Increase in Raw Milk Demand and Its Long-Run Effects on Dairy Industrial Organization in Taiwan-An Approach with Spatial Equilibrium Analysis-

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Increase in Raw Milk Demand and Its Long–Run Effects on Dairy Industrial Organization in Taiwan–An Approach with Spatial Equilibrium Analysis–

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As we know Taiwanese government restricts the import of fluid milk, but, Taiwan will be asked to open the market of fluid milk after becoming a member of WTO in near future. Thus, Taiwanese dairy industry may face the problem of severe competitions. The objective of our serial studies is to make a preliminary research of whole Taiwanese dairy industry, including four sections of dairy farmers, dairy factories, dairy importers and consumers, then to develop a spatial price equilibrium model to evaluate changes in production, consumption, and trade of dairy products under alternative Taiwan and agricultural trade policy regimes, finally to find out the future possible dairy products price in the world trade and its influence on Taiwanese dairy industry.

We can divide Taiwanese dairy industry into four sections as Figure 1 showed. In this paper, we only discuss the relation of raw milk demand and supply between dairy farmers and factories, developing a spatial equilibrium model for solving the equilibrium price for each factories and regional farmers. This study also examines the role of spatial equilibrium in the allocation of raw milk from farms to the thirty–three processing factories located in Taiwan. In the final part of this paper, we analyze the result and discuss the future problems which Taiwanese dairy industry may meet such as relocation and capacity reallocation possibilities of Taiwanese dairy factories under the situation of continuously increasing demand as well as the pressure for liberalization of fluid milk trade.

INTRODUCTION

It is well known that for higher level income households, a bigger share of total expenditure on high quality food than is the case for lower level income households. Therefore, accompanying the increase of national income in Taiwan which being considered as a developed country, there is obviously increasing tendency in the dairy products demand (Table 1). However, the self sufficiency rate of dairy products in Taiwan is still small which is between 16.32% and 21.84% during last ten years. All of imported dairy products are manufactured dairy products, currently, and fluid milk is still restrictedly imported. Therefore, Taiwanese current raw milk materials are mostly used to produce fluid drinking milk which constitutes about half in fresh drinking milk, quarter in flavored and long life milk and quarter in fermented milk. Under these conditions, the liberalization of fluid milk trade will affect Taiwanese dairy industry seriously.

We would like to forecast future possible impact on Taiwanese dairy industry under the liberalized of fluid milk market according to the following stages. (1) We try to forecast the future situation of Taiwanese dairy industry assuming that there will be no

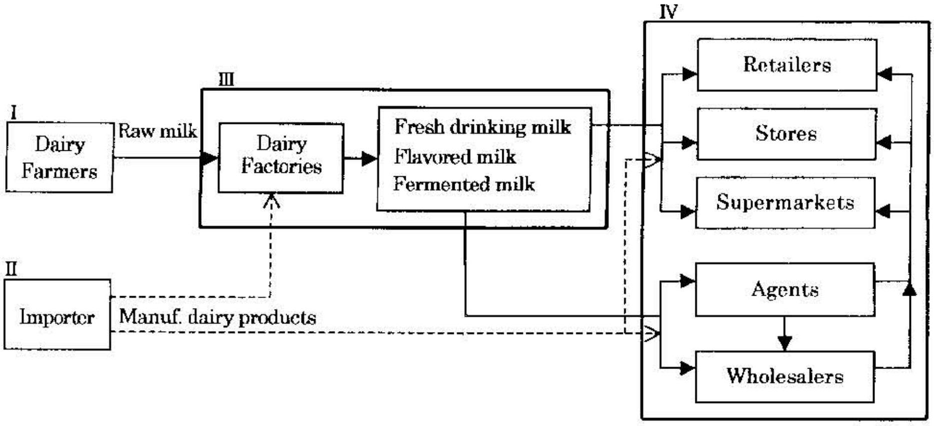


Fig. 1. Manufacturing and marketing routes of milk

Table 1. Milk consumption in Taiwan

(Unit: raw milk basis, Mt.)

Year	Population 1000 persons (1)	Domestic raw milk ton (2)	Import dairy products ton (3)	Total consumption ton (4)=(2)+(3)	Ave. milk consumption per person kg.(5)=(4)/(1)	Self supporting share in total consumption (6)=(2)/(4)*100%
1978	17102	44615	459513	504128	29.48	8.85
1979	17375	44418	474460	518878	29.86	8.56
1980	17619	47740	508810	556550	31.59	8.58
1981	17953	50154	574313	624467	34.78	8.03
1982	18270	55859	610373	666232	36.47	8.38
1983	18733	58022	718947	776969	41.48	7.47
1984	19013	66933	723822	790755	41.59	8.46
1985	19258	87879	705101	792980	41.18	11.08
1986	19455	109723	827398	937121	48.17	11.71
1987	19673	144390	775678	920068	46.77	15.69
1988	19904	173407	836895	1010302	50.76	17.16
1989	20107	172421	883770	1056191	52.53	16.32
1990	20353	203830	869057	1072887	52.71	19.00
1991	20557	225656	1041907	1267563	61.66	17.80
1992	20752	246281	1113848	1360129	65.54	18.11
1993	20944	278476	*1180106	1458582	69.64	19.09
1994	21126	289574	1186702	1476276	69.88	19.62
1995	21304	317806	1245053	1562859	73.36	20.33
1996	21520	315927	1150482	1466409	68.14	21.54
1997	21743	330469	1182416	1512885	69.58	21.84

Source: (1) Taiwan Statistical Data Book
(2) Agricultural Year Book 1997, P.D.A.F.
(3) Monthly Statistics of Exports and Imports, M.O.F.

