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Supply of Dairy Products in Developing Countries

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Abstract

Dairy products in developing countries are characterized by two properties, namely, perishability and short-periodic production. These properties are so unique that conventional studies in agricultural economics or in industrial organization might not explain the dairy product supply well. Hence, to understand this dairy product supply, we model it based on these two properties. We find that these properties invite middlemen who can efficiently deliver the products, and give rise to economies of scale in transportation and accessibility advantage in the dairy product supply. The economies of scale in transportation arise because greater production reduces average delivery costs per unit. The accessibility advantage occurs because lowering delivery costs significantly reduces total transportation costs in the long term.

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1 Introduction

Dairy products in developing countries are characterized by two properties, namely, perishability and short-periodic production. These properties are so unique that they give rise to a distinctive structure and features of the dairy products supply. Specifically, due to its perishability, the freshness of yesterday's dairy product is quite different from today's unless they are processed or stored in a refrigerator. Because agents try every means to keep them fresh, the structure of the dairy supply is constructed accordingly as well. Furthermore, due to the short-periodic production such as daily production, only relatively small amounts of dairy product can be produced every time. For this reason, only limited amounts of the dairy product can be sold every time, which is a distinctive feature of the dairy supply. As a consequence, conventional studies in agricultural economics or in industrial organization might not explain the dairy supply well. In this paper, therefore, we intend to present a simple but theoretical model of the dairy supply that can properly reflect the distinctive structure and features of the dairy supply in developing countries. In addition, dairy products account for a significant part of a developing country's economy. This study on the dairy supply, hence, could provide a better understanding of the economy in developing countries.

Typical studies on the dairy products supply have employed an econometric approach. In other words, these studies tried to develop econometric models, and, by using data, they tried to find statistically significant factors that can affect the aggregate supply of the dairy products. For example, Ladd and Winter (1961) presented an econometric model and investigated various factors such as beef prices, dairy products prices, feed supply, and so on. They employed least squares and used annual time series data covering the state of Iowa in the U.S. to estimate the effect of those factors on the aggregate supply of the dairy products. In addition, Mules (1972) also presented dairy supply models. He employed ordinary least squares and used annual wholemilk production data for Australia.¹

Recently, Jansik (2009) compared dairy supply chains in Finland and in three Baltic countries in his empirical study. He used the revealed comparative advantage (RCA) index and showed that the RCA indices indeed signify that all the four dairy supply chains have comparative advantages. Furthermore, Nivievskiy et al. (2008) analyzed empirical data on the dairy sector in Ukraine. Then, they discussed the major bottlenecks that obstruct the development of the dairy sector in Ukraine. Finally, Burki and Khan (2008) studied the efficiency of the dairy farms in Pakistan. They focused on smallholder dairy producers and collected their data in the Punjab area by conducting surveys from January 2006 to April 2006. They paid attention to the X-efficiency and concluded that animal capital, fodder, and straw are most important determinants of raising dairy output in Pakistan.²

However, dairy products in developing countries, have the two above-mentioned unique

¹ There are other econometric models studying the aggregate demand for the dairy products as well as the aggregate supply. For the information in this regard, please refer to Wilson and Thompson (1967), Oskam and Osinga (1982), and Song and Sumner (1999).

² For more information on the empirical studies of the dairy products supply in developing countries, please refer to Subbaiah et al. (2009) and Zia et al. (2011).

properties which result in the distinctive structure and features of the dairy supply. Hence, to model these distinctive structure and features of the dairy supply in developing countries, we need to consider the two properties. First, consider the distinctive structure of the dairy supply. Since dairy products are perishable, dairy farmers try to sell their product soon after production to reduce their storage costs. In addition, because of the short-periodic production property, the farmers can produce only relatively small amounts of the product every time.

As a consequence, the farmers need to frequently sell their relatively small amounts of the product. This situation of the dairy farmers invites middlemen into the dairy supply, which becomes the distinctive structure of the dairy supply in developing countries. The middlemen specialize in the delivery of the dairy product. So, they can efficiently collect and deliver the product from multiple dairy farmers, and thus can save transportation costs.

