed. As a result, there is a cutoff, $\overline{\theta}$, such that θ is more likely to be high (low) in state H (L) only for $\theta > \overline{\theta}$, but the opposite holds for $\theta < \overline{\theta}$. As a result, the contract's features in Corollary 1 now only hold for $\theta > \overline{\theta}$, while the complete reverse is true for $\theta < \overline{\theta}$. For part (ii), θ is significantly concentrated, and therefore the contract's features in Corollary 1 now only hold for $\theta < \overline{\theta}$, while the complete reverse occurs for $\theta > \overline{\theta}$.

I can summarize the insights from these two cases as follows.[21] As the quality of information that the supplier can gain by testing the new product increases, we are more likely to observe downward distortion either for all demand realizations, or for low demand realizations. As the quality of information that the buyer can gain from buying and using the new product increases, we are more likely to observe upward distortion for low demand and downward distortion for high demand.

*3.3. When to implement the contract*

The last step in solving for the optimal contract is to derive the conditions under which the buyer indeed prefers to use the contract under asymmetric information. As under the full information benchmark, the buyer's alternatives, if it chooses not to use the contract, are to sell the new product without motivating the supplier to test it first and earn $\overline{V}^*$, or to offer the old product and earn $V^*$. Notice that unlike Crémer, Khalil and Rochet (1998) and Szalay (2009), in this model the buyer does not need to distort the quantity to motivate the supplier not to test the new product. Intuitively, if the buyer does not want to induce product testing, it can offer the contract $(T(\theta), q(\theta)) = (c(q^*(\theta)), q^*(\theta))$. The supplier then earns zero profit for all realizations of θ and therefore has no incentive to learn θ. This contract is optimal for the buyer (given no product testing) because it implements $q^*(\theta)$ and earns ex-post $V(q^*(\theta);\theta) - c(q^*(\theta))$. Comparing the three options yields:

**Proposition 2:** *Under asymmetric information there is a cutoff, $C^{**}$, such that the buyer uses the contract if and only if $C < C^{**}$, where $0 < C^{**} < C^*$.*

Intuitively, as in the vertical integration benchmark, the buyer finds it profitable to perform the test on the new product if $C$ is sufficiently low. However, Proposition 2 reveals that under vertical separation, the buyer motivates the supplier to test the new product less than under vertical integration, in that vertical separation decreases the cutoff from which point onwards the buyer motivates product testing. The reason is that asymmetric information

[21] The results of these polar cases are qualitatively similar to the more general case considered in the supplementary note available at http://www.tau.ac.il/~yehezkel/.

inflicts additional costs of performing the test, in the form of the quantity distortion, either upwards or downwards. In both cases, total industry profit is lower than under full information, making it less desirable for the buyer to motivate the supplier to perform the test.

*3.4. Implementing the contract with slotting allowances*

Next, I turn to the issue of how to implement the optimal contract. One of the features of the contract is that in order to ensure the constraint $E_L(T^{**}(\theta) - c(q^{**}(\theta))) < -C/(1-\gamma)$, the buyer will set a payment that is below production costs, and possibly negative, for some realizations of θ. In this case, the supplier not only earns a negative payoff, but may actually pay the buyer instead of being paid. Ex-post, the supplier may refuse to produce a certain quantity for the buyer and to pay the buyer for doing so. This raises the problem of how to implement the contract. To solve this implementation problem, the buyer can ask the supplier to make an upfront payment, and offer the supplier an ex-post positive payment to compensate it for its production cost. The following Proposition identifies the amount of such upfront payment for the case of first-order stochastic dominance (FOSD):[22]

**Proposition 3:** *Suppose that $F_H(\theta)$ dominates $F_L(\theta)$ by FOSD. Then the buyer can implement the equilibrium contract by offering $(S, \tilde{T}(q))$, where $S = -T^{**}(\theta_0) + c(q^{**}(\theta_0))$ is an upfront payment that the supplier pays the buyer, and $\tilde{T}(q)$ is a positive payment from the buyer to the supplier and is increasing with q, where $\tilde{T}(q) = -T^{**}(\theta_0) + c(q^{**}(q)) + T^{**}(\theta^{-1}(q)) > 0$, for any $q > q^{**}(\theta_0)$, and $\theta^{-1}(q^{**}(\theta)) = \theta$ is the inverse function of $q^{**}(\theta)$.*

Proposition 3 provides a new explanation for slotting allowances. This explanation is consistent with the FTC's (2001) finding that slotting allowances can emerge because of a manufacturer's need to study the potential of a new product. Notice that even if production costs are high, making $T^{**}(\theta)$ always positive, there are still hidden slotting allowances in that for some values of θ, $T^{**}(\theta)$ does not cover all of the supplier's production costs. As the supplier may not agree to produce ex-post, if the payment is below cost, this again will require the buyer to charge upfront payment, according to the contract in Proposition 3.

The results of Proposition 3 rely on the assumption that $F_H(\theta)$ dominates $F_L(\theta)$ by *FOSD*. Intuitively, recall that Proposition 1 indicates that in this case the supplier's payoff is strictly increasing with θ. This means that the buyer charges $T^{**}(\theta)$, which is below production cost and possibly negative only for low values of θ. Moreover, $T^{**}(\theta)$ is strictly

[22] The proof follows directly from Corollary 1 and is therefore omitted.

increasing in θ. [23] Therefore, it is possible to implement the contract with a payment, $\tilde{T}(q)$ ,which is increasing in $q$. If the two distributions cannot be ranked according to *FOSD*, the contract will still include fees that are below cost and possibly negative for some realizations of θ. However, it may be the case, if $F_H(\theta)$ is significantly higher than $F_L(\theta)$ for some realizations θ, that $T^{**}(\theta)$ is decreasing with θ for some (though not all) values of θ. In such a case, implementing the menu ($T^{**}(\theta)$, $q^{**}(\theta)$) with a contract $\tilde{T}(q)$ requires the condition that the buyer consumes $q$. In the context of vertical relations between a supplier and a retailer, this requires the retailer to commit to reselling all the units that the retailer buys from the supplier to final consumers. This can be the case if the product at hand is costly to dispose of, or if a retailer can sign a contract contingent on inventory or barcode data. As I explained in section 2 supermarkets and suppliers use information systems that enable them to share such information in a verifiable way. At the same time, it is obvious that implementing such a contract becomes more difficult than in the case of *FOSD*.

