Cooperative pricing and scale efficiency: The case of Korean rice processing complexes

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Abstract

Unlike most investor-owned enterprises, cooperatives often have freedom to choose among a variety of firm objectives. Using 2002–2008 plant- and province-level data, we ask in the present article which of several alternative maximands a Korean cooperative rice processing firm pursues. In contrast to earlier studies, farmer-member supply functions are incorporated into the cooperative's optimization framework. We show that only large cooperative firms have operated at efficient scale, while small and medium-sized ones have been scale-inefficient. Because the latter operate where scale returns are increasing, mergers of small and medium-sized cooperatives likely would be cost-reducing and member-return-enhancing.

1. Introduction

Cooperative membership often has been shown to boost farmer prices, particularly when markets are scattered or weak (Bernard et al., 2008; Wollni and Zeller, 2007). More generally, private or investor-owned (IOF) farm-product buyers exhibit pricing behavior distinct from those in cooperatives or other collective organizations (Buccola, 1994; Cobia, 1989; Helmberger and Hoos, 1962; LeVay, 1983a, 1983b; Royer, 1987; Staatz, 1987). The cooperative is a business owned by the firm's users, in the processing-cooperative case by the farmer-owners supplying the raw product. Because it is controlled by, and allocates net revenues to, raw-product suppliers, the cooperative normally is assumed at least to try to minimize the cost of such nonraw-product processing inputs as labor and energy

at given raw-product volume. However, it need not try maximizing the return to raw product itself, as that may interfere with, for example, membership size goals.

Conjectures about whether a cooperative goes beyond the presumed allocative efficiency of its nonraw-product inputs to achieve pricing or scale efficiency thus depend on conjectures about the cooperative's principal objective. Many objectives have been proposed, including: (i) maximizing the price paid to members per unit of raw product delivered, (ii) maximizing total member income, and (iii) accepting all quality-acceptable raw product delivered. During the past several decades, cooperatives have faced substantial changes in market conditions and structure, especially in much stiffer competition (Cook, 1995; Harris et al., 1996; Juliá and Marí, 2002; Merrett and Walzer, 2004). These changes complicate efforts to identify a cooperative's objectives on the basis of theoretical analysis alone.

In the present study we assess the pricing and scale efficiency of Korean cooperative rice processing complexes (RPCs) and explore options for their improvement. Unlike previous studies, we incorporate raw-product cost and supply considerations in our analysis. Rice is Korea's most important farm commodity, considered either as a staple food or as a source of farm income, accounting for 54% of urban household food grain

expenditures in 2007 (Korea National Statistics Office). In 2008, rice farms covered about 60% of Korea's farm land, 70% of farm households, and 47% of farm income (Korean Ministry for Food, Agriculture, Forestry and Fisheries).

Operating under an open-membership policy, cooperatives play an important part in Korean agriculture and its rice industry in particular. Approximately 1,200 agricultural cooperatives are currently owned by 2.4 million farmer-members, estimated to be about 90% of Korean farm households. Of these, 166 have combined into rice processing complexes, representing about 60% of rice processing firms in Korea.[1] These facilities accept raw rice from farmer-members; store, process, and polish it; and sell it in consumer markets. At delivery, members initially are paid a transfer price determined by the board of directors. If a positive net return eventually is realized, additional payment is made in the form of patronage dividend.

Cooperative and IOF processors are so numerous in Korea that little pricing power likely is present in either the raw or finished rice market. However, a number of researchers have argued that cooperatives perform poorly relative to investor-owned firms. And by the turn of the 21st century, cooperatives faced rising domestic and international competition from the investor-owned sector (Lamprinakis and Fulton, 2011). Major U.S. cooperatives recently have faced bankruptcy, including Farmland Industries and Tri Valley Growers (Cross et al., 2009). The Uruguay Round Agreement on Agriculture (URAA) in 1995 similarly has created a competitive environment for Korean rice producers and cooperative processing centers. Fifty years of domestic rice price supports were gradually curtailed, and finally eliminated in 2005. Since 1995, foreign rice imports have risen under the influence of the World Trade Organization's Minimum Market Access provisions of the URAA.[2] With the diversification of Korean dietary habits, per-capita annual rice consumption has at the same time fallen from 106.5 kg in 1995 to 75.8 kg in 2008 (Korea National Statistics Office). Because consumption has dropped more quickly than production, domestic supplies have piled up, stiffening the competition among domestic producers.[3] Analysis of cooperative efficiency thus is critical to Korea's as well as other nations' adjustment to the changing world market environment.

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[1] In 2008, 166 cooperative RPCs, 114 private (IOF) RPCs, and several small milling facilities operated in Korean domestic rice markets, creating nearly competitive market conditions.

[2] Most imported rice is used to produce rice cakes, noodles, and other products rather than polished rice.

[3] Domestic rice production was estimated at 4.8 million tons and polished rice consumption at 3.7 million tons in 2008 (Korea National Statistics Office). Korean rice imports have been allowed gradually to rise, under the URAA minimum market access provisions, from 1% to 4% of base-period (1986–1988) consumption during the course of 1995–2004 and are set to reach 8% by 2014. Most imported rice has been released to domestic processing firms only for products such as rice cake and noodles. Korea is required to boost the table-consumption share of imported rice to 30% by 2014.

2. Economic theory of cooperatives

Efficiency assessments alternatively focus on technical, allocative, pricing, or scale efficiency. Distinctions among these four are best understood in the context of the four most common cooperative relationships: net revenue product (*NRP*), net marginal revenue product (*NMRP*), net average revenue product (*NARP*), and farmer-member raw-product supply (*S*). *NRP* is total revenue less total processing cost (exclusive of raw-product value) at given raw product quantity R. Its role in cooperative theory is analogous to an IOF's profit function. In the single-output case, for example, *NRP* is

$$NRP(P, \mathbf{W}, R) = Pf(\mathbf{X}, R) - \mathbf{WX}, \tag{1}$$

where P is the price the cooperative receives from selling its good (after processing and handling) in the final-product market; W is the vector of processing input prices excluding raw-product price; $f(X, R)$ is quantity of final good sold, which in turn is a function of the vector of resources X used in processing and of the quantity R of raw product delivered by members; and WX is the cost of resources, excluding raw product, used in processing.

We will suppose the cooperative utilizes labor and other resources optimally to maximize *NRP* at given R. In other words, the cooperative is technically efficient (operates on its technical frontier) and allocatively efficient in the use of its X inputs. *NRP* so maximized with respect to nonraw-product inputs **X** is:

$$NRP = \text{Max}_x\{Pf(\mathbf{X}, R) - \mathbf{WX}, \forall R\}, \tag{2}$$

of which the first-order optimization conditions are

$$\frac{P\partial f(\mathbf{X}, R)}{\partial \mathbf{X}} = \mathrm{W}. \tag{3}$$

NMRP is the change in **X**-maximized *NRP* induced by an additional raw product unit R:

$$NMRP = \frac{\partial NRP}{\partial R} = \frac{\partial[Pf(\mathbf{X}, R)/\mathbf{WX}]}{\partial R}$$
$$= \frac{P\partial f(\mathbf{X}, R)}{\partial R} - \frac{\partial \mathbf{WX}}{\partial R}. \tag{4}$$

The interpretation of this expression in terms of conventional marginal revenue and cost requires assuming a relationship between output and raw-product input. As the principal material in an assembly-line environment, raw-rice volume R can be reasonably assumed to hold a fixed proportion to finished rice output f. It follows that, up to a multiplicative constant, $\frac{P\partial f(X,R)}{\partial R}$ in (4) is marginal revenue and $\frac{\partial \mathbf{WX}}{\partial R}$ is marginal processing cost exclusive of raw product.