Next, distinctive features of the dairy supply arise from the two properties as well. Note that, because of the two properties, dairy farmers need to frequently sell relatively small amounts of their products. Here, the delivery of the relatively small amounts causes the total transportation costs to be robust against the actual weight of the product. Consequently, greater production can reduce average delivery costs per unit. We refer to this feature as Economies of Scale in Transportation. In addition, the necessity of frequent delivery makes a one-time delivery cost significantly affect the total transportation costs in the long term. As a result, lowering a one-time delivery cost results in saving a significant amount of the total transportation costs in the long term. This feature is referred to as Accessibility Advantage. Therefore, economies of scale in transportation and accessibility advantage are induced by perishability and short-periodic production in the dairy supply.³

The rest of this paper is organized as follows. Section 2 formally defines the model based on the properties of the dairy product, which are perishability and short-periodic production, so that the distinctive structure of the dairy supply, which is the role of the middlemen, is embodied in the model. Section 3 first shows the existence of an equilibrium in the model, and next reveals the two distinctive features of the dairy supply, which are economies of scale in transportation and accessibility advantage, then finally concludes with the discussion about possible extension of the model.

2 The Model

A typical dairy product market in developing countries consists of one consumer section and multiple supplier sections. That is, in this market, dairy products would be separately produced and delivered from different supplier sections, while they are consumed in the same consumer section. The formation of the different supplier sections results from the property

³ In this study, we restrict attention to the dairy products supply in developing countries. However, our results can be applied to another produce supply in developing countries if it can be also characterized by perishability and short-periodic production. That is, any produce supply with these two properties in developing countries can show the two features, economies of scale in transportation and accessibility advantage.

of the dairy product and geographic distribution of consumers and suppliers. Dairy products are perishable, so suppliers try to deliver their products as soon as they can. In addition, normally, consumers live in a relatively central area, and, around this central area, suppliers are located in a broad area. Thus, the suppliers endeavor to do business only with their nearby partners to reduce the delivery time and cost, and this suppliers' intention eventually gives rise to multiple supplier sections around one consumer section. In our supply model, we only consider one of the supplier sections. However, this supply model is compatible with a whole dairy product market model so that we can simply extend the supply model to a whole market model by including one consumer section and multiple supplier sections.

In this dairy supply model, there are two kinds of agents, namely, farmers and middlemen. The *farmers*, denoted by $j \in J$ where J is nonempty and finite, produce the product and sell them to middlemen. Next, the *middlemen*, denoted by $m \in M$ where M is nonempty and finite, buy the products from farmers and deliver and sell them to consumers. Particularly, we assume that there are at least two middlemen so that they compete with each other for the product. In this model, we consider only relatively small farmers and middlemen, who indeed represent typical dairy product suppliers. This restriction allows us to safely assume that no individual agent can affect market prices, such as a retail price $p \in \mathbb{R}_+$ and input prices $w \in \mathbb{R}_+^{\#I}$.

The middlemen trade with the farmers in Bertrand competition. That is, first, the middlemen propose unit prices of the product to each farmer. We refer to these unit prices of the product as *bids* b . Then, middlemen's bids b are an element in $\mathbb{R}_+^{\#J \times \#M}$ where $\#J$ and $\#M$ denote the numbers of farmers and middlemen, respectively. Next, each farmer individually decides how much product he will produce given the bids. Finally, the farmers sell their products to the highest bidders at the highest bids. If multiple middlemen propose the same highest bids, then each of them would equally likely buy the product.⁴

Each farmer has by two characteristics. One is his technology, and the other is his delivery cost. For any farmer $j \in J$, his *technology* $f_j : \mathbb{R}_+^{\#I} \rightarrow \mathbb{R}_+$ is a production function according to which farmer j produces his product where a set I denotes the set of inputs, used to produce the product, and $\#I$ denotes the number of inputs. So, for any input vector $x \in \mathbb{R}_+^{\#I}$, $f_j(x)$ shows the amount of the product that farmer j produces by using x . In this model, we assume that f_j is strictly concave. This assumption allows well-defined supply functions of the farmers. In addition, for any $j \in J$, farmer j 's *delivery cost* $c_j \in \mathbb{R}_+$ denotes the cost to deliver the product from his dairy farm to consumers. Therefore, each farmer j has his own technology f_j and delivery cost c_j .