## 5. The effect of the contract on social welfare

This section evaluates the effect of the contract on social welfare. If the buyer is a final buyer that internalizes all the social gains from using the new product, the buyer will use the contract that motivates the supplier to test the new product only if doing so increases social welfare. When the buyer is a downstream firm, however, it may not fully internalize the effect of the contract on final consumers, and may choose to use it even when it is inefficient to do so. The main point of this section is that the buyer may use the contract for motivating product testing even though it reduces social welfare, because it does not fully internalize the negative effect that the resulting quantity distortion has on final consumers.

The effect of the contract on social welfare has an important implication for antitrust policies with regard to slotting allowances. As I explained in the Introduction, previous antitrust investigations indicated that slotting allowances might discriminate against small suppliers that cannot afford making high upfront payments, but at the same time might enable retailers to efficiently allocate limited shelf space for products that consumers value the most. This tradeoff raises the question of whether a retailer might prefer dealing with a supplier of lower expected quality, over a supplier of higher expected quality, simply because the former can pay slotting allowances while the latter is a financially constrained and therefore cannot.

To answer this question, suppose now that there are two suppliers, $S_1$ and $S_2$ that offer new products of unknown quality. The expected quality of the product offered by $S_2$ is higher than that of $S_1$, but at the same time $S_2$ is financially constrained and cannot commit to a

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[23] Since $q_\theta^{**}(\theta) \geq 0$, $c(q^{**}(\theta))$ is weakly decreasing with θ. If $T^{**}(\theta) - c(q^{**}(\theta))$ is increasing with θ, it has to be that $T^{**}(\theta)$ is also increasing with θ.

contract that inflicts losses for some realizations of θ. I ask whether $S_2$'s financial constraint provides $S_1$ with an inefficient advantage over $S_2$, in that the buyer will prefer to motivate $S_1$ to test its new product and then use it if the state is H even though a social planner, aiming to maximize total welfare, would have preferred to use the product offered by $S_2$.

More precisely, suppose now that instead of an old and a new product, there are two suppliers, $S_1$ and $S_2$, offering two new products. As in the single supplier case, $S_1$ offers a product of a quality parameter θ distributed between $[\theta_0, \theta_1]$ according to either $f_H(\theta)$ with probability γ or $f_L(\theta)$ with probability 1 – γ. The second supplier, $S_2$, has a similar informational structure and offers a product with a quality parameter θ distributed between $[\bar{\theta}_0, \bar{\theta}_1]$ according to either $\bar{f}_H(\theta)$ with probability $\bar{\gamma}$ or $\bar{f}_L(\theta)$ with probability $1-\bar{\gamma}$.

There are two differences between the two suppliers. First, $S_2$ is financially constrained and cannot commit to a contract that does not ensures positive payoff for all realizations of θ. Below I show that this constraint will prevent the buyer from writing a contract that motivates $S_2$ to test its new product.

**Lemma 2:** *The buyer cannot write a contract for motivating $S_2$ to test its new product.*

Intuitively, any contract for motivating $S_2$ to test its new product must involve a negative payoff for some realizations of θ. However, $S_2$ will not accept such a contract.

The second difference between the two suppliers is that $S_2$ offers a new product with a higher expected profit. More precisely, let $\bar{V}^* \equiv \bar{\gamma}\, \bar{E}_H\big(V(q^*(\theta),\theta) - c(q^*(\theta))\big) + (1 - \bar{\gamma})\, \bar{E}_L\big(V(q^*(\theta),\theta) - c(q^*(\theta))\big)$ denote the expected vertical integration profit from the new product of supplier $S_2$.[24] Suppose that

$$E_H\big(V(q^*(\theta),\theta) - c(q^*(\theta))\big) > \bar{V}^* > \gamma E_H(V(q^*(\theta),\theta) - c(q^*(\theta))) + (1-\gamma)E_L(V(q^*(\theta),\theta) - c(q^*(\theta))). \quad (12)$$

That is, if the buyer does not know the states of both new products, the buyer prefers the new product of $S_2$. However, if the buyer knows that $S_1$'s new product is expected to be profitable but does not know the state of $S_2$'s new product, the buyer will prefer $S_1$ over $S_2$. It is possible to think of a variety of combinations of distribution functions and probabilities, $\bar{f}_H(\theta)$, $\bar{f}_L(\theta)$ and $\bar{\gamma}$, that satisfy condition (12), but the results below do not rely on any specific combination as long as (12) holds.

[24] I denote by $\bar{E}$ the expectation given the distribution function $\bar{f}(\theta)$.