Raw milk basis: fresh drinking milk×1, evaporated or condensed×2.2, powder or block×9, butter×20, cheese and curd×9

* The figures of this coloum from the year of 1993 to 1997 are estimated.

structural changes in Taiwanese dairy industry. (2) Then we try to find out all possible inconsistencies between the forecasted future situation and the practical structure of Taiwanese dairy industry in future. (3) Finally, we plan to make reasoning about the change of the situation of Taiwanese dairy industry in the future. In this paper, we utilize the raw milk trade flow between dairy farmers and dairy factories to estimate all of raw milk demand and supply in Taiwan. The method is to estimate supply and demand functions and to use those functions to develop the traditional single–product spatial equilibrium model assuming perfect competition. The usefulness of the model is demonstrated in the raw milk interregional market in Taiwan to pursue the equilibrium solution under perfect competition and to forecast the future raw milk supply, demand and prices. As a result, we discuss the possible development directions for both dairy farmers and factories and problems dairy industry may meet under liberalization pressure.

THEORETICAL MODEL AND APPLICATION

The spatial equilibrium model with intermediate products developed in this paper is static and involves partial equilibrium. It assumes perfect competition and homogeneous product. It also considers that there are no structural changes in supply and demand in the transition from a starting position to the new equilibrium, that is, prices and quantities are determined along supply and demand functions which remain unchanged in the basic model.

Applying econometric models, we can obtain both 14 producing counties' supply functions and 33 dairy factories' demand functions of raw milk as following analysis. Consequently, with linear supply and demand functions as well as unit transportation cost of raw milk, the objective function of the maximization problem to be solved for equilibrium solutions becomes a quadratic expression. In the presence of linear constraints, the problem can be solved by quadratic programming method. As a result, we can obtain the equilibrium solutions of raw milk supply, demand, trade flows and prices.

Raw milk supply functions for 14 raw milk producing counties

1. Distribution of dairy farms

Although Taiwanese self–sufficiency rate of dairy products is only around 20 percent, declines in the number of dairy farms but increases in milk production per farm causes the increases in total raw milk production in recent years. In this paper, we grouped 14 raw milk producing counties into 4 areas which are north, middle, south and east as shown in Table 2 according to the general division of Taiwan agricultural area. It is shown in Figure 2 that the distribution of Taiwanese dairy farms concentrates in the middle and south of Taiwan. Also it is clearly indicated in Table 2 that average scale per farm in south and east parts of Taiwan is larger than those in north and middle parts due to the higher density of population in north and middle and the cheaper land price in south and east.

2. The method of raw milk quota and price decision

From the year of 1983, Industrial Development Bureau (IDB) of Ministry Of Economics Affairs began to decide the distribution of each factory's receiving raw milk,