In contrast, *NARP* is *NRP* per unit R:

$$NARP = \frac{NRP}{R} = \frac{Pf(\mathbf{X}, R) - \mathbf{WX}}{R} = \frac{Pf(\mathbf{X}, R)}{R} - \frac{\mathbf{WX}}{R},$$
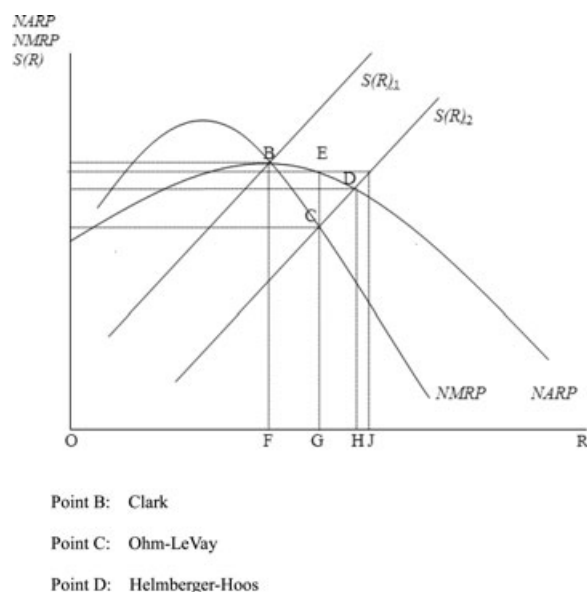$$\tag{5}$$

Fig. 1. Potential marketing cooperative equilibria.

where by the same reasoning as above, $\frac{Pf(X,R)}{R}$ is—up to a multiplicative constant—average revenue and $\frac{WX}{R}$ is average processing cost, again excluding raw product.[4] Finally, $S(R)$ facing the cooperative is the horizontal sum of farmer-members' marginal costs of producing quantity R of raw product. $S(R)$ thus represents, at given R, the farm cost of producing one more unit of the raw commodity.

Figure 1 shows prototypical $NMRP(R)$, $NARP(R)$, and $S(R)$ functions, the latter represented at two of several potential positions. Even if average revenue P falls as raw-product volume rises, $NARP$ initially may rise if there are scale economies, that is if average processing cost declines with greater volume. If input fixities such as management skill are either specified in the model or present in the data—so that scale diseconomies eventually are encountered—$NARP$ thereafter would decline in the face of the rising average processing costs. $NARP$ equals $NMRP$ at maximum $NARP$ because average equals marginal processing cost when average cost is a minimum.

2.1. Possible equilibria in marketing cooperatives

An immediate consequence of the member-owned raw input's fixed proportionality to final output is that questions about the allocative efficiency of raw-input use are not meaningful, as raw input cannot be varied at fixed output. Rather, we can speak only of the raw good's pricing or scale efficiency, satisfied if and only if those same efficiencies are satisfied in the output domain. The output-price-taking cooperative is price-efficient

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[4] $P\partial f(X, R)/\partial R$ and $Pf(X, R)/R$ in (4) and (5) are often themselves called marginal revenue product and average revenue product. We will refer to them as such.

when raw product quantity equates $NMRP$ with farm marginal cost, and scale-efficient when $NARP$ is a maximum.

In particular, note that $NARP$ defines the greatest break-even unit payment—including any advance plus final patronage dividend—the cooperative can make to members at given raw-product volume R. The cooperative equilibrium suggested by Helmberger and Hoos (1962) is motivated by assuming the cooperative allows unlimited raw-product deliveries and pays the break-even price for each unit. As Sexton et al. (1989) show, that equilibrium occurs at such a point as D in Fig. 1, where the unlimited raw-product supply $S(R)_2$ intersects $NARP$ and the corresponding unit raw-product payment is HD. Because this equilibrium does not equate marginal processing return to marginal farm cost, it cannot be price-efficient; nor in general is it scale efficient. It does maximize the quantity of raw product delivered consistent with nonnegative farm-plus-processing income, and often is associated with open-membership cooperatives.

If the cooperative instead employs a restricted-intake policy, the raw-product supply curve it faces generally will lie to the left of $S(R)_2$, as some members who might have sought membership are excluded. An equilibrium consistent with that idea, associated with restricted-membership cooperatives and first suggested by Clark (1952), can be characterized at point B in Fig. 1, where $S(R)_1$ intersects the maximum $NARP$ point. This solution—both pricing and scale efficient—is motivated by assuming the cooperative wants to earn the highest return possible per unit of raw product, including its returns to farm and processing inputs. To do so, the cooperative will restrict membership or intake-per-member so that, behaving as individual raw-product price-takers, the aggregate membership will wish to deliver the $NARP$-maximizing volume. The cooperative's break-even condition is satisfied because member price received, FB, is the cooperative's full per-unit net return. Thus, the cooperative objective defined by Clark (1952) is to maximize price paid to members per unit of raw product delivered.

Another possible solution, first offered by Ohm (1956) and later endorsed by LeVay (1983b), is that the cooperative set its equivalent raw-product price at $NMRP$ point C in Fig. 1. This can be considered the first-best optimum in that it maximizes member welfare for a given function $S(R)$. But it cannot generate the break-even condition because $NMRP$ is unequal to $NARP$ except at maximum $NARP$. And, although it is pricing efficient, it is not scale-efficient. Buccola (1994) argues the Ohm-LeVay solution is socially optimal in the short run. In the long run, however, per-unit patronage dividend EC in this equilibrium, namely full price EG less initial transfer price CG in Fig. 1, renders delivery quantity OG unstable because the positive dividend encourages members to deliver OJ rather than OG.

Sexton's (1986) game theory model of cooperation rejects the Ohm-LeVay solution, predicting cooperatives instead will operate close to the Clark solution, where $NARP$ is maximized. Sexton et al.'s (1989) examination of California cotton ginning cooperatives supports the game-theory prediction. However,

Boyle's (2004) study of Irish dairy cooperatives suggests instead that cooperative raw-product pricing is similar to a profit-maximizing firm's. In support of the Ohm-LeVay hypothesis, he finds raw-milk prices to occur where $S(R)$ intersects *NMRP* but not at maximum *NARP*.

The variety of observed cooperative pricing solutions suggests none is universal. Royer and Smith (2007) insist a cooperative's ability to pursue a variety of objectives implies that judgments about its performance should not be drawn from theoretical arguments alone. The feasibility and optimality of a cooperative's equilibrium appear to depend on context. In their review paper, Soboh et al. (2009) argue also that empirical studies typically fail to employ clear theoretical frameworks when testing alternative cooperative objectives. New studies are needed to not only identify possibilities for improved performance but to spur further development of the theory of collective organizations.

2.2. Comparing cooperative and investor-owned equilibria

A key difference between the cooperative and the competitive investor-owned firm is that, in the face of given factor prices, the IOF chooses raw-product volume R along with processing inputs X, while in the cooperative, R may be determined either centrally by the board or individually by the members. The IOF's profit function can be expressed as:

$$\pi(\mathbf{P}, \mathbf{W}, r) = Pf(\mathbf{X}, R) - \mathbf{W}\mathbf{X} - rR, \tag{6}$$

where r is raw-product price. Its decision problem then is:

$$\underset{\mathbf{X}, R}{\text{Max}} \, \pi = \{Pf(\mathbf{X}, R) - \mathbf{W}\mathbf{X} - rR\}. \tag{7}$$

The first-order condition of the solution to (7) can be decomposed into optimal choices of X and R, namely:

$$\frac{\partial Pf(\mathbf{X}, R)}{\partial \mathbf{X}} = \mathbf{W} \quad \text{and} \quad \frac{\partial [Pf(\mathbf{X}, R) - \mathbf{W}\mathbf{X}]}{\partial R} = r. \tag{8}$$

The first condition in (8) corresponds to a cooperative's maximization of *NRP* at given R—as in Eq. (3). It is allocatively efficient in the disposition of its X inputs. The second condition sets per-unit raw product payment r at the *NMRP*, in turn determined by the quantity R of raw product delivered. That is,

$$NMRP = \frac{\partial NRP}{\partial R} = \frac{\partial [Pf(\mathbf{X}, R) - \mathbf{W}\mathbf{X}]}{\partial R} = r. \tag{9}$$

Solution (9) is pricing efficient if farmer-members' marginal raw-product cost functions intersect at the same point. Provided raw-product supply coincides with that marginal cost function, the IOF thus performs the same optimization that Ohm-LeVay call for when they equate *NMRP* with marginal farm cost $S(R)$—point C in Fig. 1.

Another possible IOF equilibration constraint is the long-run zero-profit condition under free entry:

$$\pi(P, \mathbf{W}, r) = Pf(\mathbf{X}, R) - \mathbf{W}\mathbf{X} - rR = 0. \tag{10}$$

Since, from Eq. (1), $NRP(P, \mathbf{W}, R) = Pf(\mathbf{X}, R) - \mathbf{W}\mathbf{X}$, Eq. (10) is expressed for the cooperative as

$$NRP(P, \mathbf{W}, R) - rR = 0. \tag{11}$$

Differentiating *NRP* with respect to R and dividing by R gives

$$NMRP = \frac{\partial NRP}{\partial R} = r = \frac{NRP}{R} = NARP. \tag{12}$$

This condition occurs at maximum *NARP*, where *NMRP* equals *NARP*. Thus, requiring zero profit in the IOF competitive equilibrium produces a result equivalent to Clark's scale-efficient cooperative solution. That is, if the cooperative achieves the Ohm-LeVay or Clark equilibrium, it is efficient in employing processing inputs and pricing raw product.