Note that, in these farmers' characteristics, the delivery costs are set to be constant regardless of the weight of the products.⁵ This setting indeed reflects distinctive features

⁴ We adopt this setting from the Auction. In an auction, if there are multiple highest bidders, each of them would have equal chances to buy an item. This setting, however, is adopted only for the formalities in the model because, in equilibrium, the probability with which any two middlemen would propose the same bids is zero.

⁵ This setting of the constant delivery costs can represent that different farmers can produce different amounts of dairy products. This setting, however, cannot represent that one farmer can produce different

in the dairy supply that are caused by the two properties of the dairy products, namely, perishability and short-periodic production. In this model, the products are perishable, so the costs of keeping the product fresh are relatively high. As a result, the farmers try to sell their products soon after they produce. Furthermore, the products are produced in short periods. For this reason, each time, the farmers can produce only relatively small amounts of the products, and thus they can sell only the relatively small amounts. Consequently, the weight of the products has only minor influence on the actual transportation costs, which consist of fuel bills, depreciation of vehicles, and so on. Moreover, the time spent on delivering the product would be much the same regardless of the weight of the products. Hence, the delivery costs give rise to nearly the same opportunity costs. Therefore, this simple setting of the delivery costs properly reflects the distinctive features in the dairy product supply. This setting of the delivery costs, however, differs from the iceberg transportation costs⁶ discussed by Samuelson (1952) and Krugman (1991) because their transportation costs are set to be directly proportional to the weight of the products.

An optimization problem of each farmer is as follows. Given any middlemen's bids $b \in \mathbb{R}_+^{\#J \times \#M}$, let $b_j \in \mathbb{R}_+$ be the highest bid proposed to farmer j . Then, given input prices $w \in \mathbb{R}_+^{\#I}$, farmer j solves

$$\max_{x \in \mathbb{R}_+^{\#I}} b_j f_j(x) - x \cdot w. \quad (1)$$

In this problem, the objective function means that farmer j buys x units of the inputs at the unit prices w and sells $f_j(x)$ units of the product at the unit price b_j . Here, we assume that there exists at least one maximizer $x \in \mathbb{R}_+^{\#I}$, which solves this farmer's problem (1). Note that, since f_j is strictly concave, a maximizer x would be at most one. Therefore, from this optimization problem, we can derive farmer j 's *supply function*⁷ $s_j : \mathbb{R}_+^{\#J \times \#M} \times \mathbb{R}_+^{\#I} \rightarrow \mathbb{R}_+$ such that $s_j(b, w)$ denotes the amount of the product supplied by farmer j when the middlemen's bids are b and input prices are w .

Next, for each $m \in M$, middleman m solves the following optimization problem. Let $1_{>0} : \mathbb{R}_+ \rightarrow \{0, 1\}$ be the indicator function such that for each $a \in \mathbb{R}_+$, $1_{>0}(a) = 1$ if a is positive and $1_{>0}(a) = 0$ if a is zero. Then, given a retail price p , input prices w , and the other middlemen's bids $b_{-m} \in \mathbb{R}_+^{\#J \times (\#M - 1)}$, middleman m solves

$$\max_{b_m \in \mathbb{R}_+^{\#J}} \sum_{j \in J} \{(p - b_{jm})s_{jm}(b_m, b_{-m}, w) - c_j 1_{>0}(s_{jm}(b_m, b_{-m}, w))\}$$

amounts of dairy products per day.