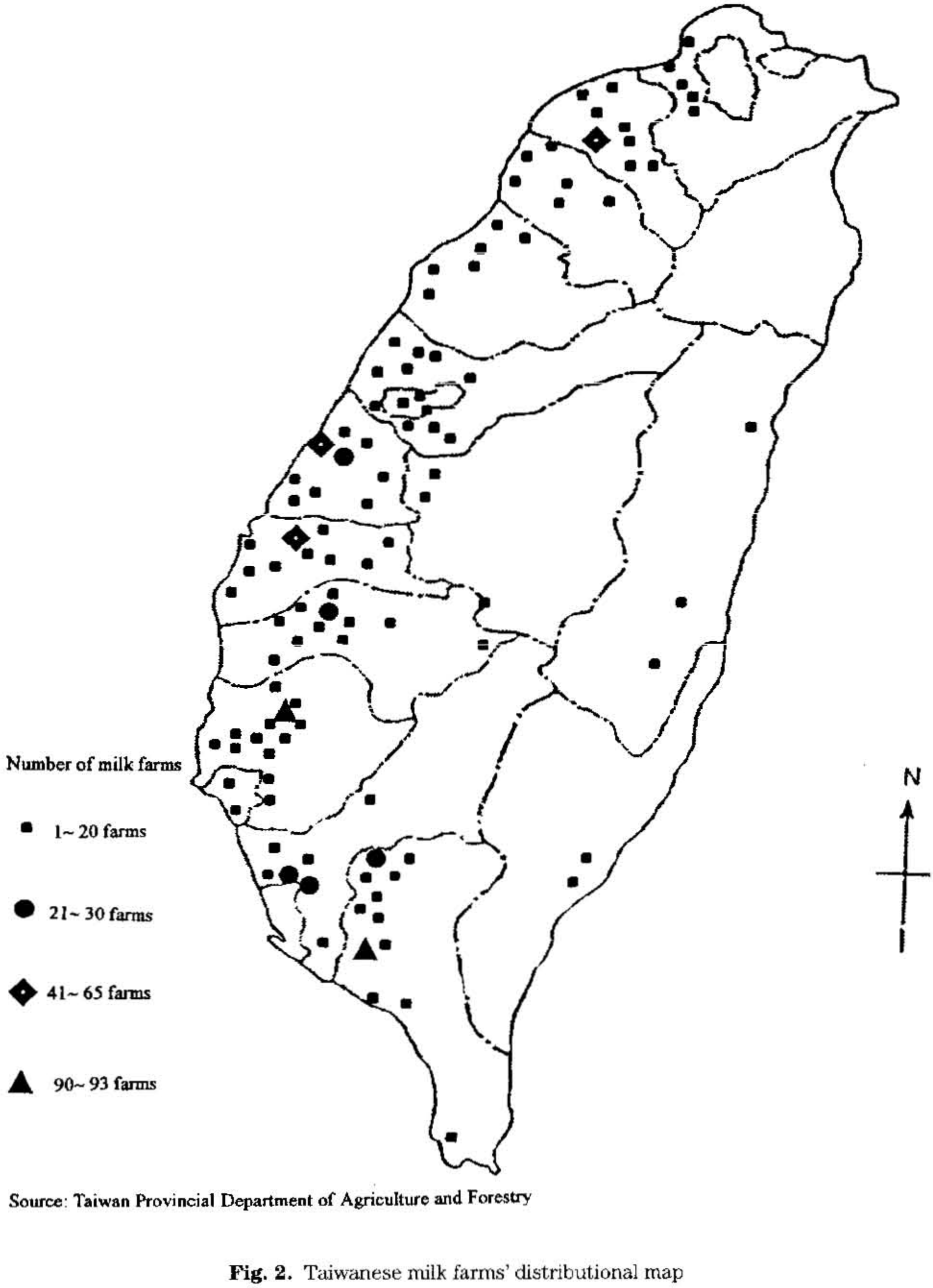


Fig. 2. Taiwanese milk farms' distributional map

Table 2. 1996 Distribution and scale of Taiwanese dairy farms

	1. Taipei	2. Taoyuan	3. Hsinchu	4. Miaoli	North (1~4)	
No. of farms	15	69	20	58	162(16.82%)	
Production	5411	20141	7459	15596	48607(15.39%)	
Ave.ton/Farm	361	292	373	269	300	
	5. Taichung	6. Changhwa	7. Nantou	8. Yunlin	9. Chiayi	Middle (5~9)
No. of farms	32	147	15	110	79	383(39.77%)
Production	7960	48480	3883	32342	21819	114484(36.24%)
Ave.ton/Farm	249	330	259	294	176	299
	10. Tainan	11. Kaoshiung	12. Pintung	South (10~12)		
No. of farms	168	72	152	392 (40.71%)		
Production	72336	22474	48117	142927(45.25%)		
Ave.ton/Farm	431	312	317	365		
	13. Taitung	14. Hwalien	East (13~14)			
No. of farms	12	14	26 (2.70%)			
Production	4233	5625	9858 (3.12%)			
Ave.ton/Farm	358	402	379			

Unit of production: Mt.
Source: Taiwan Provincial Department of Agriculture and Forestry, 1996 Sept. Survey and Statistics of Dairy Farms in Taiwan

and Taiwan Provincial Department of Agriculture and Forestry determined the area where each factory should be in charge to purchase raw milk according to IDB milk distribution standards of factories.

In another side of raw milk purchasing price of factories, it is not determined through direct market mechanism but decided indirectly through negotiation by some groups representatives such as dairy farmers, dairy factories, research institutions and government. Then factories can adjust the standard purchasing price to the actual raw milk purchasing price according to the raw milk fat rate, specific gravity, temperature, sediment and bacterium number. On the other hand, most of the factories pay all of the transportation cost between producing farms to factories.

3. Supply functions

The logarithmic linear equation for each raw milk producing area is specified as follows.

(1) $SQ^A_t=F(SQ^A_{t-1}, SP^A_t, D^B, u^A_t)$

Where SQ^A_t=total supply of raw milk in producing area, where A=N: north of Taiwan, A=M: middle of Taiwan, A=S: south of Taiwan, A=E: east of Taiwan, t=the annual observation, $SP^A=P_0/P_1$ in producing area (Figure 3), D^B=Dummy variables to measure regional (county) effects, when A=N, B=1~3; when A=M, B=1~4; when A=S, B=1~2; when A=E, B=1; u^A=disturbance term for area A.