3. Methods

3.1. Specifying the NRP and farm cost function

We now identify the cooperative's equilibria by explicitly incorporating marginal farm cost $S(R)$ into its *NMRP* and *NARP* system. This enables a more general assessment than heretofore possible of a marketing cooperative's pricing and scale efficiency. We assume *NRP* takes the translog form. Maintaining quadratic symmetry, and linear homogeneity by normalizing inputs prices with output price P, we obtain:

$$\begin{aligned}
\ln NRP_{jit} = {} & a_o + a_l \ln w_{it} + a_k \ln v_{it} + a_e \ln e_{it} + a_s \ln s_{it} \\
& + a_r \ln R_{it} + 1/2 a_{ll} \ln w_{it}^2 + 1/2 a_{kk} \ln v_{it}^2 + 1/2 a_{ee} \ln e_{it}^2 \\
& + 1/2 a_{ss} \ln s_{it}^2 + 1/2 a_{rr} \ln R_{it}^2 + a_{lk} \ln w_{it} \ln v_{it} \\
& + a_{le} \ln w_{it} \ln e_{it} + a_{ls} \ln w_{it} \ln s_{it} + a_{ke} \ln v_{it} \ln e_{it} \\
& + a_{ks} \ln v_{it} \ln s_{it} + a_{es} \ln e_{it} \ln s_{it} + a_{lr} \ln w_{it} \ln R_{it} \\
& + a_{kr} \ln v_{it} \ln R_{it} + a_{er} \ln e_{it} \ln R_{it} \\
& + a_{sr} \ln s_{it} \ln R_{it}, + \sum_j \gamma_j D_j,
\end{aligned} \tag{13}$$

where *NRP*, w, v, e, and s are P-normalized net revenue product, wage rate, capital price, energy price, and other-service price respectively, and R_{it} is quantity of raw-rice members deliver to cooperative i at time t. Provincial dummies (D_j, $j = 2, \ldots, 8$) are included to account for province-specific fixed effects. These fixed effects add a short-run character to (13) despite capital's variability. Other inputs that are unaccounted for, such as management skill, presumably carry fixity as well, allowing size diseconomies.

Logarithmically differentiating Eq. (13) with respect to the normalized input prices gives the optimal shares of processing inputs $\mathbf{X}$:

$$\begin{aligned}
S_l = {} & a_l + a_{ll} \ln w_{it} + a_{lk} \ln v_{it} + a_{le} \ln e_{it} \\
& + a_{ls} \ln s_{it} + a_{lr} \ln R_{it},
\end{aligned} \tag{14}$$

$$S_k = a_k + a_{lk} \ln w_{it} + a_{kk} \ln v_{it} + a_{ke} \ln e_{it} + a_{ks} \ln s_{it}$$
$$+ a_{kr} \ln R_{it}, \tag{15}$$

$$S_e = a_e + a_{le} \ln w_{it} + a_{ke} \ln v_{it} + a_{ee} \ln e_{it} + a_{es} \ln s_{it}$$
$$+ a_{er} \ln R_{it}, \tag{16}$$

$$S_s = a_s + a_{ls} \ln w_{it} + a_{ks} \ln v_{it} + a_{es} \ln e_{it} + a_{ss} \ln s_{it}$$
$$+ a_{sr} \ln R_{it}. \tag{17}$$

We estimate *NRP* Eq. (13) jointly with system (14)–(17) by Zellner's seemingly unrelated regression (SUR). Twenty-four linear constraints are employed to maintain the cross-equation parametric identities.

To derive raw-product supply function $S(R)$, we first specify a translog farmer cost, maintaining quadratic symmetry and normalizing input prices by capital price to maintain input-price linear homogeneity:

$$C_{jt} = \beta_o + \beta_l \ln l_{jt} + \beta_m \ln m_{jt} + \beta_g \ln g_{jt} + \beta_r \ln R_{jt}$$
$$+ 1/2\beta_{ll} \ln l_{jt}^2 + 1/2\beta_{mm} \ln m_{jt}^2 + 1/2\beta_{gg} \ln g_{jt}^2$$
$$+ 1/2\beta_{rr} \ln R_{jt}^2 + \beta_{lm} \ln l_{jt} \ln m_{jt} + \beta_{lg} \ln l_{jt} \ln g_{jt}$$
$$+ \beta_{mg} \ln m_{jt} \ln g_{jt} + \beta_{lr} \ln l_{jt} \ln R_{jt} + \beta_{mr} \ln m_{jt} \ln R_{jt}$$
$$+ \beta_{gr} \ln g_{jt} \ln R_{jt} + \sum_j \delta_j D_j. \tag{18}$$

Here C, l, m, and g are normalized cost, farm wage rate, farm materials price, and land rental rate, and R_{jt} is quantity of farm good delivered to the cooperative in province j at time t. As in the *NRP* function, provincial fixed effects (D_j, $j = 2, \dots, 8$) are included. Optimal farm input demands are derived by successively log differentiating normalized cost with respect to normalized input prices:

$$S_l = \beta_l + \beta_{ll} \ln l_{jt} + \beta_{lm} \ln m_{jt} + \beta_{lf} \ln g_{jt} + \beta_{lr} \ln R_{jt}, \tag{19}$$

$$S_m = \beta_m + \beta_{lm} \ln l_{jt} + \beta_{mm} \ln m_{jt} + \beta_{mg} \ln g_{jt} + \beta_{mr} \ln R_{jt}, \tag{20}$$

$$S_g = \beta_f + \beta_{lg} \ln l_{jt} + \beta_{mg} \ln m_{jt} + \beta_{gg} \ln g_{jt} + \beta_{gr} \ln R_{jt}. \tag{21}$$

Supply equation system (18)–(21) is estimated with SUR, maintaining 15 cross-equation parameter constraints. The capital share equation is recovered through the linear homogeneity condition requiring cost shares to sum to one, that is $\beta_l + \beta_k + \beta_m + \beta_g = 1$, $\sum_i \beta_{ij} = 0$, and $\sum_j \beta_{ij} = 0$, in which $i, j = l, k, m,$ and g (Greene, 2008). Employing these specifications, we now examine the following hypotheses about how cooperatives make raw-product pricing and volume decisions.

3.2. Hypothesis (1): Equilibrium occurs where farm supply intersects maximum NARP (Clark)

Such equilibrium, point B in Fig. 1, also maximizes the IOF's profit under long-run free-entry situations (Clark, 1952). In this sense, it is a reasonable standard for fully efficient raw-product pricing in a cooperative.

To test Hypothesis (1), we rearrange Eq. (12) to express the condition that the *NRP*'s elasticity with respect to raw-product volume R ($\varepsilon_{NRP, R}$) be unity (Sexton et al., 1989). That condition holds at maximum *NARP*, where *NMRP = NARP*, so that:

$$\frac{\partial NRP}{\partial R} = \frac{NRP}{R}. \tag{22}$$

Since $\frac{\partial NRP}{\partial R} \times \frac{R}{NRP} = \varepsilon_{NRP,R} = 1$ at this point, it can be tested by specifying the null hypothesis that the *NRP* elasticity be unity, where $t = (\varepsilon_{NRP,R} - 1)/\sigma$ and σ is standard error. To do so, we log differentiate the normalized *NRP* function with respect to R:

$$\left(\frac{\partial \ln \widehat{N R P}}{\partial \ln R} \right)_{jit} = \hat{a}_r + \hat{a}_{rr} \ln R_{it} + \hat{a}_{lr} \ln w_{it} + \hat{a}_{kr} \ln v_{it}$$
$$+ \hat{a}_{er} \ln e_{it} + \hat{a}_{sr} \ln s_{it}, \tag{23}$$

then evaluate it at every data point to generate the sample for obtaining the standard error. Failure to reject the null implies the cooperative's equilibrium occurs where $S(R)$ intersects maximum *NARP*. If the null is rejected, we must search for another equilibrium. Because Korean cooperative rice processing complexes vary substantially in size, we conduct the *NRP* elasticity test successively for small, medium, and large complexes, distinguished—as discussed at Eq. (29) below—according to the quantity of raw rice processed.

