The Strategic Use of Private Quality Standards in Food Supply Chains*

Preliminary Version

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Abstract

This paper highlights the strategic role of private quality standards in vertical relations. Considering two symmetric downstream firms that are exclusively supplied by a finite number of upstream firms, we show that there exist two asymmetric equilibria in the downstream firms' quality requirements. While one downstream firm has an incentive to exaggerate the quality requirements to attract suppliers, the other retailer's best response is to reduce the own quality requirements in order to weaken the rival's suppliers' bargaining position and, thus, to make delivery to the rival less attractive. The use of private quality standards induces a decrease in social welfare, which can be softened by the implementation of a public minimum quality standard.

JEL-Classification: L15, L42, Q13

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1 Introduction

Food scandals like the BSE crisis, the melamine found in Chinese milk in 2008 and the dioxin contamination of animal feed in Germany in 2010 have given rise to serious consumer concerns over food quality. In response, both governments and food industries have tightened food safety regulations. In particular, food retailers have implemented private quality standards, which add to public regulation. Examples include the British Retail Consortium (BRC) Global Standard for Food Safety and GlobalGAP as collective private standards and Tesco's Nature's Choice and Carrefour's Filière Qualité as individual private standards.[1] These quality standards do not only cover safety aspects, but also refer to social and environmental issues. They clarify product and process specifications, stipulate how these specifications are met and define each trading partner's responsibilities. Thereby, product standards refer to the physical properties of the final products, such as maximum residue levels (MRLs) for pesticides and herbicides, threshold values for additives and requirements for packaging material. Process standards, in turn, relate to properties of the production process, including hygiene, sanitary and pest-control measures, the prohibition of child labor, animal-welfare standards and food quality management systems. Particularly, the quality of fresh fruits, vegetables and meat products is regulated by retailers' private quality standards. The quality requirements may differ widely among the individual retailers. In Germany, for example, the MRLs for pesticides established by some large retail chains in 2008 ranged from 80% of the public MRL (Aldi, Norma), to 70% (REWE, Edeka, Plus), to as low as 33% (Lidl) (PAN Europe 2008). Moreover, even if the retailers agree on collective private standards, they tend to supplement them with individual requirements (OECD 2006), resulting in differing quality requirements at the retailers.

It is controversial whether retailers use private quality standards as a strategic instrument to gain buyer power in procurement markets.[2] This might be especially true when

[1] Besides the prevention of potential revenue losses due to reputation (OECD 2006), retailers' incentives for private standard setting might be to respond to public minimum standards (e.g., Valletti 2000; Crampes and Hollander 1995; Ronnen 1991), to pre-empt or influence public regulation (e.g., McCluskey and Winfree 2009; Lutz et al. 2000), to substitute for inadequate public regulation in developing countries (e.g., Marcoul and Veyssiere 2010), and to safeguard against liability claims (e.g., Giraud-Héraud et al. 2006b, 2008).

[2] There is also a strong debate on whether increasing quality requirements by large retailers may impose entry barriers for suppliers in developing countries, in particular for small-scale producers (e.g., OECD

suppliers must use specific technologies in order to comply with the individual quality standards of the retailers. So far, this conjecture has not been formally proven. Generally, the understanding of the strategic aspects of private quality standards in vertical relations is still underdeveloped (Hammoudi et al. 2009). We intend to narrow this gap with a theoretical analysis of retailers' quality choice and its implications for market structure and social welfare.

In our model, we consider two independent retailers that are supplied by a finite number of upstream firms. First, the retailers decide upon their quality requirements. Then, the suppliers choose which quality standard they meet. As suppliers have to fulfill the retailers' quality requirements, this decision determines which retailer they supply. Thereby, compliance with a higher quality standard is associated with higher quality costs. Given the retailers' quality requirements and the suppliers' decision, both retailers enter into bilateral negotiations with their respective suppliers about non-linear delivery tariffs. These consist of the quantity to be delivered by the supplier and a fixed payment to be made in return by the retailer. Failing to achieve an agreement with one of its suppliers, a retailer is still able to sell the quantities obtained from its remaining suppliers. However, the specification of the suppliers' outside options is more complex as suppliers cannot adjust the quality of their production in the short-term. If both retailers implement the same quality standard, a supplier's outside option is to switch its delivery to the other retailer. In the case of differing quality requirements, suppliers complying with the lower quality standard cannot switch their delivery to the retailer with the higher quality requirements, whereas suppliers producing according to the higher quality standard can opt to deliver to the retailer with the less demanding quality requirements. The retailer with the lower quality requirements, however, does not reward overcompliance with the given standard. Upon successful completion of the negotiations, production takes place and the suppliers deliver their products to the selected retailer. Finally, the retailers sell the goods to consumers, operating as local monopolists in separate markets. Later on, we complement our analytical results with further insights from a numerical example, where we allow that retailers compete in quantities in a single market.

Our analytical results show that there exist two asymmetric equilibria in the retailers'

2007, 2006; EC 2006; García Martinez and Poole 2004; Balsevich et al. 2003; Boselie et al. 2003).

quality choice under the condition that production costs are sufficiently high and increasing in the retailers' quality requirements. Considering two local retail monopolies that compete for suppliers, we find that one retailer always has a higher quality standard than the other one. By raising its quality standard, the retailer increases its price in the final consumer market. However, the more the retailer increases the quality requirements, the lower the value of the suppliers' outside option and,therefore, the weaker the suppliers' bargaining strength vis-à-vis the retailer. Nevertheless, balancing both effects, the number of suppliers delivering to that retailer is increasing in its quality requirements. The best response of the other retailer is to reduce its own quality requirements to make delivery to the high-quality retailer less attractive. Accordingly, the retailers implement different quality standards in equilibrium. It turns out that the higher quality standard exceeds the socially optimal quality level, while the other retailer demands a quality standard below the social optimum. Thus, the use of private quality standards reduces social welfare. The negative welfare effects of private quality standards can be softened by the enforcement of a public minimum quality standard (MQS). If the public MQS is binding, the retailer of the lower quality requirement cannot unrestrictedly reduce its quality requirements in response to increasing quality requirements of the other retailer. As a consequence, the high-quality retailer has less incentives to increase the quality standard, such that the quality requirements of both the high-quality and the low-quality retailers approach the social optimum.

Our analysis is related to the large theoretical literature on buyer power, which studies the sources of buyer power and its implications for the overall efficiency of vertical relations.[3] Potential sources of buyer power analyzed so far include credible threats to vertically integrate or to support market entry at the upstream level (e.g., Katz 1987; Sheffman and Spiller 1992) as well as potential delisting strategies after downstream mergers (e.g., Inderst and Shaffer 2007). We show that downstream firms' private quality standards may constitute an additional source of buyer power. With regard to the efficiency effects of buyer power, Inderst and Wey (2003, 2007) point out that the formation of large buyers and, thus, the emergence of buyer power may increase consumer surplus as well as

[3]For a survey on the sources and consequences of buyer power, see Inderst and Mazarotto (2008) as well as Inderst and Shaffer (2008).

overall welfare since suppliers' investment incentives increase. Montez (2008) shows that an upstream firm may choose higher capacities when buyers merge as long as the costs of capacity are sufficiently low. Negative welfare effects due to increased buyer power are analyzed by Inderst and Shaffer (2007). They find that a retail merger can induce the manufacturers to reduce the variety of their products in order to comply with 'average' preferences (see also Chen (2004)). Moreover, Battigalli et al. (2007) derive the result that buyer power weakens a supplier's incentive to invest in quality improvement. We show that buyer power due to private standard setting decreases social welfare.

Although quality standards receive growing attention in the theoretical economic literature, few papers address private standards in vertical relations.[4] Among the papers covering private quality standards, Bazoche et al. (2005) and Giraud-Héraud et al. (2006a) analyze individual private standards. Giraud-Héraud et al. (2006a) show that the incentive for a retailer to differentiate its business via a premium private label (PPL) is the higher the lower the public MQS. Bazoche et al. (2005), in turn, analyze the effects of a retailer's PPL for a given level of the public MQS. In their model, the retailer introducing the PPL would choose an intermediate level of the private quality standard to segment the market. Furthermore, Giraud-Héraud et al. (2006b and 2008) study collective standard setting. Both papers analyze the introduction of a collective standard for a given public MQS, assuming that retailers are price takers in the procurement market. In their models, the retailers' incentive to implement a collective standard depends on the existence of a legal liability rule.

The remainder of the paper is organized as follows. In Section 2, we present our model. A benchmark case where none of the suppliers has an outside option is analyzed in Section 3. In Section 4, we investigate the quality choice of two local retail monopolies that compete for the same suppliers, taking into account the above-described outside options for the suppliers. We introduce a numerical example in Section 5 to allow for retail competition, to conduct social welfare analysis and to analyze the impact of a public MQS on the retailers' private quality standards and on social welfare. In the last section, we

[4] For example, Valletti (2000), Crampes and Hollander (1995) and Ronnen (1991) analyze private standard setting in response to the introduction of a public minimum standard. Focussing on product differentiation, private quality decisions of firms are also studied by Motta (1993) and Gal-Or (1985, 1987), for example. However, all these papers neglect vertical supply structures.

conclude.

2 The Model

We consider a vertically-related industry with two symmetric downstream retailers D_i, $i = 1, 2$, and $N \geq 2$ symmetric upstream suppliers U_{ij}, $j = 1, ..., N$. Note that the index i refers to the retailer i the upstream firm U_{ij} delivers to. An upstream firm can be any kind of supplier, such as a primary producer, a processor or an export organization abroad. The industry structure reflects the situation in many countries where a relatively large number of suppliers face a highly concentrated retail sector (e.g., Dobson et al. 2003; OECD 2006). We assume without loss of generality that N_1 upstream firms, $U_{11}, ..., U_{1N_1}$, produce a homogeneous intermediate good and sell it exclusively to the downstream firm D_1, while the remaining $N_2 = N - N_1$ upstream firms, $U_{2N_1+1}, ..., U_{2N}$, manufacture a homogeneous intermediate good and deliver it exclusively to the downstream firm D_2. The retailers transform the received inputs on a one-to-one basis into a single consumer good each. That is, retailer D_1 produces good 1 and retailer D_2 produces good 2. Both retailers operate as local monopolists in two independent markets.[5] This allows us to analyze the quality decision of the retailers abandoning any impact of downstream competition.[6]

Each retailer implements a private quality standard $q_i, i = 1, 2$, which has to be fulfilled by the suppliers. This implies that the suppliers do not get their products sold to the retailers unless they comply with the respective quality standards. Hence, the N_1 upstream firms delivering to retailer D_1 produce at the quality level q_1, while the N_2 upstream firms supplying retailer D_2 adhere to the quality standard q_2. We assume that the product quality is observable to all agents, i.e. suppliers, retailers, and consumers.[7]

Demand. Each retailer D_i faces an inverse demand

$$p_i(X_i, q_i), \ \forall i = 1, 2, \tag{1}$$

[5] Local monopolies in retailing may, for example, result from consumers' one-stop shopping preferences.