During the 1970s, the Nerlove partial adjustment model and the polynomial distributed lag model were often used in estimating milk supply response. Chen, Courtney, and Schmitz used a polynomial lag model to determine milk supply response in California with quarterly data. Hammond used both the Nerlove partial-adjustment model and a polynomial lag model with annual data to estimate milk supply functions for major U.S. producing areas. In a 1978 study of the California dairy industry, Milligan rejected both lag specifications in favor of direct estimation of lagged profitability parameters. A bimonthly (six per year) series of data on profit margins was used (Milligan, 1978). In this paper, we combine and apply both the Nerlove partial–adjustment and Milligan model with annual data to estimate milk supply function for Taiwanese raw milk producing areas.

In this study, annual observations for 1992–1997 are used to obtain single equation estimates of raw milk supply response for four areas in Taiwan, respectively. The availability of production cost data and the other relative data facilitate the specification of return over variable costs as the measure of profitability and a detailed analysis of the lagged response to raw milk production.

According to the Nerlove partial–adjustment theory (Nerlove, 1956), it is necessary to assume some relation between desired and actual production as equation (2) in order to make the operational hypotheses. (2) $Q_t - Q_{t-1} = \lambda (Q^*_t - Q_{t-1})$ where Q^*_t=desired production, Q_t=actual production, and λ=a constant. (2) states that the change in actual production is proportional to the difference between desired and actual production.

Here, we also apply the profit maximizing theory to find a point on the production set with the maximal level of profits — this is a point where the vertical axis intercept of the associated isoprofit line is maximal. By inspection it can be seen that such an optimal point can be characterized by the tangency condition as follows (refer to Figure 3).

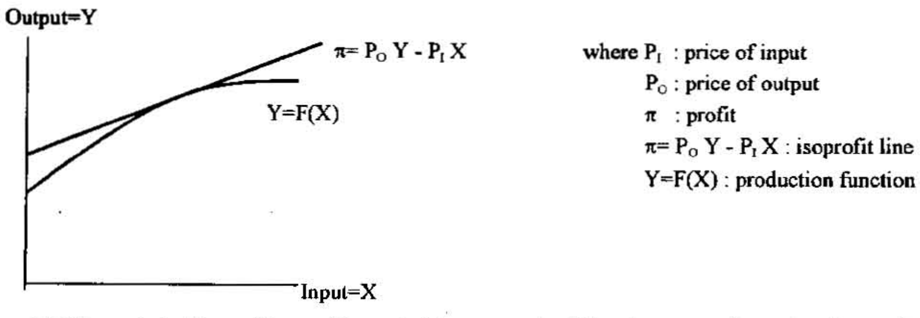
$\pi = P_o Y - P_I X$ $\quad\quad$ $d\pi/dX = P_o F'(X) - P_I = 0$

$F'(X) = P_I/P_o$ $\quad\quad$ therefore $X = G(P_o/P_I)$

From this, we can realize that producing quantity is decided by both input and output price. Therefore, in our model of supply equations, we designate the selling price of raw milk over the producing cost as the predetermined variable of SP.

4. The result and analysis

Annual time series data for counties which belong to each area in Taiwan is studied



Profit maximization. The profit-maximizing amount of input occurs where the slope of the isoprofit line (P_I / P_O) equals the slope of the production function.

Fig. 3. Conceptual representation of profit maximization

Table 3. Raw milk trade flows from 14 supply regions to 33 factories and prices in 1996

Unit: ton and NT$/kg

Factory / Area(Hsien)	1[a]	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	1[b]	8	11	2	10	2	9	2	5	4	5	5	2	2	11	13	5
1[c] Taipei	2,580					1,062		931									
2 Taoyuan						16,442		3,147					177	347			
3 Hsinchu						6,998											
4 Miaoli				631		940				11,640		86					
5 Taichung						1,404			200		1,370		370				1,290
6 Changhwa				11,223		657			22,455			773					5,153
7 Nantou				1,184									1,497				
8 Yunlin	24,040						5,522										
9 Chiayi				7,135			9,058						2,653				
10 Tainan	8,873				26,394		29,407						5,735				
11 Kaohsiung		11,260			965		4,707								1,547		
12 Pingtung			34,909		592												
13 Taitung																3,928	
14 Hwalien					4,426												
Total	35,494	11,260	34,909	20.173	32,376	27,503	48,694	4,078	22,655	11,640	1,370	859	10,432	347	1,547	3,928	6,442
%	11.3%	3.6%	11.1%	6.4%	10.3%	8.8%	15.5%	1.3%	7.2%	3.7%	0.4%	0.3%	3.3%	0.1%	0.5%	1.3%	2.1%