3.3. Hypotheses (2) and (3): Equilibrium occurs where farm supply intersects NMRP (Ohm-LeVay) or NARP (Helmberger-Hoos)

Rejecting Hypothesis (1) implies equilibrium can occur at the intersection of either $S(R)$ and *NMRP*—point C in Fig. 1— or $S(R)$ and *NARP*, point D. To test these two possibilities, we may compare sample mean raw-product deliveries $\bar{R}$ with the means defined by the two alternative equilibria, respectively $\bar{R}_{S(R)=NMRP}$ (Hypothesis 2) and $\bar{R}_{S(R)=NARP}$ (Hypothesis 3). The null of Hypothesis 2 is that $\bar{R}$ and $\bar{R}_{S(R)=NMRP}$ differ nonsignificantly from one another, and of Hypothesis (3) that $\bar{R}$ and $\bar{R}_{S(R)=NARP}$ differ nonsignificantly. Each is testable through difference-in-means tests.

The first step in deriving $R_{S(R) = NMRP}$ and $R_{S(R) = NARP}$ is to compute the farm marginal costs associated with cost function (18). Given fitted normalized farm cost $\widehat{C}_{jt} = \exp(\ln \widehat{C}_{jt})$ in province j at time t, marginal cost $MC_{jt} \equiv S(R)_{jt}$ is derived as

$$MC_{jt} = \left(\frac{\widehat{C}}{R} \right)_{jt} [\hat{\beta}_r + \hat{\beta}_{rr} \ln R_{jt} + \hat{\beta}_{lr} \ln l_{jt} + \hat{\beta}_{mr} \ln m_{jt}$$
$$+ \hat{\beta}_{gr} \ln g_{jt}], \tag{24}$$

where the term in the square brackets is cost elasticity with respect to R. The next step is to derive $NMRP_{jit}$ and $NARP_{jit}$

from the normalized *NRP* estimate, Eq. (13). Using the fitted *NRP*, that is $NRP_{jit} = \exp(\ln \widehat{NRP}_{jit})$ at cooperative i in province j at time t, we have

$$NMRP_{jit} = \left(\frac{\widehat{NRP}}{R}\right)_{jit}[\widehat{\alpha}_r + \widehat{\alpha}_{rr} \ln R_{it} + \widehat{\alpha}_{lr} \ln w_{it}$$

$$+ \widehat{\alpha}_{kr} \ln v_{it} + \widehat{\alpha}_{er} \ln e_{it} + \widehat{\alpha}_{sr} \ln s_{it}]. \quad (25)$$

$$NARP_{jit} = \left(\frac{\widehat{NRP}}{R}\right)_{jit}, \quad (26)$$

The first term on the right side of (25) is *NARP*, and the square-bracketed term is the *NRP* elasticity with respect to *R*. Thus, (25) is equivalent to $NMRP_{jit} = [NARP_{jit}] [(\varepsilon_{NRP, R})_{jit}]$. We compute the raw-rice quantity *R* at which $S(R)$ intersects *NMRP* (or *NARP*) at each observation by equating MC_{jt} to $NMRP_{jit}$ (or $NARP_{jit}$) as

$$(R_{S(R)=NMRP})_{jit} : MC_{jt} = \left(\frac{\widehat{NRP}}{R}\right)_{jit} (\varepsilon_{NRP, R})_{jit} \quad (27)$$

and

$$(R_{S(R)=NARP})_{jit} : MC_{jt} = \left(\frac{\widehat{NRP}}{R}\right)_{jit}. \quad (28)$$

Evaluating (27) and (28) at each data point allows deriving the mean and standard deviation of $R_{S(R) = NMRP}$ and $R_{S(R) = NARP}$. Hypotheses (2) and (3) are tested for the full sample as well as separately for the three cooperative size subsamples.

4. Estimation approach and data

Tests of these hypotheses are ideally conducted with cooperative-specific *NRP* and member-specific farm cost data. The former are available to us but, as in most countries, farm-level observations are not. Fortunately, they are accessible as annual provincial means. And because the cooperatives to which most farmers deliver their rice are domiciled in the farmer's own province, we can represent the observation-specific matches in (27) and (28) as explicit, stable pairings of cooperatives and their members. As indicated above, province fixed effects are used in both the *NRP* and farm cost function to represent provincial differences in otherwise unaccounted-for processing and farm resources.

Any aggregation bias of using provincial rather than individual-farm cost data to estimate (18) likely is small because most farmers in a given Korean province appear to face largely the same raw-rice prices as do IOF processors, with whom cooperative members also conduct business and to whose prices they presumably would equate their marginal production cost in order to maximize profit. Intra-province commonality of farmer marginal cost in turn is sufficient for unbiased aggregation in the neighborhood of farmers' current operations.

For the *NRP* function, we use 2002–2008 data on the 166 cooperative Regional Rice Processing Complexes (RPCs) pro-

vided by the National Agricultural Cooperative Federation of Korea. Each rice complex's *NRP* is computed as the difference between its gross revenue and total processing cost exclusive of raw-rice cost. Gross revenue is deflated by the Korean consumer price index (2005 = 100). Output price *P* is computed as the ratio of gross revenue to processed-rice volume. Processing inputs consist of capital (*K*), labor (*L*), energy (*E*), and other services (*S*), measured as follows.

Capital expenditure is measured as the opportunity cost of (interest on) and depreciation of capital stock.[5] Capital stock is obtained by the perpetual inventory method: $K_{it} = I_{it} + (1 - \theta_{it})K_{it-1}$, where K_{it} comprises buildings and machinery, I_{it} is investment, and θ_{it} is depreciation rate at cooperative *i* in time *t*. For most cooperatives, asset service lives (*T*) of buildings and machinery are assumed, respectively, to be 20 and 8 years. Hence, respective depreciation rates $\theta = 1/T$ are 5% and 12.5%. Capital stock is deflated by the national gross fixed capital formation deflator (2005 = 100). Capital expenditure is then obtained by multiplying stock by the weighted-average loan rate, deflated by the CPI (Bank of Korea).

Labor compensation includes wages and other benefits. CPI-deflated wage rate is total labor compensation divided by the annual hours worked by full and part-time RPC employees. Unlike in other Korean manufacturing, rice cooperatives face a mixed price system for energy (electricity and oil) use. Electricity prices depend on the production process in which the electricity is used. General-manufacturing price rates apply to the milling process, while lower prices apply to the storage process. Because oil is used in storage, its price is exempted from tax. Annual electricity and oil prices are respectively obtained from the Korean Electric Power Corporation and the Korean Ministry of Food, Agriculture, Forestry, and Fisheries. We compute energy price by combining per-kW-hour (kWh) electricity and oil rates and deflating with the producer price index (PPI, 2005 = 100). Per-liter oil prices are converted to an hourly basis assuming the average quantity of oil (24 l) used per hour.

Prices of other processing and handling services, such as packing materials, maintenance, transportation, insurance, and related services, are measured as an aggregate rate per worker hour. For this we divide the services' expenditures, deflated by the CPI (2005 = 100), by annual hours worked by full and part-time employees. *NRPs* and input costs are measured in (million) Korean won, and each input share is computed by dividing each deflated input cost by the deflated *NRP*.

Mean annual province-level 2002–2008 rice farming cost and factor price estimates are provided by the Korean National Statistics Office for the eight provinces in which processing complexes are located. Farm input prices consist of farm wage rate (*l*), interest and depreciation rates on depreciated capital (*k*), farm materials price (*m*), and rental rate of farm land (*g*). Wage rate is computed for both self- and hired labor.

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[5] Korean agricultural cooperatives are exempt from some or all taxes on fixed assets. We thus use only interest and depreciation rates to specify capital prices.

Table 1
Summary statistics, normalized *NRP*, and rice farming cost functions

NRP function			Rice farming cost function		
Variable	Mean	Standard deviation	Variable	Mean	Standard deviation
ln *NRP*	8.512	0.559	ln *C*	16.480	0.600
ln *w*	−4.277	0.407	ln *l*	1.822	0.245
ln *v*	−3.162	0.159	ln *m*	1.622	0.141
ln *e*	−4.333	0.180	ln *g*	2.170	0.184
ln *s*	−4.552	0.487	ln *R*	13.423	0.522
ln *R*	8.675	0.523			

Note: NRP function arguments are normalized by output price. Rice farming cost function arguments are normalized by capital price.