I assume that the same ranking holds for final consumers. Suppose that consumers' utilities are quasi-linear such that consumer surplus is:

$$CS(q;\theta) = \int_0^q p(\hat{q};\theta)d\hat{q} - p(q;\theta)q\ , \qquad (13)$$

and let $\overline{CS}* = \bar{\gamma}\ \bar{E}_H CS(q^*(\theta),\theta) + (1 - \bar{\gamma})\bar{E}_L CS(q^*(\theta),\theta)$ denote the expected consumer surplus from the product offered by $S_2$. Suppose that $E_H CS(q^*(\theta);\theta) > \overline{CS}* > \gamma E_H CS(q^*(\theta);\theta) + (1 - \gamma)E_L CS(q^*(\theta);\theta)$, such that consumers share the same preferences towards the two new products as the buyer. Total social welfare from the new product that $S_1$ offers given θ, gross of the cost of the test, is $W(q;\theta) = V(q;\theta) + CS(q;\theta) - c(q)$ and the expected social welfare from the new product that $S_2$ offers is $\bar{W}* = \bar{V}* + \overline{CS}*$.

The buyer can only motivate $S_1$ to test its new product as $S_1$ is not financially constrained. Therefore, the buyer can choose between two options. First, it can motivate $S_1$ to test its new product by offering $S_1$ the contract described in Section 3 and then if the test reveals that the state is L, use the product offered by $S_2$ and earn $\bar{V}*$. The expected profit for the buyer in this case is: $-C + \gamma E_H\big(V(q^{**}(\theta),\theta) - c(q^{**}(\theta))\big) + (1-\gamma)\bar{V}*$. The second option is to use the product offered by $S_2$ without testing it first and earn an expected profit of $\bar{V}*$. Notice that the buyer will never use the product offered by $S_1$ without testing it first, because in expectation $S_2$ offers a superior product. Comparing these two options and using Proposition 2, the buyer prefers the first option if $C < C^{**}$, where $C^{**}$ is the solution to $C^{**} = \gamma(E_H(V(q^{**}(\theta),\theta) - c(q^{**}(\theta))) - \bar{V}*)$.

Now suppose that antitrust policy prohibits the buyer from offering contracts that include tariffs below costs. Lemma 2 implies that the buyer will not be able to motivate $S_1$ to test its new product as well. This policy can increase social welfare if the buyer would like to motivate $S_1$ to test its new product, i.e., $C < C^{**}$, but social welfare is higher when the buyer uses the product of $S_2$ without testing it first. To compare between these two options, I consider first the case of FOSD. Let $q^{**}(C;\theta)$ denote the equilibrium quantity of $S_1$, when the buyer motivates product testing, evaluated at $C$. Using this definition yields:

**Proposition 4:** *Suppose that $F_H(\theta)$ dominates $F_L(\theta)$ by FOSD. Then:*

*(i) Under full information, when the buyer can observe whether $S_1$ tested its new product, the buyer asks $S_1$ to do so only if it is welfare enhancing;*

*(ii) If $\overline{CS}^* > E_H CS(q^{**}(C^{**},\theta),\theta)$, then under asymmetric information there is a cutoff, $C_W^{**}$, such that the buyer offers a welfare-enhancing contract to $S_1$ for $0 < C < C_W^{**}$ and a welfare-reducing contract for $C_W^{**} < C < C^{**}$;*

The first part of Proposition 4 reveals that under full information inefficient product testing never occurs. Intuitively, under full information the buyer can ask $S_1$ to test its new product without the need to distort the quantity. Doing so benefits both the buyer and final consumers, but the buyer compares the cost of the test with only its own benefit. As a result, whenever the buyer finds it optimal to ask $S_1$ to test its new product, it is indeed welfare enhancing to do so. However, since the buyer does not internalize the consumers' benefit from product testing, it may still not ask $S_1$ to test its new product even in cases in which it is welfare enhancing to do. The second part of Proposition 4 shows that this situation can be reversed under asymmetric information. Now, using the contract may have a negative effect on consumers because of the resulting downward distortion in the equilibrium quantity. As the buyer does not internalize this negative effect, it may offer the contract to $S_1$ even though it is welfare reducing in comparison with dealing with the more efficient $S_2$.

Proposition 4 provides a qualitative condition for an inefficient contract. First, if $C$ is low, then the contract is always welfare enhancing because from Proposition 1, the quantity distortion is insignificant. If $C$ is high, then the buyer uses the contract even though it reduces social welfare if consumer surplus from the new product of $S_2$, $\overline{CS}^*$, is higher than the expected consumer surplus from the new product of $S_1$ in state H, evaluated at the highest level of $C$ at which the buyer is willing to use the contract. Notice that this condition holds whenever $CS^*$ is sufficiently close to $E_H CS(q^{**}(C^{**},\theta),\theta)$. In other words, the contract is more likely to reduce social welfare when the cost of product testing and the value of the alternative product to final consumers are sufficiently high.

The case where the two distribution functions cannot be ranked according to FOSD is somewhat ambiguous. Now, the quantity is distorted upwards for some values of θ, which may enhance social welfare. However, it is clear that in order to maintain the assumption that $E_H(V(q^*(\theta);\theta) - c(q^*(\theta))) > E_L(V(q^*(\theta);\theta) - c(q^*(\theta)))$, it has to be that $F_L(\theta) > F_H(\theta)$ for some values of θ for which there is downward distortion. I can therefore apply a simple argument of continuity by stating that the results of Proposition 4 still hold without FOSD as long as the upward distortion is small enough. Moreover, the results of Proposition 4 are also more likely to hold when upward distortion occurs for low realizations of θ, while downward distortion occurs for high realizations of θ, as in part (i) of Corollary 2.

## 6. Conclusion

This paper considers the problem of motivating a supplier to test the quality of its new product. It provides two main results. First, the optimal contract includes downward (upward) distortion in the equilibrium quantity if the gap between the distribution functions in states L and H is positive (negative). The paper illustrates the quantity distortion for several polar cases for the relationship between the two distribution functions. In particular, the contract may include downward distortion in the equilibrium quantity for high realizations of quality and upward distortion for low realizations. Second, the buyer may use the contract even when it is socially inefficient. In particular, the buyer may prefer to deal with a less efficient supplier only because this supplier is financially unconstrained and can therefore agree to a contract that does not fully compensate it for its total cost for some realizations of the product's quality, and may include negative fees. This result provides a new insight on the motivation and effect of slotting allowances.