[6] This assumption will be relaxed in Section 5, where we consider the case that the retailers act as Cournot duopolists.

[7] Note that the product quality is not necessarily directly communicated to consumers, but consumers might be indirectly informed about the standards through third-party investigations, such as those led by environmental lobby groups.

where X_i denotes the overall quantity the retailer D_i sells to the final consumers. Given that each retailer transforms all the received inputs on a one-to-one basis into a final consumer good, the quantity X_i consists of the sum of intermediate inputs the retailer obtains from the suppliers, i.e.

$$X_i = \sum_{j=a}^{A} x_{ij} \text{ with: } \begin{cases} a = 1,\ A = N_1 & \text{for } i = 1 \\ a = N_1 + 1,\ A = N & \text{for } i = 2 \end{cases}, \tag{2}$$

where x_{ij} refers to the quantity the supplier U_{ij} sells to the retailer D_i. For simplicity, we assume that the inverse demand functions are linear. We apply standard assumptions indicating that the price is decreasing in X_i, i.e. $\partial p_i(\cdot)/\partial X_i < 0$,[8] and increasing in q_i, i.e. $\partial p_i(\cdot)/\partial q_i > 0$.[9]

Negotiations. Given the retailers' quality requirements, the upstream suppliers decide which quality standard they comply with and, thus, which retailer they supply. Before production takes place, each retailer negotiates with each of its respective suppliers a delivery contract T_{ij}. The delivery contracts are considered to be short-term.[10] As the relationships between buyers and sellers often consist of rather complex contracts using more than simple linear pricing rules (Rey and Vergé 2008), we assume that quantity-forcing contracts are negotiated between the retailers and their suppliers.[11] These contracts specify both the quantity x_{ij} the supplier U_{ij} has to deliver to the retailer D_i and the fixed payment F_{ij} the supplier U_{ij} receives from the retailer D_i in exchange for the delivery.

We assume that the downstream firms and the corresponding upstream suppliers negotiate bilaterally about the respective delivery contracts. Note that we do not allow for renegotiation in the case of negotiation breakdown between any retailer-supplier pair. Negotiation outcomes are observable to all players. Moreover, both the suppliers and the

[8] In order to simplify the notation, we omit the arguments of the functions where this does not lead to any confusion.

[9] It has been shown that consumers are willing to pay a premium for eco-labeled food (Bougherara and Combris 2009), for organic products (Gil et al. 2000), for milk quality attributes (Bernard and Bernard 2009; Brooks and Lusk 2010; Kanter et al. 2009), and for beef quality attributes (Gao and Schroeder 2009), for example.

[10] This is in accordance with observations that "a large portion of the contracts observed in the agro-food sector are short-term or single-season contracts" (Jang and Olson 2010, p. 252).

[11] Note that non-linear tariffs are commonly used in intermediate goods markets. Empirical evidence is provided by Bonnet and Dubois (2010) and Berto Villas-Boas (2007).

retailers are fully committed to these contracts.

Costs. While the downstream retailers' costs of transformation and distribution are normalized to zero, each upstream supplier incurs total costs of $C(x_{ij}, q_i)$ for producing the quantity x_{ij} at the quality level q_i, where $C(0, q_i) = 0$ and $C_{x_{ij}}(0, q_i) = 0$. The cost functions are twice continuously differentiable, increasing and strictly convex in both x_{ij} and q_i, i.e. for all $x_{ij}, q_i > 0$ it holds that

$$C_\tau(x_{ij}, q_i),\ C_{\tau\tau}(x_{ij}, q_i), C_{x_{ij}q_i}(x_{ij}, q_i) > 0 \text{ with } \tau = x_{ij}, q_i. \tag{3}$$

Note that the convexity in quantities reflects decreasing returns to scale and implies that the suppliers are capacity-constrained, while the convexity in qualities characterizes a decreasing marginal revenue from quality investments.[12] We also apply the following assumptions:

Assumption 1 *Marginal costs react stronger in quantity than in quality, i.e. for all* $x_{ij}, q_i > 0$ *we have* $C_{x_{ij}x_{ij}}(x_{ij}, q_i) > C_{x_{ij}q_i}(x_{ij}, q_i)$.

Assumption 2 *The impact of rising quality on the marginal costs of production exceeds the impact on the inverse demand, i.e.* $\partial p_i(X_i, q_i)/\partial q_i < \partial^2 C(x_{ij}, q_i)/\partial q_i \partial x_{ij}$.

The adherence to a higher quality standard not just requires the usage of more sophisticated variable inputs like high-quality raw materials (Motta 1993), but frequently involves the use of different production technologies (e.g., Mayen et al. 2009) and changes in the production processes (e.g., Codron et al. 2005). For the sake of simplicity, we normalize any quality-related fixed costs to zero. Nevertheless, we take into account that the decision to produce according to a particular quality standard is associated with fixed quality costs for investments in specific technologies, production facilities, or the development and implementation of a particular quality-management system. These specific investments preclude any short-term changes in the quality-related production process. This implies that the variable costs of quality cannot be adjusted in the short-term, neither upwards

[12] Decreasing quality gains are considered to be more realistic than constant or even increasing ones (Bazoche et al. 2005). For the suppliers' profit functions to be concave in quality, however, the cost functions have to be *sufficiently* convex in quality (cp. Bazoche et al. 2005).

nor downwards, since they at least partly hinge on the production process implemented to fulfill a certain quality standard.[13]

Profits. The downstream firms' profits are given by

$$\pi^{D_i}(\cdot) = R_i(X_i, q_i) - \sum_{j=a}^{A} F_{ij} \text{ with: } \begin{cases} a = 1,\ A = N_1 & \text{for } i = 1 \\ a = N_1 + 1,\ A = N & \text{for } i = 2 \end{cases}, \tag{4}$$

where $R_i(X_i, \cdot) = p_i(X_i, q_i)X_i$ denotes the revenue of retailer D_i. Our assumptions on the inverse demand guarantee that the profit $\pi^{D_i}(\cdot)$ is strictly concave in X_i.

For the upstream firm U_{ij} supplying the downstream firm D_i, the profit refers to

$$\pi^{U_{ij}}(\cdot) = F_{ij} - C(x_{ij}, q_i),\ \forall i = 1, 2,\ j = 1, ..., N. \tag{5}$$

In summary, we consider the following four-stage game. First, the two retailers D_i impose a private quality standard q_i. Given the quality choice of the retailers, the N upstream firms U_{ij} decide which downstream firm they intend to supply and, therefore, which quality standard they will adhere to. This decision determines the suppliers' quality-related production costs. In the third stage, both retailers negotiate with their respective suppliers about quantity-forcing delivery contracts $T_{ij}(x_{ij}, F_{ij})$. Production takes place upon successful completion of the negotiations. Finally, the retailers sell to consumers, whereby each retailer's total quantity X_i offered is restricted by the quantity-forcing contracts negotiated before. Note that both retailers act as local monopolies.

3 Benchmark Analysis

In this section, we analyze a benchmark case where the upstream firms have no outside option if the negotiations with their selected downstream firm fail. This approach enables us to investigate the retailers' quality decision as if any retailer and its suppliers were vertically integrated, neglecting any strategic considerations in the vertical relationship.

[13] For example, improved quality-management systems require higher-skilled personnel as well as more frequent documentation and sampling requirements (Rau and van Tongeren 2009; Preidl and Rau 2006). The decision for a particular inventory method applied to perishable goods is another case in point. While the FIFO (first in, first out) policy is associated with higher variable costs, the LIFO (last in, first out) policy entails lower quality-related variable costs (Reyniers and Tapiero 1995).

The benchmark analysis will be the reference case for future comparisons when we consider outside options for the upstream firms.

Downstream Markets. Since our solution concept is subgame perfection, the game is solved by backward induction. That is, we begin by solving for the retailers' quantity choice in the downstream markets. Each retailer maximizes its profit given the delivery contracts negotiated before in the form of quantity-forcing tariffs $T_{ij}(x_{ij}, F_{ij})$. Accordingly, the retailers' quantity decision in the final stage of the game is constrained by the bargaining outcome with the upstream suppliers.

Negotiations. Going backwards, we solve for the negotiation outcome in the intermediate goods market. We assume that any of the retailers failing to make an agreement with one of the suppliers is left to sell the quantities obtained from the remaining suppliers. This implies a strictly positive disagreement payoff for the retailers, even though a retailer cannot replace the missing input with the delivery by an additional supplier. In turn, the upstream suppliers have no trading alternatives in the case of disagreement with the selected retailer. Their outside option is normalized to zero. Applying the Nash bargaining solution,[14] the equilibrium bargaining outcome can be characterized by the solution of

$$\max_{x_{ij}, F_{ij}} \left[\pi^{D_i}(X_i, F_{ij}, \cdot) - \pi^{D_i}(X_i - x_{ij}, \cdot)\right] \pi^{U_{ij}}\left(x_{ij}, F_{ij}, \cdot\right), \tag{6}$$

where $\pi^{D_i}(X_i - x_{ij}, \cdot)$ refers to the profit of retailer D_i in the case of disagreement with the supplier U_{ij}, implying no delivery of x_{ij}.