Table 2
Parameter estimates of cooperative *NRP* function

Parameter	Estimated coefficient	Parameter	Estimated coefficient
α_l	−0.3801*** (0.0175)	α_{lr}	0.0269*** (0.0013)
α_k	−0.2181*** (0.0148)	α_{kr}	0.0180*** (0.0010)
α_e	−0.0513*** (0.0129)	α_{er}	0.0054*** (0.0009)
α_s	−0.2713*** (0.0210)	α_{sr}	0.0177*** (0.0015)
α_{ll}	−0.0286*** (0.0010)	d_2	0.0155 (0.0198)
α_{kk}	−0.0145*** (0.0022)	d_3	0.0448* (0.0258)
α_{ee}	0.0004 (0.0015)	d_4	−0.0291 (0.0199)
α_{ss}	−0.0225*** (0.0012)	d_5	−0.0096 (0.0206)
α_{lk}	0.0017* (0.0009)	d_6	0.0230 (0.0192)
α_{le}	−0.0014** (0.0007)	d_7	0.0310 (0.0221)
α_{ls}	0.0040*** (0.0009)	d_8	0.0489** (0.0222)
α_{ke}	0.0014 (0.0015)	Constant	−5.656*** (0.7656)
α_{ks}	−0.0017** (0.0009)	R^2	0.9995
α_{es}	0.0008 (0.0007)	Breusch-Pagan LM $\chi^2(10)$	4,616.80
α_r	1.7590*** (0.1717)	df	6332
α_{rr}	−0.0529*** (0.0197)		

Note: *, **, *** Statistical significance at 10%, 5%, and 1%, respectively. Numbers in parentheses are asymptotic standard errors. The null hypothesis in the Breusch-Pagan LM test is that equation disturbances are independent.

Materials consist of seeds, fertilizers, pesticides, and other chemicals. Input prices are deflated by the index of prices paid by farmers (2005 = 100), which includes household-consumption commodities, farm production materials, and farm wages. Area-based total costs and input prices are converted to a per-ton-yield basis using mean per-hectare yield rates reported by the Korean National Statistics Office.

5. Results and discussion

5.1. NRP *and farmer cost function estimates*

Table 1 provides summary statistics of the variables used in the estimation of normalized *NRP* and rice farm cost functions. Estimates of the normalized *NRP* function and associated cooperative input demand shares, Eqs. (13)–(17), are reported in Table 2. Most estimates are statistically significant and model explanatory power is high ($R^2 = 0.99$). Significance of the α_{rr} parameter implies returns to scale are nonconstant. Significance of α_{lr}, α_{kr}, α_{er}, α_{sr} implies, from (14) to

Table 3
Parameter estimates of rice farming cost function

Parameter	Estimated coefficient	Parameter	Estimated coefficient
β_l	0.3029*** (0.0099)	β_{lr}	−0.0001 (0.0008)
β_m	0.3092*** (0.0096)	β_{mr}	−0.0012 (0.0007)
β_g	0.2500*** (0.0108)	β_{gr}	0.0015* (0.0009)
β_{ll}	0.1972*** (0.0017)	d_2	0.0029 (0.0035)
β_{mm}	0.1772*** (0.0022)	d_4	0.0041 (0.0057)
β_{gg}	0.2344*** (0.0027)	d_5	0.0032 (0.0050)
β_{lm}	−0.0716*** (0.0013)	d_7	0.0036 (0.0042)
β_{lg}	−0.1148*** (0.0016)	d_8	0.0028 (0.0030)
β_{mg}	−0.0962*** (0.0019)	Constant	1.8532** (0.7774)
β_r	0.9255*** (0.1167)	R^2	0.9995
β_{rr}	0.0052 (0.0088)	Breusch-Pagan LM $\chi^2(6)$	37.522
		df	204

Note: *, **, ***Statistical significance at 10%, 5%, and 1%, respectively. Numbers in parentheses are asymptotic standard errors. The null hypothesis in the Breusch-Pagan LM test is that equation disturbances are independent.

Table 4
Curvature properties of *NRP* and rice farming cost functions

Principal minors (D_k)	*NRP* function	Rice farming cost function
D_1	2.20	−4.1244
D_2	71.52	3.2702
D_3	1,922.10	−2.2269
D_4	41,785.06	

Note: Hessian matrices of the normalized *NRP* and rice farming cost function, expressed at data means, are dimensioned 4 × 4 and 3 × 3, respectively. D_k indicates principal minor of order k. In the *NRP*, $D_k > 0$, and in rice farming cost $(−1)^k D_k > 0$, for all k. For viewing simplicity, elements of principal minors are divided by 10,000.

(17), that rice processing technology is nonhomothetic. On the basis of a Breusch-Pagan Lagrange multiplier (B-P LM) test [$\chi^2(10) = 4{,}616.80$], we reject, at 1% significance, the null hypothesis that the disturbances of the *NRP* and input demands are independent of one another. Joint estimation of *NRP* and factor demand shares therefore is asymptotically efficient. Fitted input shares of the normalized *NRP* estimates are positive at every observation, implying the monotonicity property is satisfied. Determinant of the *NRP* Hessian $\|\partial^2 NRP/\partial w_i \partial w_j\|$, and its principal minors, are all positive at data means, ensuring convexity in normalized input prices at least at the centroid (Table 4).

Table 3 shows estimates of the corresponding normalized rice farm cost function and associated farm factor demands, Eqs. (18)–(21). Most parameters are, as with the *NRP*, statistically significant and model explanatory power is high. The B-P LM test [$\chi^2(10) = 39.92$] suggests disturbances of the cost and input share equations are correlated with one another, implying the FGLS (SUR) estimator is asymptotically efficient. Fitted input shares (19)–(21) are positive at each observation, so the estimated cost function is monotonic. As shown in Table 4, Hessian matrix $\|[\partial^2 C/\partial w_i \partial w_j\|$ is—evaluated at data means—negative definite, its principal minors alternating in

Table 5a
Test results for cooperative equilibrium at maximum *NARP* (Hypothesis 1)

| | | Processing size (percentile) | | |
	Overall	Small (below 30)	Medium (30–70)	Large (above 70)
Elasticity (1)	1.0239***	1.0495***	1.0239***	0.9981
	(0.0099)	(0.0142)	(0.0099)	(0.0163)
	($t = 2.40$)	($t = 3.47$)	($t = 2.41$)	($t = -0.11$)
Minimum	0.9170	0.9672	0.9431	0.9170
Mean (2)	1.0239	1.0495	1.0239	0.9981
	(0.0291)	(0.0233)	(0.0187)	(0.0223)
Maximum	1.1800	1.1800	1.0827	1.0807
OBS	1272	381	510	381

Note: Row (1) elasticities are evaluated at data means. Numbers in the parenthesis are standard errors and test statistics (null hypothesis: $\varepsilon_{NRP, R} = 1$), respectively.
***Alternative hypothesis ($\varepsilon_{NRP, R} > 1$) is accepted at 1% significance in an upper tail test. Row (2) provides mean values of the estimated elasticities for all observations, and the parenthesized numbers are standard deviations.

sign beginning with the negative. The farm cost curvature properties are thus satisfied at least at data means.

Nonsignificance of β_{rr} and cross-product terms β_{lr}, β_{mr}, β_{gr} in Table 3, combined with β_r's proximity to unity, suggests rice farm technology comes close to constant returns to scale. Yet β_{gr} is statistically significant at the 10% level, implying factor shares—especially of land—do adjust as output rises. Technology then could not be completely homothetic. The nonsignificance and high-standard errors of the province fixed effects suggests only modest cross-province variation in Korea's unpriced rice farm resources like technical organization, a conclusion that—particularly since land prices are accounted for in this model—is in line with expert opinion. Inter-province technological similarities reinforce our earlier surmise that marginal costs are rather homogeneous within provinces and any aggregation bias therefore modest, because similarities in rice types and productive resources would be even greater within than between provinces.

5.2. Testing for pricing and scale efficiency

Table 5a reports *NRP* elasticities with respect to raw-rice volume *R*, both for the entire sample and for small, medium, and large rice processing complexes. The overall elasticity, evaluated at data means via Eq. (23), is 1.024 and the null hypothesis that $\varepsilon_{NRP,R} = 1$ is rejected at the 1% significance level (upper-tail test, *t*-statistic = 2.40). Thus, overall *NRP* elasticity statistically exceeds unity. If and only if *NMRP* exceeds *NARP* to the left of maximum *NARP* (Fig. 2) does the *NRP* elasticity exceed unity:

$$\frac{\partial NRP}{\partial R} > \frac{NRP}{R} \text{ so that } \frac{\partial NRP}{\partial R} \times \frac{R}{NRP} = \varepsilon_{NRP,R} > 1. \quad (29)$$

In the representative or average-sized cooperative, equilibrium thus appears to occur to the left of maximum *NARP*.
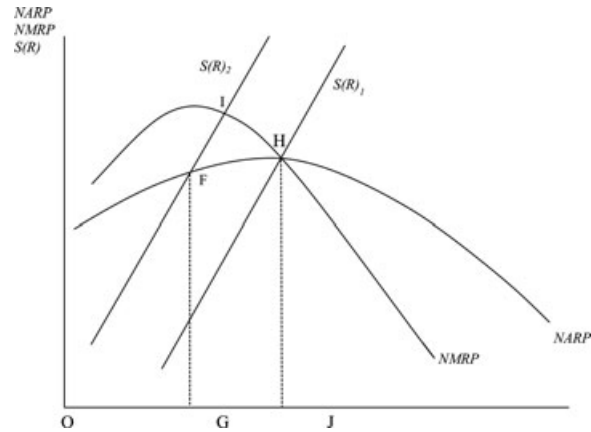

Fig. 2. Observed marketing cooperative equilibria, 2002–2008.