The paper makes two simplifying assumptions that warrant further research. First, I assume that the test reveals to the supplier that the quality is drawn from one of only two potential distribution functions, and that the buyer wants to sell the new product for only one of these two distribution functions. In a more general case, the test may reveal to the supplier the state—and therefore a certain distribution function—out of more than two potential states. In such a case, the buyer motivates the supplier to test the product, and then to accept the contract if and only if the state belongs to a certain set of high-quality states, which is endogenously determined by the buyer.

The effect of such a generalization on the results should depend on the buyer's ability to discriminate among states. Suppose first that the buyer cannot discriminate and can only offer the menu ($T(\theta)$, $q(\theta)$) that the supplier accepts for all of the buyer's preferred states. Here, the supplier's and the buyer's ex-ante profit will depend on the weighted average of all the distribution functions that belong to the set of high-quality states, because the supplier accepts the same menu in all of these states. Following the same intuition is in the model presented above, quantity distortion should therefore depend on the gap between the weighted average of all the cumulative distributions in which the buyer deals with the supplier, and the weighted average of all the cumulative distributions in which the buyer does not deal with the supplier.[25] In my model, with only one distribution for each case, $f_H(\theta)$ can represent the

[25] For a technical discussion of this point, see the supplementary note available at http://www.tau.ac.il/~yehezkel/.

former while $f_L(\theta)$ can represent the latter. Notice though that in such a generalization, the buyer would also need to be able to decide on the set of states in which he wants to deal with the supplier. In my model, with only two states, such a decision is meaningless.

The results of my model could qualitatively change, however, if the buyer can discriminate among different states within the set of the high-quality states in which he deals with the supplier. Such a discriminating contract may involve a menu of the form ($T_k(\theta)$, $q_k(\theta)$), where $k$ denote the state, such that for any state $k$,, the supplier chooses a different non-linear menu. Now, the supplier's ex-ante expected profit from testing the new product no longer depends only on a weighted average of all the distribution functions, because the supplier can choose a different contract in each state. Moreover, in such a setting the buyer may have to leave the supplier with ex-ante information rents, to ensure that the supplier chooses the contract ($T_k(\theta)$, $q_k(\theta)$) that corresponds to state $k$. This in turn may create another motivation for the buyer to distort its quantity – to reduce the supplier's information rents. It would be interesting, for future research, to investigate the direction of the quantity distortion in such a case.

A second simplifying assumption that warrants further research, is that the supplier and the buyer are risk neutral. Risk aversion may, by itself, create a motivation for the buyer to use slotting allowances in order to divide the risk between the two firms. Also, risk aversion may affect the buyer's preferences concerning which of the two states is the preferable one. This in turn may affect the direction of the quantity distortion. For future research, it would be interesting to introduce risk aversion into this contract design problem.

**Appendix**

Following are a description on how to derive the reduced maximization problem and the proofs of Lemmas 1 and 3 and Propositions 1,2 and 4.

**Deriving the reduced maximization problem in (8):**

Substituting (7) into (5), $IC_S^{ex-ante}$ and $IR_S^{ex-ante}$ yields that the buyer's problem is to set $q(\theta)$ as to maximize:

$$E_H\left(\int_{\theta_0}^{\theta} V_\theta(q(\hat\theta),\hat\theta)d\hat\theta\right)+U(\theta_0)\,, \tag{A-1}$$

Subject to the constraints:

$$U(\theta_0)\le E_H\left(V(q(\theta),\theta)-c(q(\theta))-\int_{\theta_0}^{\theta} V_\theta(q(\hat\theta),\hat\theta)d\hat\theta\right)-\frac{C}{\gamma}\,, \tag{A-2}$$

$$U(\theta_0)\ge E_L\left(V(q(\theta),\theta)-c(q(\theta))-\int_{\theta_0}^{\theta} V_\theta(q(\hat\theta),\hat\theta)d\hat\theta\right)+\frac{C}{1-\gamma}\,. \tag{A-3}$$

As (A-1) is increasing with $U(\theta_0)$, (A-2) is binding and holds in equality. Substituting (A-2) in equality into (A-1) and (A-3) yields that the buyer sets $q(\theta)$ as to maximize:

$$\max_{q(\theta)} E_H\left(V(q(\theta),\theta)-c(q(\theta))-\frac{C}{\gamma}\right), \tag{A-4}$$

subject to the constraint:

$$\begin{aligned}&E_H\left(V(q(\theta),\theta)-c(q(\theta))-\int_{\theta_0}^{\theta} V_\theta(q(\hat\theta),\hat\theta)d\hat\theta\right)\\ &-E_L\left(V(q(\theta),\theta)-c(q(\theta))-\int_{\theta_0}^{\theta} V_\theta(q(\hat\theta),\hat\theta)d\hat\theta\right)\ge\frac{C}{\gamma(1-\gamma)},\end{aligned} \tag{A-5}$$

and the condition that $q(\theta)$ is non-decreasing. In (9) I express (A-5) as a function of $T(\theta)$ which helps explaining the intuition behind it.