Factory / Area(Hsien)	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	Total	%
	6	11	12	8	14	5	14	6	1	3	11	5	6	7	4	11		
1 Taipei									631								5.204	1.7%
2 Taoyuan																	20,112	6.4%
3 Hsinchu										432							7,430	2.4%
4 Miaoli	523													1,486	291		15,596	5.0%
5 Taichung									2,973			187					7,794	2.5%
6 Changhwa	1,665			2,058				376	1,097				38	2,952			48,448	15.4%
7 Nantou				457		200								544			3,883	1.2%
8 Yunlin				2,777													32,339	10.3%
9 Chiayi				1,045					1,645		215						21,752	6.9%
10 Tainan																1,701	72,111	23.0%
11 Kaohsiung			237								3,758						22,473	7.2%
12 Pingtung		2,187	9,646								173						47,507	15.1%
13 Taitung																	3,928	1.3%
14 Hwalien					503	0	587	0									5,516	1.8%
Total	2,188	2,187	9,883	6,338	503	200	587	376	6,346	432	4.145	187	38	4,983	291	1,701	314,094	100%
%	0.7%	0.7%	3.1%	2.0%	0.2%	0.1%	0.2%	0.1%	2.0%	0.1%	1.3%	0.1%	0.0%	1.6%	0.1%	0.5%	100%	

Supply Regions	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Pooled Price	19.27	19.79	19.85	18.42	19.51	18.92	19.28	18.8	19.71	19.64	19.1	19	20.63	19.5

Factories	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Paid Price[d]	18.70	18.70	18.70	19.79	19.79	19.84	19.84	19.68	18.52	18.12	19.01	17.10	19.55	18.60	19.15	20.63	18.97
Factories	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	
Paid Price[d]	18.63	19.25	20.18	18.06	18.78	17.20	17.71	19.10	20.03	20.05	19.35	17.37	19.10	19.17	19.00	19.15	

Source: Taiwan Provincial Department of Agriculture and Forestry

[a] The number from 1 to 33 represents the factories, here we do not include the name of factories (company) because of privacy.

[b] The number in this raw indicates the area which factory is located in, and same as the number represented in the column of Area.

[c] The number of area from 1 to 4 indicates the north of Taiwan.
The number of area from 5 to 9 indicates the middle of Taiwan.
The number of area from 10 to 12 indicates the south of Taiwan.
The number of area from 13 to 14 indicates the east of Taiwan.

[d] This price does include tranportation cost.

Table 4. Raw milk supply response coefficients for 4 areas of Taiwan, 1992–1997

	Coefficients for Predetermined Variables								
Dependent Variable	Constant	SQ_{t-1}	SP	D1	D2	D3	D4	R^2	Price Elasticity
SQ^N_t	2.6882 [a](3.27)**	0.6591 (6.73)**	0.4951 (3.02)**	0.4471 (3.70)**	0.0838 (2.42)*	0.4099 (3.70)**	–	0.992	1.4524
SQ^M_t	3.8201 (5.16)**	0.5619 (6.61)**	0.2401 (1.84)	0.8106 (5.53)**	−0.3039 (−4.72)**	0.6330 (5.32)**	0.4255 (5.15)**	0.998	0.5481
SQ^S_t	2.2405 (3.16)**	0.7926 (12.00)**	0.2242 (1.65)	0.2509 (−3.38)**	−0.0569 (−1.31)	–	–	0.995	1.0809
SQ^E_t	4.3773 (4.56)**	0.4308 (3.54)**	0.6607 (3.40)**	0.1844 (3.58)**	–	–	–	0.975	1.1608

[a]t–values are in parentheses
Double and single asterisks imply significance at the 1% and 5% levels, respectively.
Logarithmic values of variables (exclude dummy variables) are used for regression analyses.

Table 5. Raw milk supply equations of 14 regions
Unit: 1000 ton, NT$/kg.

Q1 =	−2.354	+	0.392	P1
Q2 =	−9.099	+	1.476	P2
Q3 =	−3.362	+	0.544	P3
Q4 =	−7.056	+	1.230	P4
Q5 =	3.522	+	0.219	P5
Q6 =	21.894	+	1.404	P6
Q7 =	1.755	+	0.110	P7
Q8 =	14.614	+	0.941	P8
Q9 =	9.830	+	0.605	P9
Q10 =	−5.834	+	3.969	P10
Q11 =	−1.818	+	1.269	P11
Q12 =	−3.843	+	2.697	P12
Q13 =	−0.632	+	0.221	P13
Q14 =	−0.887	+	0.329	P14

We use the following equation to estimate supply equations:

$$Q = (1-e)\,\overline{Q} + e\,(\overline{Q}/\overline{P})\,P$$

where e : price elasticity of supply
$\overline{Q}$: supply quantity in 1996
$\overline{P}$: market price in 1996

by multiple regression analysis, which result for respective area is shown in Table 4. The result shows the equation (1) in respective 4 areas contains the variables that explained at least 97 percent of raw milk supply variations during 1992–1997. In north area, the average effect of a one percent increase in price change has been a 1.45 percent increase in raw milk supply which is highest among 4 areas. In contrast, in middle area there has been a 0.55 percent increase which is lowest. Based on the data of raw milk supply price elasticity presented in Table 4, as well as the regional price and quantity observations of

1996 in Table 3, linear marginal cost functions for each region are specified in Table 5.