Identical tests were conducted for the small-, medium-, and large-cooperative subsets, in which—for the simplicity of using equal-interval categories—the lowest 30% is regarded as small, the 30th to 70th percentile as medium-sized, and the 70th to 99th as large. Estimated *NRP* elasticities in small and medium-sized cooperatives were 1.050 and 1.024, respectively (Table 5a). In both, the null hypothesis of unitary *NRP* elasticity is rejected at 1% significance (upper-tail test, $t = 3.47$ and 2.41, respectively). Hence, and again following the logic of Eq. (29), we can conclude that small and medium-sized cooperatives operate, like the average one, to the left of maximum *NARP* as depicted at point F in Fig. 2.

In large cooperatives, however, we fail to reject the null hypothesis of unitary *NRP* elasticity ($t = -0.11$), suggesting, as in Clark's (1952) result, that only large entities achieve the efficient equilibrium indicated in Fig. 2's point H. This large-cooperative equilibrium is the same as IOF profit-maximizing behavior under free-entry long-run conditions. Provided they use nonraw-rice processing inputs optimally, large processing centers therefore operate at an efficient scale as well as price, maximizing the full price paid farmers. Such result is consistent with Ariyaratne et al. (2000), who find large Great Plains grain marketing and supply cooperatives to be more scale efficient than smaller ones are. Sexton et al. (1989) suggest California cotton ginning cooperatives similarly operate near maximum *NARP*, their *NRP*'s mean elasticity with respect to raw cotton volume being almost unitary at 1.0095.

That small and medium cooperatives and, unexpectedly, the average one operate to the left of maximum *NARP*, and that large cooperatives are found at the maximum itself, have a common implication: the Ohm-LeVay and Helmberger-Hoos equilibria—Hypotheses (2) and (3)—are rejected. Korean agricultural cooperatives, including those working together to operate rice complexes, do maintain the open-membership policies normally thought conducive to an Ohm-LeVay or Helmberger-Hoos solution. On the other hand most Korean rice farmers do not, as the Helmberger-Hoos model supposed, deliver their entire output to one cooperative. They sell to others in the province

Table 5b
Test results for cooperative equilibrium in Hypotheses (2) and (3)

	Overall	Processing size (percentile)	
		Small (below 30)	Medium (30–70)
Actual $\bar{R}$ (ton) (A)	6,690.26 (3,686.45)	3,391.35 (863.31)	5,911.46 (837.99)
$\bar{R}_{S(R)=NMRP}$ (ton) (B)	9,581.30 (5,263.02)	5,074.37 (1,626.06)	8,598.27 (1,824.01)
$\bar{R}_{S(R)=NARP}$ (ton) (C)	9,481.17 (5,491.53)	4,863.55 (1,620.83)	8,415.54 (1,867.23)
$\bar{R}_{NMRP=NARP}$ (ton) (D)	9,717.34 (3,385.13)	8,671.43 (2,870.76)	9,669.78 (2,990.33)
t-statistic: (B) = (D)	−0.81	−19.14***	−6.29***
t-statistic: (C) = (D)	−1.35*	−20.09***	−7.14***
t-statistic: (A) = (B)	−46.63***	−31.31***	−42.88***
t-statistic: (A) = (C)	−41.27***	−27.37***	−38.92***
t-statistic: (B) = (C)	11.66***	59.36***	27.71***
OBS	1,272	381	510

Note: Rows (A), (B), (C), and (D) show mean raw-product deliveries, where parenthesized numbers are standard deviations. Asterisks * and *** in rows (5) and (6) indicate null hypotheses (B) = (D) and (C) = (D) are rejected at, respectively, 10% and 1% significance in a lower tail test. Asterisks *** in rows (7) and (8) indicate null hypotheses (A) = (B) and (A) = (C) are rejected at 1% significance in a two-tail test. Asterisks *** in row (9) indicate null hypothesis (B) = (C) is rejected at 1% significance in an upper-tail test.

and to IOFs as well. Especially because this trend toward multiple outlets has grown, it therefore is easy to imagine that cooperatives may over-invest in processing capacity, attracting inadequate supplies to maximize their *NARP* despite an open membership policy.

It is worthwhile using another way to test whether a cooperative operates to the left of the *NARP* maximum. We do so through tests for pairwise differences between $R_{NMRP = NARP}$, $R_{S(R) = NMRP}$, $R_{S(R) = NARP}$, and sample-mean R, the first being the Clark solution and the second and third the "Ohm-LeVay" and "Helmberger-Hoos" ones but—unlike Ohm-LeVay and Helmberger-Hoos—allowing equilibrium to occur to the left *or* right of Clark. The means and variances are shown in rows 1–4, and means difference tests in rows 5–9, of Table 5b.

We first test whether the $R_{NMRP = NARP}$ and $R_{S(R) = NMRP}$ solutions significantly differ from one another. In row 5, we do not find evidence that $\bar{R}_{S(R)=NMRP}$ significantly falls short of $\bar{R}_{NMRP=NARP}$ in the overall sample, but do find evidence at the 1% level that it does so among small and medium cooperatives. It is therefore more plausible to argue that small and medium firms operate at point I in Fig. 2 than at point C in Fig. 1. Consistent with this, the null hypothesis in row 6 that $\bar{R}_{S(R)=NARP}$ equals $\bar{R}_{NMRP=NARP}$ is rejected in favor of $\bar{R}_{S(R)=NARP} < \bar{R}_{NMRP=NARP}$ at 10% significance in the average cooperative and at 1% significance in small and medium ones. Fig. 2, in other words, where farm supply lies to the left of the *NARP* maximum, better reflects small and medium, as well as whole-sample, cooperative equilibria than Fig. 1 does. In particular, except in large firms, operation at point F appears more plausible than at point H in Fig. 2.

Such reasoning implicitly assumes the regularity condition that the estimated *NARP* function is concave. We test this assumption by checking whether mean $R_{S(R) = NMRP}$ exceeds mean $R_{S(R) = NARP}$ in our data, namely whether point I in Fig. 2 involves a significantly higher raw product volume than point F does. As shown in Fig. 2, it must do so if $S(R)$ is upsloping and *NARP*

is concave, requiring *NMRP* to lie above *NARP* when output is below OJ. And in row 9 of Table 5b, $\bar{R}_{S(R)=NMRP}$ does exceed $\bar{R}_{S(R)=NARP}$ at 1% significance—in the whole sample as well as among small and medium firms. *NARP* concavity, together with upsloping raw-product supply, are thus jointly confirmed.

To now identify which of $\bar{R}_{S(R)=NMRP}$ and $\bar{R}_{S(R)=NARP}$ (that is, points I and F in Fig. 2) best corresponds to the data at these three firm sizes, we test the significance of the difference between the means of actual member deliveries R and the deliveries implied, respectively, by points I and F, the respective null hypotheses being $\bar{R} = \bar{R}_{S(R)=NMRP}$ and $\bar{R} = \bar{R}_{S(R)=NARP}$. And, at 1% significance, we reject both these null hypotheses (rows 7 and 8 of Table 5b). In particular, mean actual deliveries lie below both point F and point I, so that point F is the more accurate predictor of the cooperative's intended equilibrium. Furthermore, intersection of $S(R)$ with *NMRP* (point I) is infeasible because, to the left of maximum *NARP*, *NMRP* exceeds *NARP* at given R, implying that transfer price r (height of *NMRP*) exceeds the full per-unit distribution of total revenue product (height of *NARP*). The cooperative would at this point thus be in financial deficit, requiring subsidy. The subsidy would have to be a lump-sum one because it otherwise would be incorporated into the *NARP* and *NMRP* functions, whose necessary relationship with one another would maintain point I's infeasibility.