**Proof of Lemma 1:**

Substituting (7) into (9) yields

$$\int_{\theta_0}^{\theta_1}\left(V(q(\hat\theta),\hat\theta)-c(q(\hat\theta))-\int_{\theta_0}^{\hat\theta} V_\theta(q(\tilde\theta),\tilde\theta)d\tilde\theta\right)\left(f_H(\hat\theta)-f_L(\hat\theta)\right)d\hat\theta\ge\frac{C}{\gamma(1-\gamma)}\,. \tag{A-6}$$

Integrating by parts the left hand side of (A-6) and evaluating at $q(\theta) = q^*(\theta)$ yields:

$$\int_{\theta_0}^{\theta_1}\left(V(q^*(\hat\theta),\hat\theta)-c(q^*(\hat\theta))-\int_{\theta_0}^{\hat\theta}V_\theta(q^*(\tilde\theta),\tilde\theta)d\tilde\theta\right)\left(f_H(\hat\theta)-f_L(\hat\theta)\right)d\hat\theta$$
$$=\int_{\theta_0}^{\theta_1}\left(V_q(q^*(\hat\theta),\hat\theta)-c_q(q^*(\hat\theta))\right)q_\theta{}^*(\hat\theta)\left(F_L(\hat\theta)-F_H(\hat\theta)\right)d\hat\theta \qquad \text{(A-7)}$$
$$=0<\frac{C}{\gamma(1-\gamma)},$$

where the second equality follows because $V_q(q^*(\theta),\theta) = c_q(q^*(\theta))$.

**Proof of Proposition 1:**

The plan of the proof is the following. First, I will solve for the optimal contract ignoring the constraint $q_\theta(\theta) > 0$. Second, I will prove the properties of the optimal contract. Third, I will show that the solution satisfies the second order condition and the condition that $q_\theta(\theta) > 0$ if $C$ is low enough or if $\gamma$ is not too close to either 0 or 1.

First, I start by solving for the optimal contract. To this end, substituting (7) into (9) and rearranging yields that the Lagrangian is:

$$L(q(\theta),\lambda)=\int_{\theta_0}^{\theta_1}\left(V(q(\theta),\theta)-c(q(\theta))-\frac{C}{\gamma}\right)f_H(\theta)d\theta \qquad \text{(A-8)}$$
$$+\lambda\left(\int_{\theta_0}^{\theta_1}\left(\left(V(q(\theta),\theta)-c(q(\theta))-V_\theta(q(\theta),\theta)\frac{1-F_H(\theta)}{f_H(\theta)}\right)f_H(\theta)-\left(V(q(\theta),\theta)-c(q(\theta))-V_\theta(q(\theta),\theta)\frac{1-F_L(\theta)}{f_L(\theta)}\right)f_L(\theta)\right)d\theta\right.$$
$$\left.-\frac{C}{\gamma(1-\gamma)}\right).$$

Differentiating (A-8) with respect to $q(\theta)$ and $\lambda$ and rearranging yields that $(q^{**}(\theta), T^{**}(\theta))$, and $\lambda^{**}$ are the solution to:

$$V_q(q(\theta),\theta)-c_q(q(\theta))=\lambda V_{q\theta}(q(\theta),\theta)\frac{F_L(\theta)-F_H(\theta)}{\left(f_H(\theta)+\lambda(f_H(\theta)-f_L(\theta))\right)}, \qquad \text{(A-9)}$$

$$E_H\left(V(q(\theta),\theta)-c(q(\theta))-V_\theta(q(\theta),\theta)\frac{1-F_H(\theta)}{f_H(\theta)}\right)$$
$$-E_L\left(V(q(\theta),\theta)-c(q(\theta))-V_\theta(q(\theta),\theta)\frac{1-F_L(\theta)}{f_L(\theta)}\right)=\frac{C}{\gamma(1-\gamma)}, \qquad \text{(A-10)}$$

$$T(\theta) = V(q(\theta),\theta) - \int_{\theta_0}^{\theta} V(q(\hat{\theta}),\theta)d\hat{\theta}$$
$$- E_H\left(V(q(\theta),\theta) - c(q(\theta)) - V_\theta(q(\theta),\theta)\frac{1-F_H(\theta)}{f_H(\theta)} - \frac{C}{\gamma}\right), \tag{A-11}$$

where (A-9) and (A-10) are the first order conditions for (A-8) with respect to $q(\theta)$ and $\lambda$ respectively, and (A-11) is derived from (7) (notice that $U(\theta_0)$ is the last term in (A-11)). The second order condition for (A-8) with respect to $q(\theta)$ requires that

$$\begin{aligned} &\left(f_H(\theta) + \lambda(f_H(\theta) - f_L(\theta))\right)\left(V_{qq}(q(\theta),\theta) - c_{qq}(q(\theta))\right) \\ &+\lambda V_{qq\theta}(q(\theta),\theta)\left(F_H(\theta) - F_L(\theta)\right) \\ &< 0. \end{aligned} \tag{A-12}$$

Next, I turn to the second part of showing the properties of the optimal solution. Let $q(\lambda;\theta)$ denotes the solution to (A-9) given $\lambda$ and let $T(\lambda;\theta)$ denotes the right-hand side of (A-11) evaluated at $q(\lambda;\theta)$. $\lambda^{**}$ is therefore the solution to

$$E_H\left(T(\lambda;\theta) - c(q(\lambda;\theta))\right) - E_L\left(T(\lambda;\theta) - c(q(\lambda;\theta))\right) = \frac{C}{\gamma(1-\gamma)}, \tag{A-13}$$

and $q^{**}(\theta) = q(\lambda^{**};\theta)$. Now, if $C = 0$, then $\lambda^{**} = 0$ and $q^{**}(\theta) = q^*(\theta)$. To see why, notice that (A-7) is satisfied in equality for $q(\lambda;\theta) = q^*(\theta)$ and $C = 0$. Substituting $q(\lambda;\theta) = q^*(\theta)$ into (A-9), the left hand side in (A-9) equals to zero implying $\lambda^{**} = 0$. Next suppose that $C/\gamma(1 - \gamma) > 0$. To show that the term in the left hand side of (A-13) is increasing with $\lambda$, the derivative of the left hand side of (A-13) is with respect to $\lambda^{**}$ is