Raw milk demand functions for 33 dairy factories

1. Distributions of dairy factories

In Figure 4, showing the distribution of all 33 Taiwanese raw milk manufacturing factories in 1996, it is obvious that most of factories are located in north and middle parts of Taiwan since milk consumption is also concentrated in those parts and this causes some transportation problems between raw milk producers and factories (Lin and Kawaguchi, 1998). Based on the data of Table 6, we can know that the three leading dairy companies account for more than 68 percent of total raw milk processing in Taiwan. We can reason that some small dairy factory will be sacrificed under future severer competitions if Taiwan dairy companies behave as high density oligopolists.

2. Demand functions

The logarithmic linear equation for raw milk factory is specified as follows.

(3) $QD=F(PD, I, D_N, u)$

Where QD=total raw milk demand of factory; PD=price paid by factory; I=per capita personal annual income; D_N=Dummy variables to measure area (north, middle, south, and east) effects, when N=1～3; D_N=Dummy variables to measure year (year of 1996=1, other years=0) effects, when N=4; u=disturbance term.

The factory demand is the endogenous variable and factory paid price is the predetermined variable for the raw milk demand equation. Several other forces may also influence the position of factory demand curve for raw milk. Since raw milk demand for factory is derived from consumer demand for fluid milk products, the factors influencing consumer demands for milk products are undoubtedly reflected through the marketing system to affect factory's expectations about the quantity of each wholesale cut demanded at various wholesale prices. Primary among these factors are the level of consumer income and the size of the consuming population, which were introduced directly into the demand equation to estimate the influence of changes in these variables. Because Taiwan population and per capita personal income have been highly correlated (r=0.97), a per capita income variable was specified in the model to account for the effect of both income and population effects.

Table 6. Raw milk processing shares among top dairy companies

Year	1992	1993	1994	1995	1996	1997
Number of dairy company	30	31	30	30	29	28
Total processing quantity (100 ton)	2417	2744	2853	3152	3141	3271
Top 3's dairy company share	1566 (64.79%)	1754 (63.92%)	1818 (63.72%)	2087 (66.21%)	2104 (66.99%)	2233 (68.27%)
Top 10's dairy company share	2145 (88.75%)	2412 (87.90%)	2514 (88.12%)	2818 (89.40%)	2841 (90.45%)	2983 (91.20%)

Source: Taiwan Provincial Department of Agriculture and Forestry, 1992–1997 Survey and Statistics of Dairy Factories in Taiwan