Small and medium-sized—and some large—Korean rice processing cooperatives did typically receive subsidies during our 2002–2008 sample period. But unlike lump sums, they came in the form of interest-free loans on the short-term capital used to buy raw rice from members. Such interest savings reduced recipients' capital costs, lifting their *NRP* (and thus *NARP* and *NMRP*) functions above where they would have been in the absence of a subsidy. Because these subsidies were costs-avoided rather than direct receipts, they necessarily are reflected in the *NRP* data. Our *NARP* function estimate thus represents the cooperative's maximum break-even raw-rice price, again rendering point I in Fig. 2 infeasible for small and medium-sized

rice cooperatives. Of points I and F then, only F, where farm supply $S(R)$ intersects the *NARP* function, is feasible.[6]

In general, these results show that average cooperative equilibrium, and the raw-rice pricing it implies, does not conform to the pricing efficiency depicted in (8) or the scale efficiency in (12). To check the robustness of this result, we conducted, as in Conrad and Unger (1987) and Boyle (2004), a log-likelihood ratio (LR) test discriminating between the raw-rice pricing behavior of a cost-minimizing IOF and a cooperative that minimizes the cost of nonraw-rice processing inputs only. That LR test suggests cooperative equilibrium occurs where $S(R)$ intersects *NARP* to the left of maximum *NARP* (see Appendix).

5.3. Interpreting cooperative scale inefficiency

These results collectively imply that the mean Korean cooperative rice processing complex—and small and medium-sized ones in particular—do not succeed in minimizing unit cost. The inoptimality is tied to their underutilization of raw rice, likely because of their failure to adequately adjust to the decline in rice production and consumption during the past two decades. Rice processing complex construction began in 1991 and almost 70% of the centers were in operation by 1995. Their capacity at the time of construction probably coincided with current demand. For instance, average consumption and production during the three years prior to rice complex construction (1988–1990) were, respectively, 5.134 and 5.852 million tons. Since then, consumption has fallen by about 30% and production by 20%. In particular, consumption during the 2007–2009 period was only 3.673 million tons and production only 4.722 million tons (Korean National Statistics Office, Korean Ministry of Food, Agriculture, Forestry, and Fisheries). The average rice-processing complex thus appears to be suffering from over-capacity.

In contrast, the larger complexes have processed the equilibrium rice quantities depicted at OJ in Fig. 2. In particular, we fail to reject the null hypothesis of no difference between a large cooperative's mean actual deliveries R and equilibrium $R_{NMRP = NARP}$ (Table 6). Hence, only large cooperatives appear to employ a processing-cost-minimizing volume of raw rice and to pay a raw-rice price that would call forth such quantity.

5.4. Policy implications

Consider now the small and medium-sized cooperatives, which operate to the left of maximum *NARP*. The up-sloping *NARP* curve these firms face implies a down-sloping average

Table 6
Test results for efficient raw-rice allocation in processing

	Overall	Processing size (percentile)		
		Small (below 30)	Medium (30–70)	Large (above 70)
Actual $\bar{R}$ (tons) (1)	6,690.26 (3,686.45)	3,391.35 (863.31)	5,911.46 (837.99)	11,031.65 (3,625.76)
Equilibrium quantity (tons) (2)	$\bar{R}_{S(R)=NARP}$	$\bar{R}_{S(R)=NARP}$	$\bar{R}_{S(R)=NARP}$	$\bar{R}_{NMRP=NARP}$
	9,481.17 (5,491.53)	4,863.55 (1,620.83)	8,415.54 (1,867.23)	10,826.9 (3,971.74)
t-statistic (3)	−41.27***	−27.37***	−38.92***	0.79
OBS	1,272	381	510	381

Note: Rows (1) and (2) give mean values; numbers in the parenthesis are standard deviations. Row (3) is the test statistic of the difference between the means in rows (1) and (2). The null hypothesis is (1) = (2). ***Alternative hypothesis, namely (1) < (2), is accepted at 1% significance in a lower tail test.

processing cost curve. That is, unexploited scale economies are present because average processing cost falls as raw-rice quantity rises. The interest-free short-term loans granted these cooperatives to buy members' raw-rice serves, as we have said, to shift their *NARP* functions upward. Thus we can assume that our estimated *NARP* function rests, in Fig. 2's low-R domain, higher than it would in the absence of subsidy, tending to flatten the *NARP* function and reduce overall rice processing scale economies. But the flattening is not great, and the scale economies, and hence pricing inefficiency of operating below the *NARP* maximum, clearly are not eliminated. Processing scale matters for the efficient operation of small- and medium-sized Korean rice cooperative complexes.

Pricing efficiency can be achieved in small and medium-sized cooperatives either by boosting supply from $S(R)_2$ to $S(R)_1$ or by shifting *NARP* upward in Fig. 2. The former may be affected by expanding membership, the latter by reducing processing cost. As noted earlier, rice production and consumption recently have fallen in Korea and an individual cooperative's chance of boosting its membership thus is small. Mergers among nearby rice complexes, in which some capacity is retired and processing is allocated to the facilities most efficient in scale, technology, and location, are the more promising way to exploit the scale economies available. The merged entity's *NARP* curve would shift above the mean of its originating firms, allowing the merged $S(R)$ to intersect maximum *NARP* (OJ in Fig. 2).

To verify this claim, we test Hypotheses (1), (2), and (3) for the processing complexes which merged during the sample period.[7] We find that the merged complexes achieved maximum *NARP*. In particular, and as shown in Table 7, pre-merger mean *NRP* elasticity at the to-be-merged complexes exceeded unity ($\varepsilon_{NRP, R} = 1.03$) at 1% significance ($t = 3.02$). And we fail to reject the null hypothesis that means *NRP* elasticity was unity

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[6] The falling-short of actual below predicted raw rice deliveries suggests the raw-rice supply intercept estimate in Table 3 is negatively biased, namely that mean marginal farm cost is greater than what Table 3 represents. Some marginal farm costs—such as of owner effort—appear to be missing from our data. Had they been available, our conclusion that small- and medium-sized cooperatives undershoot the efficiency-maximizing equilibrium would have been even stronger than we presently draw.

[7] Mergers reduced the number of cooperative RPCs, from 200 in 2002 to 166 in 2008.

Table 7
Performance of merged cooperatives before and after merger

	Before merger	After merger
Elasticity (1)	1.0311 (0.0103)[***]	0.9973 (0.0166)
	($t = 3.02$)	($t = -0.16$)
Minimum	0.9379	0.9170
Mean (2)	1.0311 (0.0311)	0.9973 (0.0279)
Maximum	1.1800	1.0506
Actual $\bar{R}$(tons) (3)	5,332.70 (2,721.36)	12,084.93 (6,109.28)
Equilibrium quantity (tons) (4)	$\bar{R}_{S(R)=NARP}$	$\bar{R}_{NMRP=NARP}$
	7,351.62 (3,907.15)	10,778.75 (3,370.83)
t-statistic (5)	-18.86[***]	1.44
OBS	250	46

Note: Row (1) figures are evaluated at data means. Numbers in parenthesis are standard errors and test statistics (null hypothesis: $\varepsilon_{NRP, R} = 1$), respectively. [***] in (1) indicates the alternative hypothesis ($\varepsilon_{NRP, R} > 1$) is accepted at 1% significance in an upper-tail test. Row (2) figures are mean values of the estimated elasticities for all observations; numbers in the parenthesis are standard deviations. Rows (3) and (4) are mean values, and numbers in parenthesis are standard deviations. Row (5) values are test statistics for the difference between the means of (3) and (4). [***] in Row (5) indicates the alternative hypothesis (actual R < equilibrium quantity) is accepted at 1% significance in a lower tail test.

after the merger [$\varepsilon_{NRP, R} = 0.997$, $t = -0.16$]. Moreover, on the basis of a lower-tail test ($t = -18.76$), pre-merger actual deliveries R were significantly lower than at the observed equilibrium ($R_{S(R) = NARP}$). Yet we fail to reject the null that actual deliveries equaled $R_{NMRP = NARP}$ after the merger ($t = 1.44$). In sum, evidence suggests that promoting mergers effectively improved overall cooperative efficiency.

6. Summary and conclusions

The objective of this study has been to assess raw-rice pricing and scale efficiency in Korean cooperative rice processing complexes and, where appropriate, to identify ways of improving such efficiency. For this purpose, we used 2002–2008 revenue and cost data in 166 processing cooperatives to estimate net revenue product functions, and 2002–2008 farm cost data in eight provinces to estimate farmer-member rice cost functions. Combining net revenue product with farm supply information, we then tested alternative cooperative equilibria by comparing actual deliveries with those deduced from the farm marginal cost, net average revenue product (*NARP*), and net marginal revenue product (*NMRP*) functions. The comparisons were conducted separately for small, medium, and large cooperative processing operations.