$$\begin{aligned} &\frac{\partial}{\partial\lambda}\left(E_H\left(T(\lambda;\theta) - c(q(\lambda;\theta))\right) - E_L\left(T(\lambda;\theta) - c(q(\lambda;\theta))\right)\right)\Big|_{\lambda=\lambda^{**}} \\ &= \int_{\theta_0}^{\theta_1} \frac{f_H(\theta)V_{\theta q}(q(\theta),\theta)}{f_H(\theta) + \lambda^{**}(f_H(\theta) - f_L(\theta))}\left[(F_H(\theta) - F_L(\theta))\frac{\partial q(\lambda^{**};\theta)}{\partial\lambda}\right]d\theta. \end{aligned} \tag{A-14}$$

Since $f_H(\theta) - \lambda^{**}(f_H(\theta) - f_L(\theta))$ is always positive for low values of $\lambda^{**}$ and since by assumption, $V_{\theta q}(q,\theta) > 0$, the sign of (A-14) is determined according to the sign of the term in the squared brackets. If $F_H(\theta) > F_L(\theta)$, then the right hand side of (A-9) is decreasing with $\lambda$, implying that $q(\lambda;\theta)$ is increasing with $\lambda$, and the term in the squared brackets in (A-14) is positive. Likewise, if $F_H(\theta) < F_L(\theta)$, then the right hand side of (A-9) is increasing with $\lambda$, implying that $q(\lambda;\theta)$ is decreasing with $\lambda$, and the term in the squared brackets in (A-14) is positive. Consequently, the term in the left hand side of (A-13) is increasing with $\lambda$. This in turn implies that $\lambda^{**}$ is increasing with $C/\gamma(1-\gamma)$, and $\lambda^{**} > 0$ if $C/\gamma(1-\gamma) > 0$. As for $q^{**}(\theta)$, since $\lambda^{**} > 0$, it follows from (A-9), that $q^*(\theta) - q^{**}(\theta) > (<) = 0$ if $F_L(\theta) > (<) = F_H(\theta)$ and the gap $|q^*(\theta) - q^{**}(\theta)|$ is increasing with $C/\gamma(1-\gamma)$.

Next, I turn to show that $T^{**}(\theta) - c(q^{**}(\theta))$ is increasing (decreasing) with $\theta$ if $F_L(\theta) > (<) = F_H(\theta)$. Substituting (7) into $T^{**}(\theta) - c(q^{**}(\theta))$ and differentiating with respect to $\theta$:

$$\frac{d}{d\theta}\Big(T^{**}(\theta) - c(q^{**}(\theta))\Big) = \Big(V_q(q^{**}(\theta);\theta) - c_q(q^{**}(\theta))\Big) q_\theta^{**}(\theta) \qquad \text{(A-15)}$$

Since $q_\theta^{**}(\theta) > 0$ and since $V_q(q^*(\theta);\theta) - c_q(q^*(\theta)) = 0$ is the first order condition under vertical integration, it follows that (A-15) is positive (negative) if $q^*(\theta) - q^{**}(\theta) > (<) = 0$.

Next I turn to the third part of showing that the above solution satisfies the condition $q_\theta^{**}(\theta) \geq 0$ and the second order condition if $C$ is low and $\gamma$ is intermediate. Notice first that $q^*(\theta)$ is increasing with $\theta$. Since $q(0;\theta) = q^*(\theta)$ and $q(\lambda;\theta)$ is continuous with $\lambda$, it follows that $q^{**}(\theta)$ is increasing with $\theta$ if $\lambda^{**}$ is not too high, which in turn holds if $C/\gamma(1-\gamma)$ is not too high. As for the second order condition in (A-12), it always holds for $\lambda = 0$, and therefore for $C = 0$. As (A-12) is continuous in $\lambda$, it holds if $\lambda > 0$ but not too high or if $C/\gamma(1-\gamma)$ is not too high. The exact condition on $C/\gamma(1-\gamma)$ from which on these two conditions do not hold depends on the two distribution functions.

**Proof of Proposition 2:**

Suppose first that $V^* > \hat{V}^*$. In this case the buyer will use the contract if

$$-C + \gamma E_H(V(q^{**}(\theta),\theta) - c(q^{**}(\theta))) + (1-\gamma)V^* \geq V^*. \qquad \text{(A-16)}$$

From Proposition 1, the gap $|q^*(\theta) - q^{**}(\theta)|$ is increasing with $C$ and equals to zero for $C = 0$. Therefore, $V(q^{**}(\theta);\theta) - c(q^{**}(\theta))$ is decreasing with $C$ and equals to $V(q^*(\theta);\theta) - c(q^*(\theta))$ for $C = 0$. Thus the left hand side of (A-16) is decreasing with $C$, and the inequality holds for $C < C^{**}$, where $C^{**}$ is the solution to

$$C^{**} = \gamma(E_H V(q^{**}(\theta),\theta) - c(q^{**}(\theta)) - V^*). \qquad \text{(A-17)}$$