The equilibrium quantity x_{ij}^B the retailer D_i negotiates with each supplier U_{ij} is, thus, implicitly given by

$$\frac{\partial p_i(X_i^B, \cdot)}{\partial X_i} X_i^B + p_i(X_i^B, \cdot) - \frac{\partial C(x_{ij}^B, q_i)}{\partial x_{ij}} = 0. \tag{7}$$

Note that the equilibrium quantity maximizes the joint profit of the respective retailer-supplier pair. We find that $x_{ij}^B(q_i, N_i)$ is decreasing in the retailer's quality requirements as a rising q_i leads to higher costs of production for suppliers. Likewise, $x_{ij}^B(q_i, N_i)$ is

[14] This cooperative approach can be interpreted in terms of a non-cooperative bargaining like the alternating-offers bargaining proposed by Rubinstein (1982). If the time interval between offers becomes relatively small, the solution of the dynamic non-cooperative process converges to the symmetric Nash bargaining solution (Binmore et al. 1986).

decreasing in the number of suppliers delivering to D_i. The equilibrium quantity $x_{ij}^B(q_i, N_i)$ is not affected by the other retailer's quality as we consider two separate downstream markets. Note further that the retailers sell exactly what they get from the upstream suppliers, i.e. X_i^B. That is, the negotiations impose a binding constraint on the retailers' quantity decision as a retailer does not internalize the suppliers' costs of production when maximizing its profit.

The fixed fees are set so as to share the joint profit, whereby each party gets its disagreement payoff plus half of the incremental gains from trade. More precisely, the retailer and a given supplier share equally the marginal contribution of the supplier's delivery to the overall revenue of the retailer, i.e. $R_i(X_i^B, \cdot) - R_i(X_i^B - x_{ij}^B, \cdot)$, as well as the supplier's total costs of $C(x_{ij}^B, q_i)$. Hence, the equilibrium fixed fee is given by

$$\begin{aligned} F_{ij}^B(\cdot) &= \frac{1}{2}\left[\Delta R_i(X_i^B, \cdot) + C(x_{ij}^B, q_i)\right] \qquad (8) \\ \text{with} &: \quad \Delta R_i(X_i^B, \cdot) = R_i(X_i^B, \cdot) - R_i(X_i^B - x_{ij}^B, \cdot). \end{aligned}$$

Lemma 1 *For given N_i and q_i, the equilibrium delivery tariff is given by $T_{ij}(x_{ij}^B, F_{ij}^B)$ where $x_{ij}^B(q_i, N_i)$ maximizes the joint profit of each retailer-supplier pair and the fixed fee $F_{ij}^B(q_i, N_i)$ shares the joint profit. Comparative statics reveal that $x_{ij}^B(q_i, N_i)$ is decreasing in both q_i and N_i, i.e. $\partial x_{ij}^B(q_i, N_i)/\partial q_i < 0$ and $\partial x_{ij}^B(q_i, N_i)/\partial N_i < 0$.*

Proof. See Appendix. ■

Delivery. When deciding about which downstream firm to deliver to, the upstream firms balance their profits in either case. Showing that the difference in the upstream firms' profits, i.e. $\Delta\pi^{U_{ij}} = \pi^{U_{1j}}(x_{1j}^B, F_{1j}^B, N_1, q_1, q_2) - \pi^{U_{2j}}(x_{2j}^B, F_{2j}^B, N_2, q_1, q_2)$, $\forall j = 1, ..., N$, is monotonically decreasing in N_1 and assuming

$$\pi^{U_{1j}}(x_{1j}^B, F_{1j}^B, 1, \cdot) > \pi^{U_{2j}}(x_{2j}^B, F_{2j}^B, N-1, \cdot)$$

and

$$\pi^{U_{1j}}(x_{1j}^B, F_{1j}^B, N-1, \cdot) < \pi^{U_{2j}}(x_{2j}^B, F_{2j}^B, 1, \cdot),$$

the equilibrium number of firms selling to D_1, i.e. $N_1^B(q_1, q_2)$, is implicitly given by

$$\pi^{U_{1j}}(x_{1j}^B, F_{1j}^B, N_1^B, \cdot) \equiv \pi^{U_{2j}}(x_{2j}^B, F_{2j}^B, N_2^B, \cdot), \forall j = 1, ..., N.$$

Correspondingly, $N_2^B = N - N_1^B$ upstream firms decide to supply D_2.

Lemma 2 *There exists a $N_i^B(q_i, q_k)$, $i = 1, 2$, $k \neq i$, that is increasing in q_i, while it is decreasing in q_k.*

Proof. See Appendix. ■

Our results show that the higher the quality requirements implemented by a retailer, the more suppliers decide to deliver to that retailer. Increasing quality requirements lead to higher production costs, such that the equilibrium quantity x_{ij}^B each supplier delivers to the selected retailer is decreasing in q_i (see Lemma 1). As a consequence, the overall quantity X_i^B the retailer sells is likewise decreasing in q_i, resulting in a higher price in the final consumer market. As long as the price increase more than compensates for the higher production costs, i.e. $\left(\partial p_i(X_i^B, \cdot)/\partial q_i\right) x_{ij}^B - \partial C(x_{ij}^B, q_i)/\partial q_i > 0$, suppliers benefit from choosing to deliver to the retailer with the higher quality standard. Accordingly, $N_i^B(q_i, q_k)$ is increasing in q_i, while it is decreasing in q_k.

Quality. In the first stage of the game, both retailers decide about the quality standards they implement. Using our previous results, the equilibrium quality requirements of the retailers are given by the maximization of the retailers' reduced-profit functions, i.e.

$$\begin{aligned} q_i^B \quad &: \quad = \arg\max R_i\left(X_i^B, q_1, q_2\right) - \sum_{j=a}^{A} F_{ij}^B\left(q_1, q_2\right) \\ \text{with} \quad &: \quad \begin{cases} a = 1,\ A = N_1^B(q_1, q_2) & \text{for } i = 1 \\ a = N_1^B(q_1, q_2) + 1,\ A = N & \text{for } i = 2 \end{cases} . \end{aligned} \tag{9}$$

Operating in two separate markets, both downstream firms implement the same equilibrium quality requirements, $q_1^B = q_2^B = q^B$. Thus, we have

Proposition 1 *If the upstream firms have no outside option in the case of negotiation breakdown, there exist only symmetric equilibria in the quality requirements of the retailers,*

$q_1^B = q_2^B = q^B$. *Consequently, the suppliers split up equally between both retailers, i.e.* $N_1^B(q_1, q_2) = N_2^B(q_1, q_2) = N/2$.

Proof. See Appendix. ■

4 Private Standards in Local Retail Monopolies

In contrast to the previous section, we now take into account suppliers' trading alternatives in the case of negotiation breakdown. That is, if a supplier fails to achieve an agreement with the selected retailer, it is basically able to switch to the other retailer. The existence of this trading alternative, however, is only given when the supplier fulfills the private quality standard imposed by the alternative retailer. Thus, a supplier is able to switch whenever both downstream firms implement the same quality requirements. If, however, the retailers' quality standards differ, we distinguish two cases. First, upstream firms that adhere to the lower quality standard have no outside option in the case of negotiation breakdown. That is, they cannot switch their delivery to the retailer with the higher quality requirements as they are unable to increase their product's quality in the short-term. Second, the suppliers who produce according to the higher quality standard—and, therefore, originally negotiate with the retailer who imposes the higher quality level—can opt to deliver to the retailer with the less demanding quality requirements as there is always the possibility of overcompliance with a given standard. As switching suppliers cannot modify the production process in the short-term, they still incur the variable costs associated with the higher quality requirements. However, they are able to adjust the quantity to be produced as production starts upon successful completion of negotiations.

Assuming $q_1 \geq q_2$ without loss of generality, the negotiations in the intermediate goods market proceed as follows. Each supplier U_{ij} negotiates with its selected retailer D_i about a quantity-forcing contract. In the case of disagreement with D_1, the supplier U_{1j} can switch to the other retailer D_2. However, the supplier U_{2j} can only switch to D_1 if $q_1 = q_2$, while it has no outside option in the case of $q_1 > q_2$. Using subgame perfection as our equilibrium concept, we analyze the negotiations in the intermediate goods market by proceeding backwards.[15] That is, we first analyze the negotiation outcome when the

[15] As in the benchmark case, the quantity choice of the downstream retailers is constrained by the

supplier U_{1j} has switched from D_1 to D_2 and then turn to the negotiations between the supplier and its initially chosen retailer D_1.

Specification of the Disagreement Payoffs. After a negotiation breakdown with retailer D_1, any upstream supplier U_{1j} can switch its delivery to retailer D_2 as it also complies with the respective quality requirements q_2. We denote an upstream firm that switches from D_1 to D_2 by $\widetilde{U}_{2j}$ with $j = 1, ..., N_1$. The switching supplier $\widetilde{U}_{2j}$ negotiates with D_2 about a delivery tariff in the form of $\widetilde{T}_{2j}(\widetilde{x}_{2j}, \widetilde{F}_{2j})$, taking the contracts between D_2 and the initial suppliers U_{2j} as given. As the switching upstream firm can adjust its quantity but not its quality-related production costs, the switching supplier's production costs amount to $C(\widetilde{x}_{2j}, q_1)$. Thus, the profit of the switching supplier $\widetilde{U}_{2j}$ refers to

$$\widetilde{\pi}^{\widetilde{U}_{2j}}(\cdot) = \widetilde{F}_{2j} - C(\widetilde{x}_{2j}, q_1). \tag{10}$$

The profit of the downstream retailer D_2 is, then, given by

$$\widetilde{\pi}^{D_2}(\cdot) = R_2(X_2 + \widetilde{x}_{2j}, \cdot) - \sum_{l=N_1+1}^{N} F_{2l} - \widetilde{F}_{2j}, \ \forall j = 1, ..., N_1. \tag{11}$$

If the switching upstream firm $\widetilde{U}_{2j}$ also fails to achieve an agreement with D_2, it has no further outside option. Hence, its disagreement payoff refers to zero when negotiating with D_2. In turn, D_2 still sells the quantities of those suppliers it has already made an agreement with, i.e. suppliers U_{2j}. The disagreement payoff of retailer D_2 is, thus, given by

$$\pi^{D_2}(\cdot) = R_2(X_2, \cdot) - \sum_{l=N_1+1}^{N} F_{2l}. \tag{12}$$

Using (10), (11) and (12), the equilibrium bargaining outcome between D_2 and the switching firm $\widetilde{U}_{2j}$ can be characterized by the solution of

$$\max_{\widetilde{x}_{2j}, \widetilde{F}_{2j}} \left[\widetilde{\pi}^{D_2}(\cdot) - \pi^{D_2}(\cdot)\right] \widetilde{\pi}^{\widetilde{U}_{2j}}(\cdot). \tag{13}$$

Taking as given the negotiated quantities with the initial suppliers, the equilibrium quan-

negotiation outcome with the upstream suppliers. Again, this constraint is always binding.

tity $\widetilde{x}^*_{2j}$ of the switching supplier is implicitly determined by

$$\frac{\partial p_2(X_2+\widetilde{x}^*_{2j},\cdot)}{\partial \widetilde{x}_{2j}}(X_2+\widetilde{x}^*_{2j})+p_2(X_2+\widetilde{x}^*_{2j},\cdot)-\frac{\partial C(\widetilde{x}^*_{2j},q_1)}{\partial \widetilde{x}_{2j}}=0. \tag{14}$$

This quantity maximizes the joint profit of retailer D_2 and the switching supplier. Note that the equilibrium quantity of the switching supplier reacts in the quality requirements of both retailers. More precisely, $\widetilde{x}^*_{2j}(q_1,q_2)$ is decreasing in the quality requirements of the initially chosen retailer, D_1, as this increases the production costs of the supplier. In turn, the quantity is increasing in the quality requirements of retailer D_2 the supplier switches to. This is due to the fact that a higher quality q_2 positively affects the price in the final cosumer market without influencing the production costs of the switching supplier.