⁶ The iceberg transportation costs were first employed by Samuelson (1952). Then, Krugman (1991) adapted Samuelson's iceberg transportation costs by introducing the concept of the increasing returns to transportation. That is, in Krugman (1991), as the transportation distance increases, the rate of the transportation costs decreases. For more information, please refer to McCann (2005) and Cukrowski and Fischer (2000) as well as Samuelson (1952) and Krugman (1991). McCann (2005) compared these two kinds of iceberg transportation costs, and Cukrowski and Fischer (2000) applied them to their model.

⁷ Halvorson (1958), Ladd and Winter (1961), and Mules (1972) concretely formulated aggregate supply functions of the dairy products. Moreover, they presented empirical estimates of the parameters of their supply functions.

where b_{jm} denotes middleman m 's bid to farmer j and $s_{jm}(b, w)$ denotes an amount of the product supplied by farmer j to middleman m when bids are b and input prices are w . Note that, for simplicity's sake, this optimization problem is set to describe the situation in which middleman m spends the delivery cost c_j whenever he collects a positive amount of the product from farmer j . This setting, however, can reflect more general situations with adjustment of the farmers' setting. For example, suppose that dairy farms are close to each other or are located along one road. Then, middlemen have an incentive to sequentially collect the products from these farms to save their delivery costs. In these cases, if we model those farms as a single dairy farm, then the setting in this model can properly describe these situations.

Now, we are ready to define an *equilibrium* in the dairy supply model.

Definition 1 (Equilibrium) *Given a retail price p and input prices w , an equilibrium in this dairy supply model is a pair of farmers' supply functions $s^* = \{s_j^*\}_{j \in J}$ and middlemen's bids $b^* = \{b_m^*\}_{m \in M}$ such that 1) each s_j^* solves farmer j 's problem (1) given any arbitrary bids and 2) no middleman can increase his profit by deviating from his bids b_m^* responding to both the other middlemen's bids b_{-m}^* and the supply functions s^* .*

3 Results

The first result, Theorem 1, shows that, given any retail price p and input prices w , there exists an equilibrium (s^*, b^*) in the dairy supply model. This Theorem 1 is proven by using Lemma 1 below. Lemma 1 ensures that farmers' factor demand functions are well-defined. That is, given middlemen's bids b and input prices w , we can always find the amounts of the inputs demanded by each farmer. Since farmers' supply functions are simple composites of the technology and the factor demand functions, Lemma 1 eventually guarantees that farmers' supply functions are well-defined.

Lemma 1 *For each $j \in J$, let a function $x_j : \mathbb{R}_+^{\#J \times \#M} \times \mathbb{R}_+^{\#I} \rightarrow \mathbb{R}_+^{\#I}$ be a factor demand function. Then, x_j is well-defined and continuous.*

Proof. Given any bids $b \in \mathbb{R}_+^{\#J \times \#M}$ and any input prices $w \in \mathbb{R}_+^{\#I}$, there exists at least one input vector $x^* \in \mathbb{R}_+^{\#I}$ that maximizes the objective function in farmer j 's problem (1) according to the assumption. Since the technology f_j is strictly concave, this input vector x^* is uniquely determined. Hence, $x_j : \mathbb{R}_+^{\#J \times \#M} \times \mathbb{R}_+^{\#I} \rightarrow \mathbb{R}_+^{\#I}$ is a well-defined function, that is, for each $(b, w) \in \mathbb{R}_+^{\#J \times \#M} \times \mathbb{R}_+^{\#I}$, $x_j(b, w) \in \mathbb{R}_+^{\#I}$ is uniquely defined. In addition, since f_j is concave, it is continuous. Therefore, x_j is continuous as well according to the Theorem of the Maximum.⁸ ■

⁸ For detailed information on the Theorem of the Maximum, please refer to Stokey, Lucas, and Prescott (1989, Theorem 3.6).