Since $V(q^{**}(\theta);\theta) - c(q^{**}(\theta)) < V(q^*(\theta),\theta) - c(q^*(\theta))$ for $C > 0$, the right hand side in (A-17) is lower than the term in the first line in (4), implying that $C^{**} < C^*$. Also, if $C = 0$, (A-16) always holds because $V(q^{**}(\theta),\theta) - c(q^{**}(\theta)) = V(q^*(\theta),\theta) - c(q^*(\theta))$ and by assumption, $E_H(V(q^*(\theta),\theta) - c(q^*(\theta))) > V^*$. Next suppose that $V^* < \hat{V}^*$. In this case the buyer will use the contract if

$$\begin{aligned} &-C + \gamma E_H(V(q^{**}(\theta),\theta) - c(q^{**}(\theta))) + (1-\gamma)V^* \\ &\geq \gamma E_H(V(q^*(\theta),\theta) - c(q^*(\theta))) + (1-\gamma)E_L(V(q^*(\theta),\theta) - c(q^*(\theta))). \end{aligned} \tag{A-18}$$

Since $V(q^{**}(\theta);\theta) - c(q^{**}(\theta))$ is decreasing with $C$, the left hand side of (A-18) is decreasing with $C$, implying that the buyer will use the contract if $C < C^{**}$, where $C^{**}$ is the solution to:

$$\begin{aligned} C^{**} &= (1-\gamma)\left(V^* - E_L\left(V(q^*(\theta),\theta) - c(q^*(\theta))\right)\right) \\ &-\gamma E_H\left(V(q^*(\theta),\theta) - c(q^*(\theta))\right) - E_H\left(V(q^{**}(\theta),\theta) - c(q^{**}(\theta))\right). \end{aligned} \tag{A-19}$$

Since $V(q^{**}(\theta),\theta) - c(q^{**}(\theta)) < V(q^*(\theta),\theta) - c(q^*(\theta))$ for $C > 0$, the right hand side of (A-19) is lower than the second line in (3), implying that $C^{**} < C^*$. Also, if $C = 0$, (A-18) always holds because $V(q^{**}(\theta),\theta) - c(q^{**}(\theta)) = V(q^*(\theta),\theta) - c(q^*(\theta))$ and by assumption, $E_L(V(q^*(\theta),\theta) - c(q^*(\theta))) < V^*$.

**Proof of Lemma 2:**

Any contract that motivates $S_2$ to test its new product must satisfy the constraint that $S_2$ prefers to test the new product over the option of agreeing to the contract without testing it first:

$$-C + \bar{\gamma}\, \bar{E}_H\left(T(\theta) - c(q(\theta))\right) \geq \bar{\gamma}\, \bar{E}_H\left(T(\theta) - c(q(\theta))\right) + (1 - \bar{\gamma})\, \bar{E}_L\left(T(\theta) - c(q(\theta))\right),$$

$$\Downarrow$$

$$\bar{E}_L\left(T(\theta) - c(q(\theta))\right) \leq -C/(1 - \bar{\gamma}).$$

This in turn requires setting $T(\theta) - c(q(\theta)) \leq -C/(1 - \bar{\gamma}) < 0$ for at least some realizations of $\theta$.

**Proof of Proposition 4:**

Consider first full information. Testing the new product increases social welfare if: $-C + \gamma E_H W(q^*(\theta),\theta) + (1-\gamma)\overline{W}^* \geq \overline{W}^*$, or:

$$C < C_W^* \equiv \gamma(E_H W(q^*(\theta),\theta) - \overline{W}^*). \tag{A-20}$$

Using (3) yields: $C_W^* - C^* = \gamma(E_H CS(q^*(\theta),\theta) - \overline{CS}^*) > 0$, hence the buyer always uses the contract when it increases social welfare. Next consider asymmetric information. Now it is socially optimal to use the contract if:

$$-C + \gamma E_H W(q^{**}(C, \theta),\theta) + (1-\gamma)\overline{W}^* \geq \overline{W}^*. \qquad \text{(A-21)}$$

Under FOSD, the left-hand side of (A-21) is strictly decreasing with $C$ and therefore (A-21) holds iff $C < C_W^{**}$, where $C_W^{**}$ solves (A-21) in equality. Moreover, evaluating the left hand side of (A-21) at $C = 0$ yields: $-0 + \gamma E_H W(q^{**}(0, \theta),\theta) + (1-\gamma)\overline{W}^* = \gamma(E_H W(q^*(\theta),\theta) - \overline{W}^*) + \overline{W}^* \geq \overline{W}^*$, hence (A-21) is always satisfied at $C = 0$, implying that $C_W^{**} > 0$. Moreover, $C^{**} - C_W^{**} = \gamma(\overline{CS}^* - E_H CS(q^{**}(C^{**},\theta),\theta))$ which is positive if $\overline{CS}^* > E_H CS(q^{**}(C^{**},\theta),\theta)$.