The gains from trade are shared by the fixed fee. Each negotiating party gets its disagreement payoff plus half of the incremental gains from trade. In particular, the retailer and the switching supplier share equally the marginal contribution of the supplier's delivery to the overall revenue of the retailer, i.e. $R_2(X_2+\widetilde{x}^*_{2j},\cdot)-R_2(X_2,\cdot)$, as well as the supplier's total costs of $C(\widetilde{x}^*_{2j},q_1)$. Hence, the fixed fee is given by

$$\widetilde{F}^*_{2j}(\cdot)=\frac{1}{2}\left[R_2(X_2+\widetilde{x}^*_{2j},\cdot)-R_2(X_2,\cdot)+C(\widetilde{x}^*_{2j},q_1)\right]. \tag{15}$$

Lemma 3 *For given N_i, there exists an equilibrium delivery contract $\widetilde{T}_{2j}(\widetilde{x}^*_{2j},\widetilde{F}^*_{2j})$, where $\widetilde{x}^*_{2j}$ maximizes the joint profit of the retailer-supplier pair $D_2-\widetilde{U}_{2j}$ and the fixed fee shares the joint profit. Comparative statics reveal that $\widetilde{x}^*_{2j}$ is decreasing in q_1, i.e. $\partial\widetilde{x}^*_{2j}/\partial q_1<0$, while it is increasing in q_2, i.e. $\partial\widetilde{x}^*_{2j}/\partial q_2>0$.*

Proof. See Appendix. ■

Negotiations. We turn now to the negotiations between any upstream firm U_{1j} and its initially selected retailer D_1. If the retailer does not reach an agreement with the supplier, its disagreement payoff is given by

$$\widehat{\pi}^{D_1}(\cdot)=R_1(X_1-x_{1j},\cdot)-\sum_{l=1}^{N_1-1}F_{1l}. \tag{16}$$

Referring to Lemma 3, we specify the disagreement payoff of the upstream firm U_{1j} as

$$\widetilde{\pi}^{\widetilde{U}_{2j}*}(\cdot) = \widetilde{F}^*_{2j}(\cdot) - C(\widetilde{x}^*_{2j}, q_1). \tag{17}$$

Using (16) together with (4),(5) and (17), the equilibrium bargaining outcome between D_1 and U_{1j} can be characterized by the solution of

$$\max_{x_{1j}, F_{1j}} \left[\pi^{D_1}(\cdot) - \widehat{\pi}^{D_1}(\cdot)\right]\left[\pi^{U_{1j}}(\cdot) - \widetilde{\pi}^{\widetilde{U}_{2j}*}(\cdot)\right]. \tag{18}$$

Analoguously to x^B_{ij} defined in (7), the equilibrium quantity x^*_{1j} each supplier U_{1j} delivers to D_1 is implicitly given by

$$\frac{\partial p_1(X^*_1, \cdot)}{\partial X_1} X^*_1 + p_1(X^*_1, \cdot) - \frac{\partial C(x^*_{1j}, q_1)}{\partial x_{1j}} = 0. \tag{19}$$

The fixed fees F^*_{1j} sharing the joint profits refer to

$$F^*_{1j}(\cdot) = \frac{1}{2}\left[\Delta R_1(X^*_1, \cdot) + C(x^*_{1j}, q_1) + \widetilde{F}^*_{2j} - C\left(\widetilde{x}^*_{2j}, q_1\right)\right]. \tag{20}$$

Note that the equilibrium fixed payment $F^*_{1j}(\cdot)$ is increasing in the outside option of the supplier, i.e. $\widetilde{\pi}^{\widetilde{U}_{2j}} = \widetilde{F}^*_{2j} - C\left(\widetilde{x}^*_{2j}, q_1\right)$. In other words, the supplier's outside option strengthens its bargaining power vis-à-vis the downstream firm.

Regarding the negotiations between D_2 and U_{2j}, the equilibrium quantity x^*_{2j} is implicitly determined by

$$\frac{\partial p_2(X^*_2, \cdot)}{\partial X_2} X^*_2 + p_2(X^*_2, \cdot) - \frac{\partial C(x^*_{2j}, q_2)}{\partial x_{2j}} = 0, \tag{21}$$

while the equilibrium fixed fee F^*_{2j} is given by

$$F^*_{2j}(\cdot) = \begin{cases} \frac{1}{2}\left[\Delta R_2(X^*_2, \cdot) + C(x^*_{2j}, q_2) + \widetilde{F}^*_{1j} - C\left(\widetilde{x}^*_{1j}, q_2\right)\right] & \text{if } q_1 = q_2 \\ \frac{1}{2}\left[\Delta R_2(X^*_2, \cdot) + C(x^*_{2j}, q_2)\right] & \text{if } q_1 > q_2 \end{cases}, \tag{22}$$

where $\widetilde{\pi}^{\widetilde{U}_{1j}} = \widetilde{F}^*_{1j} - C\left(\widetilde{x}^*_{1j}, q_2\right)$ denotes the outside option of supplier U_{2j} if switching to D_1 is possible, i.e. if $q_1 = q_2$. Apparently, the supplier earns less if it is not able to transfer its delivery to the other retailer in the case of disagreement, i.e. if $q_1 > q_2$.

Lemma 4 *For given N_i, there exists an equilibrium delivery contract $T_{ij}(x_{ij}^*, F_{ij}^*)$, $i = 1, 2$, where x_{ij}^* maximizes the joint profit of the retailer-supplier pair and the fixed fee F_{ij}^* shares the joint profit. Analoguously to the benchmark case, comparative statics reveal that x_{ij}^* is decreasing in q_i. Furthermore, x_{ij}^* is increasing in N_i and decreasing in N_k, $i = 1, 2$, $k \neq i$.*

Proof. See Appendix. ■

Delivery Choice of Upstream Firms. Taking the quality choice of the downstream firms as given, the upstream firms decide which of the two downstream firms to supply and, thereby, which quality standard to adhere to. Showing that the difference in the upstream firms' profits, i.e. $\Delta\pi^{U_{ij}} = \pi^{U_{1j}}(x_{1j}^*, F_{1j}^*, N_1, q_1, q_2) - \pi^{U_{2j}}(x_{2j}^*, F_{2j}^*, N_2, q_1, q_2)$, $\forall j = 1, ..., N$, is monotonically decreasing in N_1 and assuming

$$\pi^{U_{1j}}(x_{1j}^*, F_{1j}^*, 1, \cdot) > \pi^{U_{2j}}(x_{2j}^*, F_{2j}^*, N-1, \cdot)$$

and

$$\pi^{U_{1j}}(x_{1j}^*, F_{1j}^*, N-1, \cdot) < \pi^{U_{2j}}(x_{2j}^*, F_{2j}^*, 1, \cdot),$$

the equilibrium number of firms selling to D_1, i.e. $N_1^*(q_1, q_2)$, is implicitly given by

$$\pi^{U_{1j}}(x_{1j}^*, F_{1j}^*, N_1^*, q_1, q_2) \equiv \pi^{U_{2j}}(x_{2j}^*, F_{2j}^*, N_2^*, q_1, q_2). \tag{23}$$

That is, the upstream firms will split such that there is no incentive for any supplier to change the retailer. In equilibrium, all suppliers will earn equal profits. If retailer D_1 increases q_1, two countervailing effects prevail. First, any supplier U_{1j} benefits from a higher q_1 as this leads to a higher price in the final consumer market and, thus, to a larger joint profit with retailer D_1. However, the higher q_1 relative to q_2, the worse the bargaining position of U_{1j}. That is, an increasing q_1 lowers the outside option of supplier U_{1j}. The reason is that the production costs are strictly increasing in q_1 and cannot be adjusted in the short-term, while D_2 does not value the higher quality of the product. In short, U_{1j} gets a smaller share of a larger pie when q_1 is increasing. We find that the first effect dominates the second, taking the quality requirements q_2 as given. Hence, $N_1^*(q_1, q_2)$ is increasing in q_1. In turn, $N_1^*(q_1, q_2)$ is decreasing in q_2, even though a higher q_2 improves the outside option of suppliers U_{1j} and, thus, their bargaining position vis-à-vis retailer D_1. Again, the price effect dominates the bargaining effect.