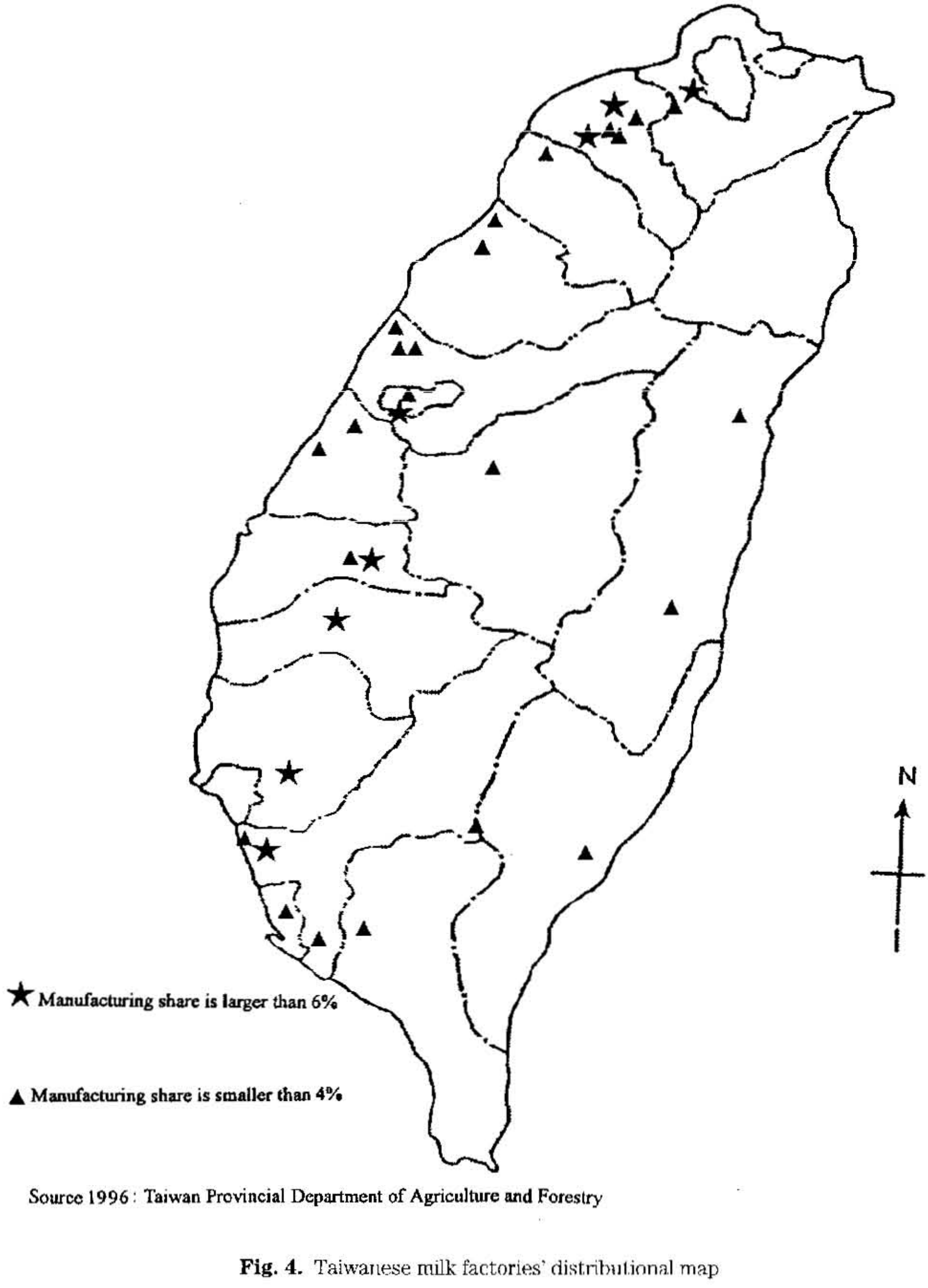


Fig. 4. Taiwanese milk factories' distributional map

Demand fluctuations among areas in raw milk marketing system are thought to occur and be affected by climates, geographical features and land use patterns. Consequently, dummy variables associated with each area were specified to account for area demand shifts due to otherwise unquantified variables in the demand equations. In addition, in 1996, the raw milk supply did not increase as usual because the mad cow disease of BSE (Bovine Spongiform Encephalopathy) occurred in Europe which led to prohibit the import of cow from Europe in Taiwan. Therefore, we use dummy variables to measure year (year of 1996=1, other years=0) effects.

3. The result and analysis

Annual time series data covering four areas in Taiwan are studied by multiple regression analysis, which result is shown in Table 7. The result shows the equation (3) contains the variables that explained approximately 99 percent of raw milk supply variations during 1992–1997. The average effect of one percent increase in price change has been a 0.71 percent reduction in raw milk demand among 33 factories. In another side, the average effect of 1 percent increase in income change has been a 1.15 percent increase in raw milk demand. Based upon the data of raw milk demand price elasticity and income elasticity indicated in Table 7, as well as the price paid by factories and observations in Table 3, linear demand functions for each factories are specified in Table 8.

Application of spatial price equilibrium (SPE) model

Spatial equilibrium analysis is well known as a quantitative method to analyze the structure of interregional competition of various products. This new approach to the spatial pricing and allocation problem began at development of activity analysis model by Koopmans (1949) and Dantzing (1951). Stephen Enke (1951) formulated the problem concerning competitive equilibrium among spatially separated markets and suggested how a solution in the case of linear market functions might be obtained by electric analogue. Samuelson (1952) showed how this purely descriptive problem in non–normative economics can be cast mathematically into a maximum problem and relates the Enke specification to a standard problem in linear programming, the so–called Koopmans–Hitchcock minimum–transport–cost problem. Operational effectiveness of the mathematical programming approach for the solution of market equilibrium over space was significantly enhanced by the Takayama and Judge (1964) quadratic programming formulation of spatial price and allocation models, and Takayama and Judge (1971)

Table 7. Raw milk demand response coefficients for Taiwanese dairy factories, 1992–1997

Coefficients for Predetermined Variables

Dependent Variable	Constant	Price Elasticity	Income Elasticity	D1	D2	D3	D4	R^2
QD_{it}	2.6882 (–0.28)[a]	−0.714 (–3.57)**	1.148 (6.33)**	−0.019 (−0.62)	−0.339 (−10.85)**	−3.152 (−99.97)**	−0.082 (−2.16)*	0.999

[a]t–values are in parentheses

Double and single asterisks imply significance at the 1% and 5% levels, respectively.

Logarithmic values of variables (exclude dummy variables) are used for regression analyses.

Table 8. Raw milk demand functions of 33 dairy factories in1996
Unit: 1000 ton, NTS/kg.