Theorem 1 (Existence of Equilibrium) *Given any retail price $p \in \mathbb{R}_+$ and any input prices $w \in \mathbb{R}_+^{\#I}$, there exists an equilibrium.*

Proof. See Appendix. ■

In the dairy supply model, there could be multiple equilibria. This is because, in some cases, the middlemen could choose different equilibrium bids even though the farmers always choose the same equilibrium supply functions. However, if the farmers' supply functions s^* are concave in the middlemen's bids, then there exist unique equilibrium bids, and therefore there exists only one equilibrium in the dairy supply model.

Next, Theorem 2 below characterizes the equilibrium in the dairy supply model. All the equilibria in this model have the same characteristics in common. Theorem 2 formulates such characteristics of the equilibria.

Theorem 2 (Characteristics of Equilibrium) *In equilibrium, for any farmer $j \in J$ and for any middleman $m \in M$, we have*

$$(p - b_{jm}^*)s_{jm}^*(b^*, w) - c_j 1_{>0}(s_{jm}^*(b^*, w)) = 0.$$

Proof. By way of contradiction, suppose that there exists an equilibrium in which we have $(p - b_{jm}^*)s_{jm}^*(b^*, w) - c_j 1_{>0}(s_{jm}^*(b^*, w)) > 0$. Let m and m' be distinct middlemen. Then, middleman m' can raise his profit by proposing $b'_{jm'} > b_{jm}^*$ such that middleman m' 's profit from the trade with farmer j is positive. This contradicts the definition of the equilibrium in which any middleman cannot raise his profit. Therefore, in equilibrium, we have $(p - b_{jm}^*)s_{jm}^*(b^*, w) - c_j 1_{>0}(s_{jm}^*(b^*, w)) = 0$ for each j and m . ■

Theorem 2 shows that, in equilibrium, every middleman has zero profit. These characteristics of the equilibrium result from the Bertrand competition⁹ among the middlemen. More concretely, the middlemen compete for the dairy product by setting their bids, which are indeed their prices for the dairy product. Note that, in this trade, each farmer faces multiple potential middlemen. Hence, just like in the Bertrand model, the middlemen have incentives to raise their bids until no middlemen cannot raise their bids, which in turn means each of the middlemen has zero profit.¹⁰

Here, these characteristics of the equilibrium reveal distinctive features in the dairy product supply, namely, Economies of Scale in Transportation and Accessibility Advantage. The following Corollaries 1 and 2 formally present these distinctive features. Note that these two corollaries shed light on different features in the dairy supply, and accordingly they are based on different hypotheses to emphasize their own results.

Corollary 1 (Economies of Scale in Transportation) *Suppose that the farmers have the same delivery cost c , that is, $c_j = c$ for each $j \in J$. In equilibrium, if $s_{jm}^*(b^*, w) > s_{j'm'}^*(b^*, w) > 0$, then we have $b_{jm}^* > b_{j'm'}^*$.*

⁹ For more information on the Bertrand competition, please refer to Mas-Colell et al. (1995, Sec. 12.C)

¹⁰ For the information on the empirical results about the net relationship between changes in the bids b and changes in the retail product price p , please refer to Kinnucan and Forker (1987).

Proof. According to Theorem 2, if the farmers have the same delivery cost c , then we have

$$\begin{aligned} & (p - b_{jm}^*)s_{jm}^*(b^*, w) - c1_{>0}(s_{jm}^*(b^*, w)) \\ &= (p - b_{j'm'}^*)s_{j'm'}^*(b^*, w) - c1_{>0}(s_{j'm'}^*(b^*, w)) = 0. \end{aligned}$$