Lemma 5 *There exists a $N_i^*(q_i, q_k)$, $i = 1, 2$, $k \neq i$, that is increasing in q_i, but decreasing in q_k, i.e. $\partial N_i^*(q_i, q_k)/\partial q_i > 0$ and $\partial N_i^*(q_i, q_k)/\partial q_k < 0$. Note that $N_i^*(q_i, q_k)$ reacts stronger in q_i than in q_k, i.e. $|\partial N_i^*(q_i, q_k)/\partial q_i| > |\partial N_i^*(q_i, q_k)/\partial q_k|$.*

Proof. See Appendix. ■

Private Quality Standards. We now turn to the analysis of the retailers' quality decision. Using (23) together with our previous results, the equilibrium quality requirements of the retailers are given by the maximization of the retailers' reduced-profit functions, i.e.

$$\begin{aligned} q_i^* \quad &: \quad = \arg\max R_i\left(X_i^*, q_1, q_2\right) - \sum_{j=a}^{A} F_{ij}^*\left(q_1, q_2\right) \qquad (24) \\ \text{with} \quad &: \quad \begin{cases} a = 1,\ A = N_1^*(q_1, q_2) & \text{for } i = 1 \\ a = N_1^*(q_1, q_2) + 1,\ A = N & \text{for } i = 2 \end{cases}. \end{aligned}$$

Analyzing the first-order conditions for $q_1 \geq q_2$ without loss of generality, we have

Proposition 2 *If the costs of production are sufficiently high and increasing in q_i, there exists an asymmetric equilibrium in the downstream firms' quality choice, i.e. $q_1^* > q^B > q_2^*$.*

Proof. See Appendix. ■

Although retailers operate as local monopolists and, therefore, do not compete for final consumers, they compete for the delivery by upstream suppliers.[16] Delivery to retailer D_1 becomes the more attractive the higher the respective quality requirements q_1, taking q_2 as given (see Lemma 5). A higher q_1 realtive to q_2 implies relatively higher costs of production when delivering to $D_1$and, thus, a lower profit when switching to D_2. As a consequence, the bargaining position of U_{1j} vis-à-vis D_1 is decreasing in q_1 which makes delivery to D_1 less attractive. The best response of D_2 to an increasing q_1 is, thus, to

[16] Note that the negotiations with the upstream suppliers constitute a binding constraint for the quantity choice of the retailers. Furthermore, we assume convex costs of production such that a higher number of suppliers leads to lower production costs at the margin, taking q_1 and q_2 as given.

lower its quality requirements q_2, even though this comes along with a reduced price in the final consumer market. In sum, we find that one retailer exceeds and the other retailer undercuts the quality standard analyzed in the benchmark case. Combining Proposition 2, Lemma 4 and Lemma 5, we get:

Corollary 3 *In equilibrium, more suppliers deliver to D_1 than to D_2, implying $x_{2j}^* > x_{1j}^*$.*

5 Linear Example

We now illustrate our results based on a numerical example that satisfies all our assumptions made in the previous analysis. This enables us to conduct welfare analysis, to study the interplay between a public MQS and the retailers' private quality standards, and to extend our model by allowing the retailers to compete in one single market. Assuming that the retailers compete in quantities and their products constitute imperfect substitutes, the analysis still reveals asymmetric equilibria in the retailers' quality decision. The extent of asymmetry in the retailers' quality choice becomes the more pronounced the stronger the retailers compete.

Using the generalized Dixit (1979) utility function, representative consumer's utility can be written as

$$U(X_1, X_2, \cdot) = q_1 X_1 + q_2 X_2 - \frac{1}{2}\left(X_1^2 + X_2^2 + 2\sigma X_1 X_2\right) - p_1 X_1 - p_2 X_2, \qquad (25)$$

where $\sigma \in [0, 1)$ indicates the substitutability between the retailers' products 1 and 2.[17] That is, the more σ approaches one, the higher the degree of substitutability between the products. Differentiating (25) with respect to X_1 and X_2, we obtain the following inverse demand functions

$$p_i(\cdot) := \max\{q_i - X_i - \sigma X_k, 0\}, \ \forall i, k = 1, 2, \ i \neq k. \qquad (26)$$

Assuming that any upstream firm's production costs are increasing and convex in both

[17] The derivation of the linear example can be found in the Appendix.

the selected quality requirements and the quantity, we apply the follwing cost functions

$$C(x_{ij}, q_i) = \frac{q_i^2}{2(2 - q_i^2)} x_{ij}^2 \text{ for } 0 < q_i < \sqrt{2}. \tag{27}$$

Quality Choice. Assuming $q_1 \geq q_2$ without loss of generality and denoting the reaction functions of retailers D_1 and D_2 by $r_1(q_2)$ and $r_2(q_1)$, respectively, the reaction functions and the implied asymmetric equilibrium are illustrated in Figures 1a and 1b.

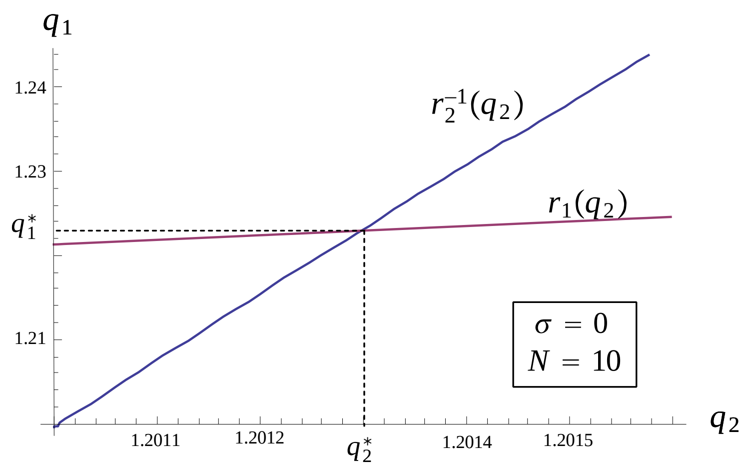

Figure 1a: Reaction Functions for $\sigma = 0$

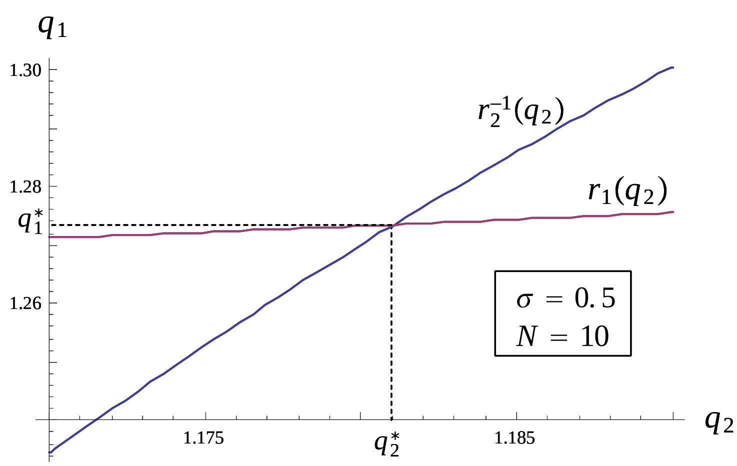

Figure 1b: Reaction Functions for $\sigma = 0.5$

It turns out that the spread between q_1^* and q_2^* is increasing in the degree of substitutability (see Figure 2). This is due to the fact that downstream competition becomes the more intense the closer substitutes the products are. In the case of local monopolies ($\sigma = 0$), retailer D_2 decreases its quality requirements in order to make the delivery to retailer D_1 less attractive. If the retailers operate in the same market and compete in quantities ($\sigma > 0$), there is an additional effect. By increasing its quality requirements, D_1 commits to sell a lower quantity to final consumers. As quantities are strategic substitutes in our setting, the best response of the competitor D_2 is to increase its quantity in the final consumer market. D_2 is able to do so by reducing its quality requirements. That is, retailers tighten their quality requirements resulting in higher prices in the final consumer market in order to counter the effects of more intense downstream competition.

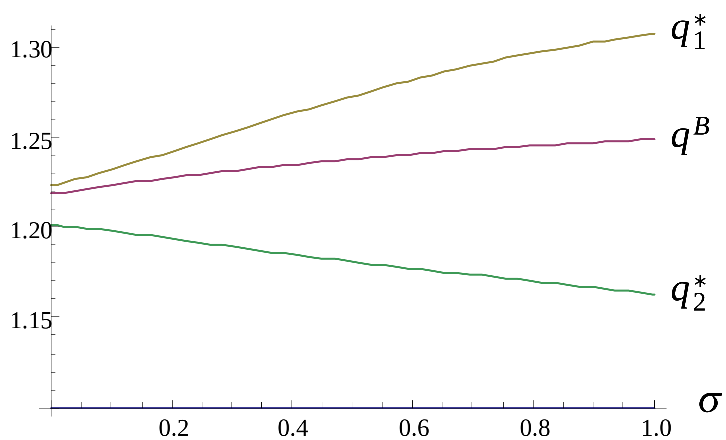

Figure 2: Quality Requirements q_i^* and q^B in σ for $N = 10$, $i = 1, 2$

Social Welfare. In order to evaluate the welfare effect of the retailers' private standard setting, we compare the profit-maximizing quality levels to the quality requirements obtained under welfare maximization. For this purpose, we define social welfare as the sum of consumer surplus and industry profit, whereby industry profit refers to the sum of the retailers' and the suppliers' profits, i.e. we have

$$W(\cdot) = U(X_1^*(\cdot), X_2^*(\cdot), \cdot) - N_1^*(\cdot)\, C(x_{1j}^*(\cdot), q_1) - N_2^*(\cdot)\, C(x_{2j}^*(\cdot), q_2). \tag{28}$$

Note that we evaluate social welfare for given negotiation outcomes and, therefore, pursue a second-best approach. The reason is that public authorities are not assumed to be in a position to regulate the negotiation process between the retailers and suppliers. Hence, we get the socially optimal quality requirements by differentiating (28) with respect to q_i,

$$q_i^W := \arg\max W(\cdot), \ \forall i = 1, 2. \tag{29}$$

If the upstream firms have an outside option, the profit-maximizing quality choice of the downstream firms will deviate from the socially optimal quality levels. Numerical analysis reveals that $q_1^* > q_1^w > q_2^w > q_2^*$ for all σ. That is, D_1 exaggerates in its quality requirements q_1^* by exceeding the socially optimal quality level q_1^w, while the best response of D_2 leads to quality requirements q_2^* that undercut the socially optimal quality level q_2^w (see Figure 3).