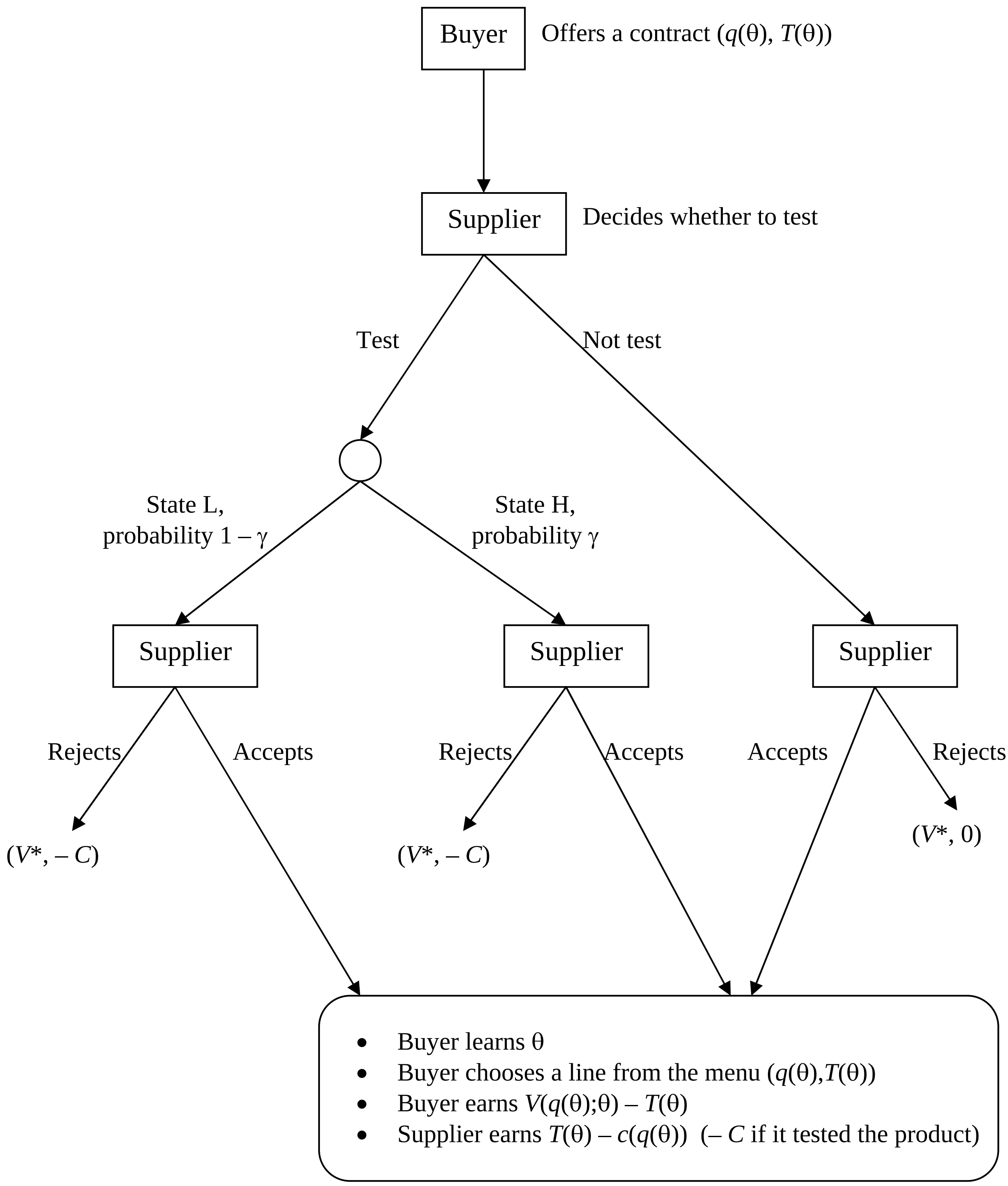


**Figure 1: The timing of the game**

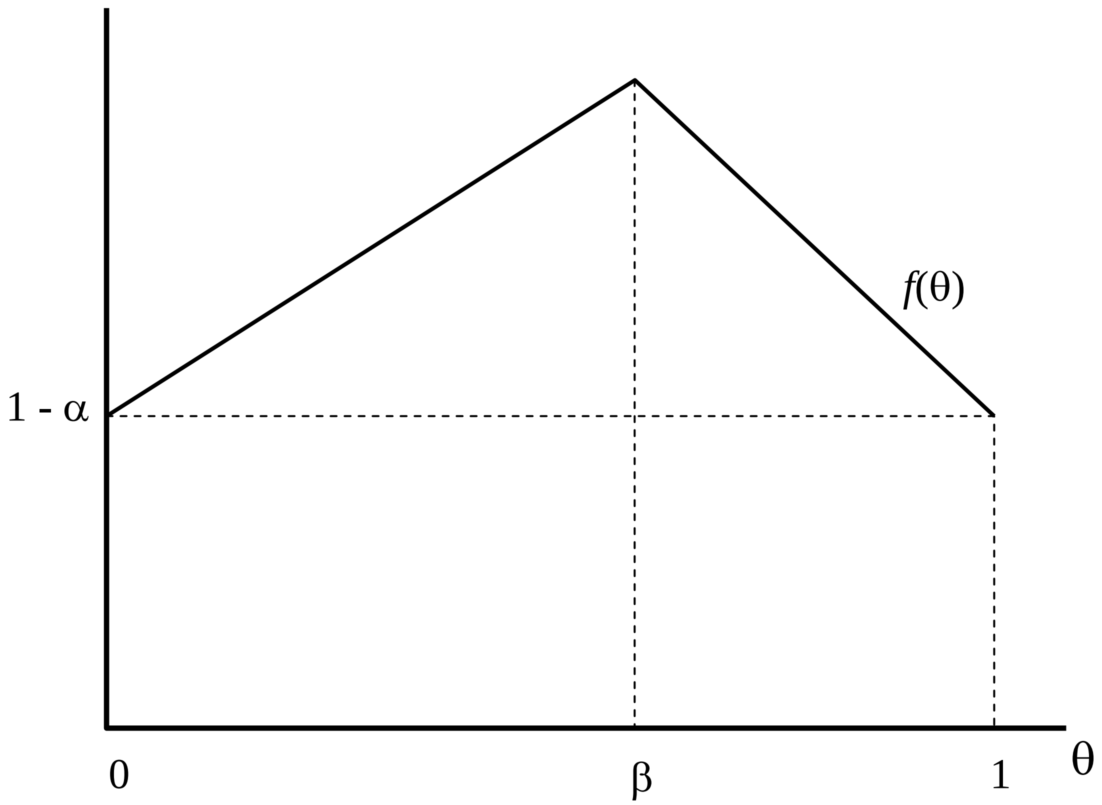


**Figure 2: The example of unimodal distribution function**

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