On the basis of their observed behavior, large cooperative rice processing complexes appear strongly to operate at the Clark equilibrium—where marginal farm cost intersects maximum *NARP*—and hence to be efficient raw-product pricers. Small and medium-sized cooperatives, and the average one in our sample, on the other hand resist both the Clark and Ohm-LeVay equilibria, attracting rice supply quantities that equate farm marginal cost to *NARP* at the left of the *NARP* maximum.

Because they undershoot rather than overshoot the *NARP* maximum, these latter solutions resist the Helmberger-Hoos equilibrium as well, despite equating farm supply with *NARP* as Helmberger and Hoos postulated. In any event, only the large cooperatives appear to employ their members' raw products efficiently.

Wollni and Zeller (2007) and Bernard et al. (2008) show cooperative membership can boost farmer output prices. Assuming, nevertheless, that Korean rice cooperatives are output price takers, their operation below the maximum of an upward-sloping *NARP* function implies the presence of unexploited processing scale economies. Small and medium firms thus operate, on average, at inefficient scale, depressing implicit raw-product prices below what they might have been. Improving that efficiency will require reducing capacity and rationalizing the number, sizes, and locations of their processing and handling facilities. Much of that rationalization will involve retiring excess capacity or re-allocating it to such specialized uses as drying or storage.

As government economic policy has become more market-oriented and preferential treatment of cooperatives curtailed, Korean rice markets have become increasingly competitive. Rice imports under the URAA minimum-market-access provisions have expanded and rice demand simultaneously fallen, inducing excessive rice supplies. Cooperative mergers targeted toward more efficient raw-rice use and scale appear to be the only effective way of meeting this competitive challenge from the noncooperative sector. We do in fact find evidence that post-merger rice processing complexes have moved in the direction of an efficient equilibrium, where net average revenue product is maximized.

Cooperative efficiency depends upon, in addition to operating volume, such structural factors as member delivery contract terms, capital subscription and retirement plans, and the distribution of voting rights (e.g., Cook, 1995). We have not examined these important questions. But it is worth noting that a transition from small to large cooperative operations tends to increase the diversity of member farm sizes and structures and of member ages and financial incentives. Such heterogeneity may create its own strains on cooperative efficiency, possibly dampening the benefits of cooperative merger.

Appendix: Robustness Test for Aggregate Scale Efficiency

The following procedure was used to check for robustness of our finding that the full-sample cooperative equilibrium occurs away from the *NARP* maximum. This robustness test is motivated by noting that, if raw-product volume R is selected in the way an IOF would optimally do, it should be included as one of the shares in Eqs. (14)–(17). We examine whether the mean cooperative treats raw product as a share along with labor, capital, energy, and materials by conducting a log-likelihood ratio test, following Boyle's (2004) application in Conrad and Unger (1987). For this test, we specify two different systems. The first

is an *NRP*-maximizing system for competitive firms and the other an *ad hoc* one (Boyle, 2004). If cooperatives maximize *NRP* by setting raw-rice price *r* optimally as competitive IOFs do under free entry, raw-rice share

$$\left(\frac{rR}{NRP}\right)_{jit} = a_r + a_{lr} \ln(w)_{it} + a_{kr} \ln(v)_{it} + a_{er} \ln(e)_{it}$$

$$+ a_{sr} \ln(s)_{it} + a_{rr} \ln R_{it} \qquad (A.1)$$

can be added to *NRP* system (13)–(17) because, by Hotelling's lemma, it constitutes one of the *NRP*-maximizing input demands.

As noted earlier, cooperatives buy raw rice at a transfer price approved by their boards of directors and initially pay that price to members. Thus, raw-rice cost *rR* is measured as each cooperative's expenditure for rice purchases, deflated here by the Korean index of prices received by farmers (2005 = 100).[8] As the alternative to the above null hypothesis, we replace (A.1) in the estimation system with

$$\left(\frac{rR}{NRP}\right)_{jit} = \gamma_r + \gamma_{lr} \ln(w)_{it} + \gamma_{kr} \ln(v)_{it} + \gamma_{er} \ln(e)_{it}$$

$$+ \gamma_{sr} \ln(s)_{it} + \gamma_{rr} \ln R_{it}. \qquad (A.2)$$

The resulting arbitrary system, which we will call the unrestricted one, thus consists of Eqs. (13)–(17), and (A.2).

Parameters γ in (A.2) are independent of parameters α in (13)–(17) and (A.1). The number of parameters is 28 in the restricted system and 34 in the unrestricted system because cross-equation linear parametric restrictions are applied to (A.1) but not to (A.2). Based on SUR estimates of the two systems, we conduct an LR test in which χ^2 ($n = 6$) $= -2(\ln L(r) - \ln L(ur))$, where *n* is the number of restrictions and $\ln L(r)$ and $\ln L(ur)$ are the log-likelihood values of the restricted and unrestricted estimates, respectively. If we reject the null, aggregate cooperative pricing occurs where *S(R)* intersects *NARP* away from the *NARP* maximum.

Table A1 reports the estimation results of the two systems. Parameter estimates are mostly significant and model explanatory power is high ($R^2 = 0.99$) in each. FGLS estimators in the restricted and unrestricted systems are each asymptotically efficient because in the B-P LM test [$\chi^2(15) = 3,932.50$ and 5,154.22, respectively] we reject the null that disturbances in input-share equations are independent of one another. Monotonicity is satisfied, and convexity is satisfied at least at data means. The log-likelihood ratio ($\chi^2(6) = 756.04$) is high, rejecting the null hypothesis at 1% significance. Together with our test result for Hypothesis (1), this LR test thus confirms our finding that means cooperative volume is scale-inefficient.

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[8] Note that cooperative price *r* of raw rice is not generally the same as that paid by investor-owned firms.

Table A1
Restricted vs. unrestricted *NRP* estimation

Parameter	*NRP*-maximizing (restricted)	Arbitrary (unrestricted)
α_l	−0.4068*** (0.0178)	−0.3732*** (0.0175)
α_k	−0.2149*** (0.0166)	−0.2133*** (0.0147)
α_e	−0.0382** (0.0162)	−0.0464*** (0.0129)
α_s	−0.2837*** (0.0206)	−0.2633*** (0.0209)
α_{ll}	−0.0297*** (0.0011)	−0.0283*** (0.0010)
α_{kk}	−0.0138*** (0.0023)	−0.0145*** (0.0022)
α_{ee}	0.0043** (0.0020)	0.0007 (0.0015)
α_{ss}	−0.0229*** (0.0014)	−0.0223*** (0.0012)
α_{lk}	−0.00009 (0.0010)	0.0017* (0.0009)
α_{le}	−0.0043*** (0.0010)	−0.0015** (0.0007)
α_{ls}	0.0053*** (0.0010)	0.0042*** (0.0009)
α_{ke}	0.0075*** (0.0019)	0.0016 (0.0015)
α_{ks}	−0.0027*** (0.0010)	−0.0016* (0.0009)
α_{es}	0.0007 (0.0009)	0.0009 (0.0007)
α_r	1.0799*** (0.1068)	1.5970*** (0.1420)
α_{rr}	0.0286** (0.0116)	−0.0350** (0.0162)
α_{lr}	0.0281*** (0.0013)	0.0264*** (0.0013)
α_{kr}	0.0196*** (0.0011)	0.0176*** (0.0010)
α_{er}	0.0066*** (0.0011)	0.0051*** (0.0009)
α_{sr}	0.0191*** (0.0015)	0.0171*** (0.0015)
γ_r		4.4338*** (0.2503)
γ_{rr}		0.0280 (0.0179)
γ_{kr}		0.4062*** (0.0717)
γ_{lr}		0.0400* (0.0212)
γ_{er}		0.4874*** (0.0662)
γ_{sr}		0.0181 (0.0172)
Constant	−2.7969*** (0.5139)	−4.9143*** (0.6435)
R^2	0.9995	0.9995
Breusch-Pagan LM test $\chi^2(15)$:	3,932.50	5,154.22
Log-likelihood	17,507.3	17,885.3
Log-likelihood ratio: $\chi^2(6)$		756.04

Note: *,**, ***Statistical significance at 10%, 5%, and 1%. Parenthesized numbers are asymptotic standard errors. Null hypothesis in the Breusch-Pagan LM test is that equation disturbances are independent. For convenience, estimates of provincial dummy variables are not included in the table.

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