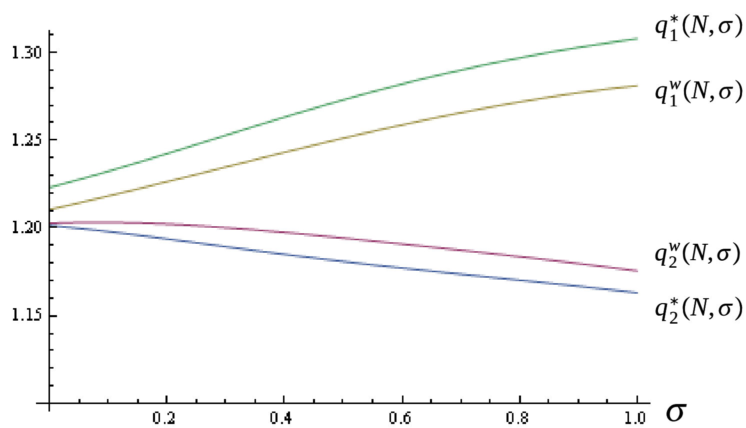

Figure 3: Quality Requirements q_i^* and q_i^w in σ for

$N = 10$, $i = 1, 2$

Decomposing social welfare, we find that the downstream firms gain, while the upstream firms lose due to the retailers' profit-maximizing quality requirements, i.e. $\pi^{U_{1j}}(q_1^*, q_2^*, \cdot) = \pi^{U_{2j}}(q_1^*, q_2^*, \cdot) < \pi^{U_{1j}}(q_1^w, q_2^w, \cdot) = \pi^{U_{2j}}(q_1^w, q_2^w, \cdot)$, as long as the products are sufficiently close substitutes, i.e. σ is sufficiently large. Also, the consumer surplus is smaller under profit maximization than under welfare optimization. Thus, the strategic use of private quality requirements in vertical relations implies a welfare loss.

Minimum Quality Standard. The unfavorable welfare effect of the retailers' quality choice can be softened by the enforcement of a binding public MQS. The optimal level of the public MQS, $\widetilde{q}_2^w$, is obtained by maximizing (28) with respect to q_2, whereby the higher quality, q_1, is determined by the best response of retailer D_1, i.e.

$$\widetilde{q}_2^w := \arg\max W(r_1(q_2), q_2, N_1^*(r_1(q_2), q_2)). \tag{30}$$

Our numerical analysis reveals that the implementation of a public MQS increases social welfare (see Figures 4a and 4b). The stronger the downstream competition, i.e. the higher σ, the smaller the optimal public MQS, but the larger the interval in which raising the lower quality requirement above its profit-maximizing level is welfare-increasing.

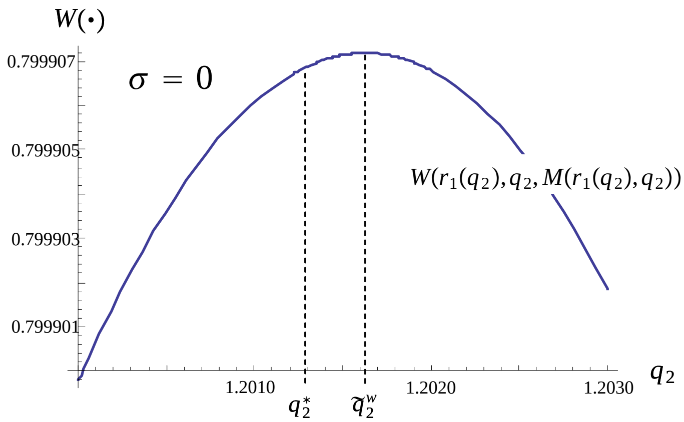

Figure 4a: Welfare Effects of MQS for $\sigma = 0$

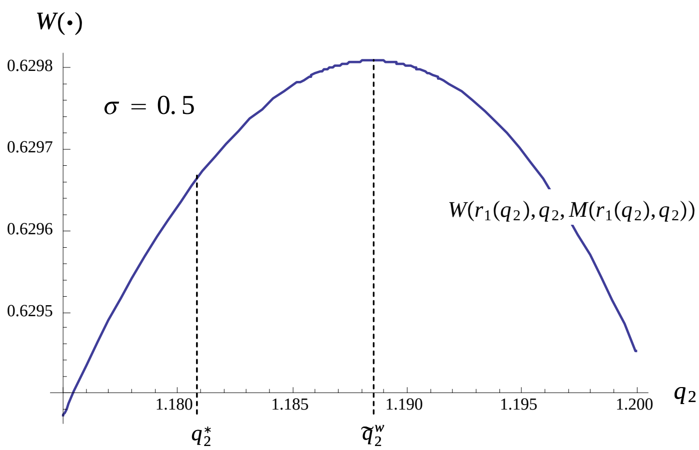

Figure 4b: Welfare Effects of MQS for $\sigma = 0.5$

6 Conclusion

We analyze the strategic role of private quality standards in vertical relations and its impact on both market structure and social welfare. Considering two local monopolies at the downstream level and an infinite number of upstream suppliers, we study bilateral and simultaneous negotiations in the intermediate goods market. If the negotiations between a retailer and one of its suppliers fail, the supplier is able to switch its delivery to the other retailer as long as it complies with the respective quality requirements. In this framework, there exist two asymmetric equilibria in the downstream firms' quality choice where one retailer implements a strictly higher quality standard than the other retailer. Competing for the delivery by upstream suppliers, one retailer increases its quality requirements, improving the gains from trade with the supplier. The other retailer, then, reacts by reducing its own quality requirements to weaken the suppliers' bargaining position when delivering to the high-quality retailer. By this, it becomes less attractive for suppliers to deliver to the high-quality retailer. Hence, the retailers use their private quality standards to attract suppliers, but at the same time the retailers' use of private quality standards erodes their suppliers' bargaining strength vis-à-vis the retailers. The spread in the quality requirements is increasing in the degree of downstream competition. Due to higher marginal costs of production, a more demanding quality standard by one retailer induces a lower quantity sold in the final consumer market. The best response of the competing retailer is to reduce its quality requirements in order to increase its quantity in the final consumer market. This effect becomes the more pronounced the less differentiated the retailers are and, thus, the more they compete.

Our results are limited to cases where the level of production costs is sufficiently high and where the increase in production costs for higher quality requirements is sufficiently strong. Furthermore, we assume that suppliers cannot easily change their production process to comply with different quality requirements. Accordingly, the effect we describe in this model can be observed in industries where producers face high quality-related production costs and are locked in their production process in the short-term. Examples include the production of fruits and vegetables.

It turns out that social welfare is decreasing in the retailers' strategic use of their quality requirements. While the quality requirements set by the high-quality retailer exceed the corresponding socially optimal quality level, those set by the low-quality retailer undercut the welfare-optimal low quality. Public regulation in the form of a MQS can remedy this unfavorable welfare outcome as it increases the lower quality level.

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Appendix

Proof of Lemma 1. Maximizing (6) with respect to x_{ij} and F_{ij}, we obtain the following first-order conditions

$$\frac{\partial \pi^{D_i}(X_i,\cdot)}{\partial x_{ij}}\pi^{U_{ij}}(x_{ij},\cdot)+\frac{\partial \pi^{U_{ij}}(x_{ij},\cdot)}{\partial x_{ij}}\left[\pi^{D_i}(X_i,\cdot)-\pi^{D_i}(X_i-x_{ij},\cdot)\right]=0 \qquad (31)$$

and

$$-\pi^{U_{ij}}\left(x_{ij}, F_{ij}\right)+\pi^{D_i}(X_i, F_{ij}, \cdot)-\pi^{D_i}(X_i-x_{ij}, \cdot)=0. \tag{32}$$

A rearrangement of (32) yields

$$\frac{\pi^{D_i}(X_i, \cdot)-\pi^{D_i}(X_i-x_{ij}, \cdot)}{\pi^{U_{ij}}\left(x_{ij}, \cdot\right)}=1. \tag{33}$$

Using (33) and rearranging (31), we further obtain

$$\frac{\partial \pi^{D_i}(X_i, \cdot)}{\partial x_{ij}}=-\frac{\partial \pi^{U_{ij}}(x_{ij,} \cdot)}{\partial x_{ij}}. \tag{34}$$

With $\partial X_i/\partial x_{ij}=1$, it follows that the optimal quantity, x_{ij}^B, is implicitly given by

$$H_i := \frac{\partial p_i(X_i^B, \cdot)}{\partial X_i} X_i^B + p_i(X_i^B, \cdot) - \frac{\partial C(x_{ij}^B, q_i)}{\partial x_{ij}}=0. \tag{35}$$

Solving (33) for F_{ij}^B, we get

$$F_{ij}^B(\cdot)=\frac{1}{2}\left[R_i(X_i^B, \cdot)-R_i(X_i^B-x_{ij}^B, \cdot)+C(x_{ij}^B, q_i)\right]. \tag{36}$$

Analyzing the comparative statics of $x_{ij}^B(q_i, q_k)$ in both q_i and q_k, we obtain

$$\frac{\partial H_i}{\partial x_{ij}}\frac{\partial x_{ij}^B}{\partial q_i}+\frac{\partial H_i}{\partial q_i}=0 \text{ and } \frac{\partial H_i}{\partial x_{ij}}\frac{\partial x_{ij}^B}{\partial q_k}=0 \tag{37}$$

implying

$$\frac{\partial x_{ij}^B}{\partial q_i}=-\frac{\partial H_i/\partial q_i}{\partial H_i/\partial x_{ij}} \text{ and } \frac{\partial x_{ij}^B}{\partial q_k}=0. \tag{38}$$

Using $\partial H_i/\partial x_{ij} = 2\left(\partial p_i(X_i^B, \cdot)/\partial X_i\right)\partial X_i^B/\partial x_{ij} - \partial^2 C(x_{ij}^B, q_i)/\partial x_{ij}^2 < 0$ and applying Assumption 1, we obtain

$$sign\left(\frac{\partial x_{ij}^B}{\partial q_i}\right)=sign\left(\frac{\partial H_i}{\partial q_i}\right)=sign\left(\frac{\partial p_i(X_i^B, \cdot)}{\partial q_i}-\frac{\partial^2 C(x_{ij}^B, q_i)}{\partial x_{ij}\partial q_i}\right)<0. \tag{39}$$

Furthermore, we have

$$\frac{\partial x_{ij}^B}{\partial N_i}=-\frac{\partial H^B(\cdot)/\partial N_i}{\partial H^B(\cdot)/\partial x_{ij}}<0 \tag{40}$$

since

$$sign\left(\frac{\partial x_{ij}^B}{\partial N_i}\right) = sign\left(\frac{\partial H_i}{\partial N_i}\right) = sign\left(2\frac{\partial p_i(X_i, X_k, q_i)}{\partial X_i}x_{ij}\right) < 0. \tag{41}$$

Defining

$$H_k := \frac{\partial p_k(X_k^B, \cdot)}{\partial X_k}X_k^B + p_k(X_k^B, \cdot) - \frac{\partial C(x_{kj}^B, q_k)}{\partial x_{kj}} = 0, \tag{42}$$

we have

$$\frac{\partial x_{kj}^B}{\partial N_1} = -\frac{\partial H_k/\partial N_1}{\partial H_k/\partial x_{kj}} > 0 \tag{43}$$

as $\partial G(\cdot)/\partial x_{kj} = 2\left(\partial p_k(X_k, \cdot)/\partial X_k\right)\partial X_k/\partial x_{kj} - \partial^2 C(x_{kj}, q_k)/\partial x_{kj}^2 < 0$ and $\partial G(\cdot)/\partial N_1 = -2\left(\partial p_k(X_k, \cdot)/\partial X_k\right)x_{kj} > 0$.