Hence, if $s_{jm}^*(b^*, w) > s_{j'm'}^*(b^*, w) > 0$, then we have

$$p - b_{jm}^* - \frac{c}{s_{jm}^*(b^*, w)} = p - b_{j'm'}^* - \frac{c}{s_{j'm'}^*(b^*, w)} = 0,$$

and thus $b_{jm}^* > b_{j'm'}^*$. ■

Corollary 1 means that, other things being equal, relatively large-size farmer j will be offered a higher unit price for the product b_{jm}^* than relatively small-size farmer j' . This is because relatively large-size farmer j has a smaller average delivery cost per unit $\frac{c}{s_{jm}^*(b^*, w)}$ than relatively small-size farmer j' . So the middlemen have greater incentives to trade with farmer j than with farmer j' . These greater incentives bring the stronger competition among the middlemen, and as a result farmer j is offered the higher unit price for the product $b_{jm}^* > b_{j'm'}^*$. Note that, in typical economic models, higher unit prices usually result from producers' market power. In this dairy supply model, no farmer has market power because every farmer is simply a price taker. Nevertheless, large-size farmers are offered higher unit prices due to the advantages of their average delivery costs per unit.

Consequently, Corollary 1 reveals the first distinctive feature in the dairy supply model, namely, Economies of Scale in Transportation. In this model, large-size farmers' advantages of the average delivery costs per unit result from increasing returns to scale in transportation. These increasing returns to scale in transportation, however, are caused by the unique properties of the dairy product, which are perishability and short-periodic production. As a consequence, perishability and short-periodic production eventually give rise to the economies of scale in transportation in this model, and therefore the economies of scale in transportation are a distinctive feature in this dairy supply model.

In fact, economies of scale can arise from various sources. Classical studies found the sources of the economies of scale in production and consumption processes. For example, Haldi and Whitcomb (1967) and Krugman (1980) showed that increasing returns to scale in the production function can cause economies of scale in production. In addition, Nelson (1988) showed that economies of scale in consumption can result from household public goods or returns in household production of goods and services such as cooking a meal. In the current model, distinguished from these classical studies, we find the source in the transportation process. That is, we demonstrate that economies of scale in transportation can occur due to the increasing returns to scale in transportation based on the unique properties of the dairy product, namely, perishability and short-periodic production.

Corollary 2 (Accessibility Advantage) *Suppose $s_{jm}^*(b^*, w) = s_{j'm'}^*(b^*, w) > 0$ in equilibrium. If $c_j < c_{j'}$, then we have $b_{jm}^* > b_{j'm'}^*$ in equilibrium.*

Proof. According to Theorem 2, if $s_{jm}^*(b^*, w) = s_{j'm'}^*(b^*, w) > 0$ and $c_j < c_{j'}$, then we have

$$p - b_{jm}^* - \frac{c_j}{s_{jm}^*(b^*, w)} = p - b_{j'm'}^* - \frac{c_{j'}}{s_{j'm'}^*(b^*, w)} = 0,$$

and thus $b_{jm}^* > b_{j'm'}^*$. ■

Corollary 2 means that, other things being equal, farmer j who has the relatively small delivery cost c_j will be offered the higher unit price for the product b_{jm}^* than farmer j' , who has the relatively large delivery cost $c_{j'} > c_j$. As in Corollary 1, this is because farmer j is more attractive to the middlemen than farmer j' . Thus, the middlemen raise their bids for the product of farmer j , and as a result farmer j is offered the higher unit price for the product $b_{jm}^* > b_{j'm'}^*$. Again, note that, in this dairy supply model, farmers' higher unit prices are due not to their market power, but to the advantages of their delivery costs. Here, farmers' advantages of the delivery costs are based on perishability and short-periodic production, which are the unique properties of the dairy product.

In this dairy supply model, farmer j can enjoy his delivery cost advantage whenever he sells his product. Moreover, all the farmers, including farmer j , sell their products frequently, almost every day, because of the perishability and short-periodic production of the dairy product, which in turn means that farmer j can enjoy this advantage almost every day. As a result, this advantage becomes significant in the long term, and thus it can be a distinctive feature in the dairy product supply. Therefore, Corollary 2 reveals the second distinctive feature in the dairy supply model, namely, Accessibility Advantage.