Proof of Lemma 2. We first show that

$$\frac{\partial \Delta\pi^U(\cdot)}{\partial N_1} = \frac{\partial\left[\pi^{U_{1j}}(x_{1j}^B, F_{1j}^B, \cdot) - \pi^{U_{2j}}(x_{2j}^B, F_{2j}^B)\right]}{\partial N_1} < 0. \tag{44}$$

Using $X_i^B = N_i^B x_{ij}^B$, applying the envelope theorem as well as $p_i(X_i^B, \cdot) - p_i(X_i^B - x_{ij}^B, \cdot) = \left(\partial p_i\left(X_i^B, \cdot\right)/\partial X_i\right)x_{ij}^B$, we get

$$\begin{aligned}
\frac{\partial \Delta\pi^U(\cdot)}{\partial N_1} &= \Phi_1 + \Phi_2 < 0 && (45)\\
\text{with} \quad &: \quad \Phi_1 = \frac{\partial p_i\left(X_i^B, \cdot\right)}{\partial X_i}x_{ij}^B\left(x_{ij}^B + (N_1^B - 1)\frac{\partial x_{ij}^B}{\partial N_1}\right) < 0\\
\text{and} \quad &: \quad \Phi_2 = \frac{\partial p_k\left(X_k^B, \cdot\right)}{\partial X_k}x_{kj}^B\left(x_{kj}^B - (N_2^B - 1)\frac{\partial x_{kj}^B}{\partial N_1}\right) < 0
\end{aligned}$$

as it holds that $\partial X_i^B(\cdot)/\partial N_1 = x_{ij}^B + N_1^B \partial x_{ij}^B/\partial N_1 > 0$ as well as $\partial X_k^B(\cdot)/\partial N_1 = -x_{kj}^B + N_2^B \partial x_{kj}^B/\partial N_1 < 0$. The two latter inequalities are obtained by using (40) and (43) and plugging in the corresponding expressions for $\partial H^B(\cdot)/\partial N_1$, $\partial H^B(\cdot)/\partial x_{ij}$, $\partial G^B(\cdot)/\partial N_1$ and $\partial G^B(\cdot)/\partial x_{kj}$. Note also that $x_{ij}^B + M^B \partial x_{ij}^B/\partial N_1 < x_{ij}^B + \left(N_1^B - 1\right)\partial x_{ij}^B/\partial M$ and $-x_{kj}^B + N_2^B \partial x_{kj}^B/\partial N_1 > -x_{kj}^B + \left(N_2^B - 1\right)\partial x_{kj}^B/\partial N_1$. Given $\partial\Delta\pi^U(\cdot)/\partial N_1 < 0$, the comparative statics of $N_1^B(q_i, q_k)$ in q_i refer to

$$sign\left(\frac{\partial N_1^B}{\partial q_i}\right) = sign\left(\frac{\partial \Delta\pi^U}{\partial q_i}\right) > 0 \tag{46}$$

since

$$\frac{\partial \Delta\pi^U}{\partial q_i} = \frac{\frac{\partial p_i\left(X_i^B,\cdot\right)}{\partial q_i}x_{ij}^B - \frac{\partial C(x_{ij}^B,q_i)}{\partial q_i} + 2\frac{\partial p_i\left(X_i^B,\cdot\right)}{\partial X_i}(N_1^B-1)\frac{\partial x_{ij}^B}{\partial q_i}x_{ij}^B}{2} > 0 \tag{47}$$

as long as $\left(\partial p_i\left(X_i^B,\cdot\right)/\partial q_i\right)x_{ij}^B - \partial C(x_{ij}^B, q_i)/\partial q_i > 0$ holds in equilibrium. Analoguously, we have $\partial N_1^B(q_i, q_k)/\partial q_k < 0$ since

$$\frac{\partial \Delta\pi^U}{\partial q_k} = -\frac{\frac{\partial p_k\left(X_k^B,\cdot\right)}{\partial q_k}x_{kj}^B - \frac{\partial C(x_{kj}^B,q_k)}{\partial q_k} + 2\frac{\partial p_k\left(X_k^B,\cdot\right)}{\partial X_k}(N_1^B-1)\frac{\partial x_{kj}^B}{\partial q_k}x_{kj}^B}{2} < 0. \tag{48}$$

Proof of Proposition 1. To prove that there exists only symmetric equilibria in qualities, we first show that $\partial q_i/\partial q_k > 0$. That is, the rivals' strategies are strategic complements. Defining

$$\pi^{D_i} = N_1^B\Gamma_i \tag{49}$$

with

$$\Gamma_i = \left[p_i^B(X_i^B,\cdot)x_{ij}^B(\cdot) - \frac{1}{2}\left(M^B p_i^B(X_i^B,\cdot)x_{ij}^B - (M^B-1)p_i(X_i^B - x_{ij}^B,\cdot)x_{ij}^B + C(\cdot)\right)\right]$$

and using $\partial M^B/\partial q_i = -\partial M^B/\partial q_k$, we obtain

$$\frac{\partial^2\pi^{D_i}}{\partial q_i\partial q_k} = \frac{\partial M^B}{\partial q_i}\left(\frac{\partial\Gamma_i}{\partial q_k} - \frac{\partial\Gamma_i}{\partial q_i}\right) + \Gamma_i\frac{\partial^2 M^B}{\partial q_i\partial q_k} + M^B\frac{\partial^2\Gamma_i}{\partial q_i\partial q_k}. \tag{50}$$

Assuming $\partial^2\pi^{D_i}/\left(\partial q_i\partial q_i\right) < 0$, we have

$$sign\left(\frac{\partial q_i}{\partial q_k}\right) = sign\left(\frac{\partial^2\pi^{D_i}}{\partial q_i\partial q_k}\right). \tag{51}$$

Comparing

$$\frac{\partial\Gamma_i}{\partial q_i} = \frac{1}{2}\left(\frac{\partial p_i}{\partial q_i}x_{ij} - \frac{\partial C(\cdot)}{\partial q_i}\right) - \left(M^B-1\right)\frac{\partial p_i}{\partial X_i}x_{ij}\left(\frac{\partial x_{ij}}{\partial q_i} + \frac{\partial x_{ij}}{\partial M}\frac{\partial M^B}{\partial q_i}\right) < 0 \tag{52}$$

and

$$\frac{\partial\Gamma_i}{\partial q_k} = -\left(M^B-1\right)\frac{\partial p_i}{\partial X_i}x_{ij}\frac{\partial x_{ij}}{\partial M}\frac{\partial M^B}{\partial q_k} > 0, \tag{53}$$

we have

$$|\partial\Gamma_i/\partial q_i| > |\partial\Gamma_i/\partial q_k| \tag{54}$$

if $((\partial p_i/\partial q_i)\,x_{ij} - \partial C\,(\cdot)\,/\partial q_i) - 2\left(M^B - 1\right)(\partial p_i/\partial X_i)\,x_{ij}\,(\partial x_{ij}/\partial q_i) < 0$. Then, we analyze $\partial^2 M^B/\partial q_i \partial q_k$, which is given by

$$\frac{\partial^2 M^B}{\partial q_i \partial q_k} = \frac{\partial \Delta\pi^{U_{ij}}/\partial q_i * \partial^2 \Delta\pi^{U_{ij}}/\partial M \partial q_k}{\left(-\partial \Delta\pi^{U_{ij}}/\partial M\right)^2} > 0 \tag{55}$$

since $\partial^2 \Delta\pi^{U_{ij}}/\partial q_i \partial q_k = 0$,

$\partial \Delta\pi^{U_{ij}}/\partial q_i = 1/2\left[(\partial p_i\,(\cdot)\,/\partial q_i - \partial C(\cdot)/\partial q_i + 2(M-1)\,(\partial p_i\,(\cdot)\,/\partial X_i)\,(\partial x_{ij}/\partial q_i))\,x_{ij}\right] > 0$

and $\partial^2 \Delta\pi^{U_{ij}}/\partial M \partial q_k = (\partial p_k\,(\cdot)\,/\partial X_k)\,(\partial x_{kj}/\partial q_k)\left(2x_{kj} - (M-1)\frac{\partial x_{kj}}{\partial M}\right) > 0$. Finally, we have

$$\begin{aligned}\frac{\partial \Gamma_i}{\partial q_k \partial q_i} &= -\frac{\partial M^B}{\partial q_i}\frac{\partial p_i}{\partial X_i}x_{ij}\frac{\partial x_{ij}}{\partial M}\frac{\partial M^B}{\partial q_k} \\ &\quad -\left(M^B - 1\right)\frac{\partial p_i}{\partial X_i}\left(\frac{\partial x_{ij}}{\partial q_i}\frac{\partial x_{ij}}{\partial M}\frac{\partial M^B}{\partial q_k} + x_{ij}\frac{\partial x_{ij}}{\partial M}\frac{\partial^2 M^B}{\partial q_k \partial q_i}\right).\end{aligned} \tag{56}$$

Defining $\partial^2 M^B/(\partial q_k \partial q_i) = \tau\left(\partial M^B/\partial q_i\right)$ and using (52), we rewrite (50) as

$$\frac{\partial p_i}{\partial X_i}\frac{\partial x_{ij}}{\partial M}\left[(2M^B - 1)x_{ij}\frac{\partial M^B}{\partial q_i} + \left(M^B - 1\right)\left(-\tau x_{ij} + \frac{\partial x_{ij}}{\partial q_i}\right)\right]$$

$$-\left[\frac{1}{2}\left(\frac{\partial p_i\left(X_i^B,\cdot\right)}{\partial q_i}x_{ij}^B - \frac{\partial C(x_{ij}^B, q_i)}{\partial q_i}\right) - \left(M^B - 1\right)\frac{\partial p_i}{\partial X_i}x_{ij}\left(\frac{\partial x_{ij}}{\partial q_i} + \frac{\partial x_{ij}}{\partial M}\frac{\partial M^B}{\partial q_i}\right)\right] > 0,$$

since $\tau < \partial M^B/\partial q_i$, $\partial \Delta\pi^{U_{ij}}/\partial q_i > \partial^2 \Delta\pi^{U_{ij}}/\partial M \partial q_k$ and $x_{ij}^B(\partial M^B/\partial q_i) > \partial x_{ij}^B/\partial q_i$. Hence, it holds that $\partial^2 \pi^{D_i}/\left(\partial q_i \partial q_i\right) > 0$. Since Milgrom and Roberts (1990), there exists only symmetric equilibria.