Finally, we can extend this dairy supply model. So if we introduce one consumer section and multiple supplier sections into the dairy supply model, then we can model a complete dairy products market. In this complete dairy products market model, we can still observe the same results as in the supply model, that is, economies of scale in transportation and accessibility advantage. In addition, if we adopt some assumptions, then we can prove the existence of an equilibrium. For example, suppose that there exists a continuous demand function of the consumers $D : \mathbb{R}_+ \rightarrow \mathbb{R}_+$ where $D(p)$ denotes the amount of the products demanded by the consumers when the retail price is p . Assume that we have $\lim_{p \rightarrow 0} D(p) = \infty$ and $\lim_{p \rightarrow \infty} D(p) = 0$ and each of the farmers' supply functions $s_j(\cdot, w)$ is concave in bids. Then, by using Brouwer's Fixed Point Theorem, we can show there exists an equilibrium in this complete dairy products market model.

Appendix

Proof of Theorem 1.

Proof. Note that farmer j 's supply function $s_j^* : \mathbb{R}_+^{\#J \times \#M} \times \mathbb{R}_+^{\#I} \rightarrow \mathbb{R}_+$ is the composite of the technology f_j and the factor demand function x_j , that is, $s_j^*(\cdot) = f_j(x_j(\cdot))$. Here, f_j is continuous since it is concave, and x_j is well-defined and continuous according to Lemma 1. Hence, s_j^* is well-defined and continuous as well. In addition, given a retail price p and input prices w , let $b^* \in \mathbb{R}_+^{\#J \times \#M}$ be middlemen's bids such that, for each j

$\in J$ and for each $m \in M$, *i*) $(p - b_{jm}^*)s_{jm}^*(b^*, w) - c_j 1_{>0}(s_{jm}^*(b^*, w)) = 0$ and *ii*) $b^* \geq b'$ if $(p - b_{jm}^*)s_{jm}^*(b', w) - c_j 1_{>0}(s_{jm}^*(b', w)) = 0$. Here, since $s_{jm}^*(\cdot, w)$ is continuous in bids, the term $c_j 1_{>0}(s_{jm}^*(\cdot, w))$ can also be continuous in bids if we consider only bids b'' such that $s_{jm}^*(b'', w) > 0$. As a consequence, there exist bids b^* that satisfy the condition *i*). Moreover, because of the condition *ii*), such bids b^* are uniquely determined.

Now, we show that the pair (s^*, b^*) is indeed an equilibrium. First, suppose that every middleman plans to bid according to the bidding plan b^* . Next, consider middleman m 's incentive to deviate from his bidding plan b_m^* . Then, if middleman m would propose a lower bid $b_{jm} < b_{jm}^*$, farmer j would not sell his product to middleman m , which would result in zero profit to middleman m . Furthermore, any bid $b_{jm} > b_{jm}^*$ would give rise to middleman m 's losses. This is because we have 1) $(p - b_{jm}''')s_{jm}^*(b''', w) - c_j 1_{>0}(s_{jm}^*(b''', w)) < 0$ for any $b''' \in \mathbb{R}_+^{\#J \times \#M}$ such that $b_{jm}''' > p$, 2) $s_{jm}^*(\cdot)$ is continuous, and 3) the bids b^* are the highest bids that result in zero profit to every middleman. Thus, if $b_{jm} > b_{jm}^*$, then we have $(p - b_{jm})s_{jm}^*(b_{jm}, b_{-jm}^*, w) - c_j 1_{>0}(s_{jm}^*(b_{jm}, b_{-jm}^*, w)) < 0$ where $b_{-jm}^* \in \mathbb{R}_+^{\#J \times \#M - 1}$ denotes the bids of b^* except b_{jm}^* , which in turn shows middleman m 's losses. Accordingly, middleman m has no incentive to deviate from his bidding plan b_m^* . Likewise, no middleman has an incentive to deviate from b^* . Consequently, the supply functions $s^* = \{s_j^*(\cdot)\}_{j \in J}$ and the bids b^* satisfy all the conditions for an equilibrium, and therefore they are an equilibrium. ■

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