Proof of Lemma 3. Maximizing (13) with respect to $\widetilde{x}_{2j}$ and $\widetilde{F}_{2j}$, we get

$$\left[\widetilde{\pi}^{D_2}(X_2 + \widetilde{x}_{2j},\cdot) - \pi^{D_2}(X_2,\cdot)\right]\frac{\partial \widetilde{\pi}^{\widetilde{U}_{2j}}(\cdot)}{\partial \widetilde{x}_{2j}} + \widetilde{\pi}^{\widetilde{U}_{2j}}(\widetilde{x}_{2j},\cdot)\frac{\partial\left(\widetilde{\pi}^{D_2}(\cdot) - \pi^{D_2}(\cdot)\right)}{\partial \widetilde{x}_{2j}} = 0 \tag{57}$$

and

$$\widetilde{\pi}^{D_2}(\cdot) - \pi^{D_2}(\cdot) - \widetilde{\pi}^{\widetilde{U}_{2j}}(\cdot) = 0. \tag{58}$$

A rearrangement of (58) yields

$$\frac{\widetilde{\pi}^{D_2}(\cdot)-\pi^{D_2}(\cdot)}{\widetilde{\pi}^{\widetilde{U}_{2j}}(\cdot)}=1. \tag{59}$$

Using (59) and rearranging (57), we further obtain

$$\frac{\partial\widetilde{\pi}^{D_2}}{\partial\widetilde{x}_{2j}}=-\frac{\partial\widetilde{\pi}^{\widetilde{U}_{2j}}}{\partial\widetilde{x}_{2j}}. \tag{60}$$

It follows that the optimal quantity $\widetilde{x}_{2j}^*$ is implicitly given by

$$\widetilde{G}:=\frac{\partial p_2(X_2+\widetilde{x}_{2j}^*,\cdot)}{\partial\widetilde{x}_{2j}}(X_2+\widetilde{x}_{2j}^*)+p_2(X_2+\widetilde{x}_{2j}^*,\cdot)-\frac{\partial C(\widetilde{x}_{2j}^*,q_1)}{\partial\widetilde{x}_{2j}}=0. \tag{61}$$

Solving (59) for $\widetilde{F}_{2j}^*$, we get

$$\widetilde{F}_{2j}^*(\cdot)=\frac{1}{2}\left[p_2(X_2+\widetilde{x}_{2j}^*,\cdot)(X_2+\widetilde{x}_{2j}^*)-p_2(X_2,\cdot)X_2+C(\widetilde{x}_{2j}^*,q_1)\right]. \tag{62}$$

Applying the implicit-function theorem and using $\partial\widetilde{G}(\cdot)/\partial\widetilde{x}_{2j}=2\partial p_2(X_2+\widetilde{x}_{2j}^*,\cdot)/\partial\widetilde{x}_{2j}-\partial^2C(\widetilde{x}_{2j}^*,q_1)/\partial\widetilde{x}_{2j}^2<0$, we obtain

$$sign\left(\frac{\partial\widetilde{x}_{2j}^*}{\partial q_1}\right) = sign\left(\frac{\partial\widetilde{G}(\cdot)}{\partial q_1}\right)=sign\left(-\frac{\partial^2C(\widetilde{x}_{2j}^*,q_1)}{\partial\widetilde{x}_{2j}\partial q_1}\right)<0 \tag{63}$$

$$sign\left(\frac{\partial\widetilde{x}_{2j}^*}{\partial q_2}\right) = sign\left(\frac{\partial\widetilde{G}(\cdot)}{\partial q_2}\right)=sign\left(\frac{\partial p_2(X_2+\widetilde{x}_{2j}^*,\cdot)}{\partial q_2}\right)>0. \tag{64}$$

Proof of Lemma 4. The proof of Lemma 4 is similar to the proof of Lemma **1.**

Proof of Lemma 5. Using $X_1^*=M^*x_{1j}^*$ and $X_2^*=(N-M^*)\,x_{2j}^*$, applying the envelope theorem and using $p_1(X_1^*,\cdot)-p_1\left(X_1^*-x_{1j}^*,\cdot\right)=(\partial p_1(X_1^*,\cdot)/\partial X_1)\,x_{1j}^*$ as well as $p_2(X_2^*+\widehat{x}_{2j}^*,\cdot)-p_2(X_2^*,\cdot)=(\partial p_2(X_2^*,\cdot)/\partial X_2)\,\widehat{x}_{2j}^*$, we have

$$\begin{aligned}\frac{\partial\Delta\pi^U(\cdot)}{\partial M} &= \Lambda_1+\Lambda_2<0 \qquad (65)\\ \text{with} &: \Lambda_1=\frac{\partial p_1(X_1^*,\cdot)}{\partial X_1}x_{1j}^*\left(x_{1j}^*+(M^*-1)\frac{\partial x_{1j}^*}{\partial M}\right)<0\\ \text{and} &: \Lambda_2=-\frac{1}{2}\frac{\partial p_2(X_2^*,\cdot)}{\partial X_2}(2x_{2j}^*-\widetilde{x}_{2j}^*)\left(-x_{2j}^*+(N-M^*-1)\frac{\partial x_{2j}^*}{\partial M}\right)<0.\end{aligned}$$

It holds $\partial \Delta\pi^U / \partial M < 0$ as long as $2x^*_{2j} - \widetilde{x}^*_{2j} > 0$ as $\partial X^*_1/\partial M = x^*_{1j} + M^* \partial x^*_{1j}/\partial M > 0$ and $\partial X^*_2/\partial M = -x^*_{2j} + (N - M^*)\, \partial x^*_{2j}/\partial M < 0$. Accordingly, we have

$$sign\left(\frac{\partial M^*(q_1, q_2)}{\partial q_1}\right) = sign\left(\frac{\partial \Delta\pi^U}{\partial q_1}\right) \tag{66}$$

$$sign\left(\frac{\partial M^*(q_1, q_2)}{\partial q_2}\right) = sign\left(\frac{\partial \Delta\pi^U}{\partial q_2}\right). \tag{67}$$

Turning to $\partial\Delta\pi^U/\partial q_1$ and assuming $\left(\partial p_1\left(X^*_1, \cdot\right)/\partial q_1\right) x^*_{1j} - \partial C(x^*_{1j}, q_1)/\partial q_1 > 0$, it holds

$$\frac{\partial \Delta\pi^U(\cdot)}{\partial q_1} = \frac{1}{2}\left[\frac{\partial p_1\left(X^*_1, \cdot\right)}{\partial q_1} x^*_{1j} - \frac{\partial C(x^*_{1j}, q_1)}{\partial q_1} - \frac{1}{2}\frac{\partial C\left(\widetilde{x}^*_{2j}, q_1\right)}{\partial q_1} + \Upsilon_1\right] > 0 \tag{68}$$

$$\text{with} \quad : \quad \Upsilon_1 = 2(M^* - 1)\frac{\partial p_1\left(X^*_1, \cdot\right)}{\partial X_1}\frac{\partial x^*_{1j}}{\partial q_1} x^*_{1j} > 0$$

as we can show that $\Upsilon_1 - (1/2)\partial C\left(\widetilde{x}^*_{2j}, q_1\right)/\partial q_1 > 0$. This implies that $\partial M^*(q_1, q_2)/\partial q_1 > 0$. Analoguously, it holds for $\partial\Delta\pi^U/\partial q_2$ that

$$\frac{\partial \Delta\pi^U(\cdot)}{\partial q_2} = -\frac{1}{2}\left[\frac{\partial p_2\left(X^*_2, \cdot\right)}{\partial q_2}\left(x^*_{2j} - \frac{1}{2}\widetilde{x}^*_{2j}\right) - \frac{\partial C(x^*_{2j}, q_2)}{\partial q_2} + \Upsilon_2\right] < 0 \tag{69}$$

$$\text{with} \quad : \quad \Upsilon_2 = \frac{\partial p_2\left(X^*_2, \cdot\right)}{\partial X_2}\frac{\partial x^*_{2j}}{\partial q_2}\left(2(N - M^* - 1)x^*_{2j} - (N - M^*)\widetilde{x}^*_{2j}\right) > 0.$$

The sign determination is based on assuming $2(N - M^* - 1)x^*_{2j} - (N - M^*)\widetilde{x}^*_{2j} > 0$ and $\left(\partial p_2\left(X^*_2, \cdot\right)/\partial q_2\right)\left(x^*_{2j} - \frac{1}{2}\widetilde{x}^*_{2j}\right) - \left(\partial C(x^*_{2j}, q_2)/\partial q_2\right) > 0$, and on showing that $\Upsilon_2 - (1/2)\left(\partial p_2\left(X^*_2, \cdot\right)/\partial q_2\right)\widetilde{x}^*_{2j} > 0$ by applying Assumption (1). Thus, $\partial M^*(q_1, q_2)/\partial q_2 < 0$. For later reference, note that $\left|\partial M^*(q_1, q_2)/\partial q_1\right| > \left|\partial M^*(q_1, q_2)/\partial q_2\right|$.

Proof of Proposition 2.