D1	=	60.8367	−1.3552	DP 1	+	0.0001496	(I 1	− I_0)
D2	=	19.2996	−0.4299	DP 2	+	0.0000475	(I 2	− I_0)
D3	=	59.8340	−1.3329	DP 3	+	0.0001471	(I 3	− I_0)
D4	=	34.5765	−0.7278	DP 4	+	0.0000850	(I 4	− I_0)
D5	=	55.4925	−1.1681	DP 5	+	0.0001364	(I 5	− I_0)
D6	=	47.1401	−0.9898	DP 6	+	0.0001159	(I 6	− I_0)
D7	=	83.4615	−1.7524	DP 7	+	0.0002052	(I 7	− I_0)
D8	=	6.9897	−0.1480	DP 8	+	0.0000172	(I 8	− I_0)
D9	=	38.8307	−0.8734	DP 9	+	0.0000955	(I 9	− I_0)
D10	=	19.9510	−0.4587	DP 10	+	0.0000491	(I 10	− I_0)
D11	=	2.3482	−0.0515	DP 11	+	0.0000058	(I 11	I_0)
D12	=	1.4723	−0.0359	DP 12	+	0.0000036	(I 12	− I_0)
D13	=	17.8804	−0.3810	DP 13	+	0.0000440	(I 13	− I_0)
D14	=	0.5948	−0.0133	DP 14	+	0.0000015	(I 14	− I_0)
D15	=	2.6516	−0.0577	DP 15	+	0.0000065	(I 15	− I_0)
D16	=	6.7326	−0.1359	DP 16	+	0.0000166	(I 16	− I_0)
D17	=	11.0416	−0.2431	DP 17	+	0.0000271	(I 17	− I_0)
D18	=	3.7502	−0.0839	DP 18	+	0.0000092	(I 18	− I_0)
D19	=	3.7485	−0.0811	DP 19	+	0.0000092	(I 19	− I_0)
D20	=	16.9395	−0.3497	DP 20	+	0.0000417	(I 20	− I_0)
D21	=	10.8633	−0.2506	DP 21	+	0.0000267	(I 21	− I_0)
D22	=	0.8621	−0.0191	DP 22	+	0.0000021	(I 22	− I_0)
D23	=	0.3428	−0.0083	DP 23	+	0.0000008	(I 23	− I_0)
D24	=	1.0061	−0.0237	DP 24	+	0.0000025	(I 24	− I_0)
D25	=	0.6445	−0.0141	DP 25	+	0.0000016	(I 25	− I_0)
D26	=	10.8770	−0.2262	DP 26	+	0.0000267	(I 26	− I_0)
D27	=	0.7404	−0.0154	DP 27	+	0.0000018	(I 27	− I_0)
D28	=	7.1045	−0.1529	DP 28	+	0.0000175	(I 28	− I_0)
D29	=	0.3205	−0.0077	DP 29	+	0.0000008	(I 29	− I_0)
D30	=	0.0651	−0.0014	DP 30	+	0.0000002	(I 30	− I_0)
D31	=	8.5409	−0.1856	DP 31	+	0.0000210	(I 31	− I_0)
D32	=	0.4988	−0.0109	DP 32	+	0.0000012	(I 32	− I_0)
D33	=	2.9155	−0.0634	DP 33	+	0.0000072	(I 33	− I_0)

We use the following equation to estimate demand equations:
$D=[D_0(1-\beta)+\gamma(D_0/I_0)(I-I_0)]+\beta(D_0/P_0)P$
where β: price elasticity, γ: income elasiticity
D_0: demand in 1996 , P_0: price in 1996
I_0: income in 1996

presented two versions of the spatial pricing and allocation models: a perfectly competitive market model and a monopoly model. Hashimoto (1985) presented a SPE model that describes behavior of an oligopolistic market, characterized as a Nash non–cooperative game.

Recently the SPE model has been widely adopted either in theoretical advances or in empirical applications. Several approaches have been taken to study the implications of trade liberalization and the formation of regional blocs on the agricultural sector. The approach taken in this paper is based on the mathematical programming models developed by Samuelson (1952) and Takayama and Judge (1964, 1971), to analyze the allocation of raw milk under perfectly competitive market.

By developing the economic theory and explaining the economic reason, the equilibrium condition of the problem can be derived. Making use of the estimated linear regional demand and marginal cost functions, the equilibrium condition of interconnected competitive markets is either expressed as optimal condition of a Quadratic Programming Problem (QPP)or expressed as a Linear Complementary Problem (LCP). Given this QPP or LCP formulation, a computational algorithm is specified to obtain directly and efficiently the competitive equilibrium solution for regional prices and interregional flows.

2. Model Description

It is assumed there are n supply areas and each of them produces one given commodity. And there are m regions (factories) that demand this commodity. The commodity is assumed to be traded freely from any supply area to any consuming region; moreover, traded freely by transmission dealers among any consuming regions.

The notation listed below will be used in this paper.

Y_j = raw milk demand in factory j (j = 1, 2,........, m), m=33
X_i = raw milk supply in producing county i (i = 1, 2,.......,n), n=14
X_{ij} = the shipped amount from supply county i to factory j.
PD_j = price paid in factory j.
MC_i = marginal cost in supply county i.
FC_i = fixed cost portion of total cost in supply county i.
VC_i = variable cost portion of total cost in supply county i.
MR_i = marginal revenue in supply county i.
NSP = net social payoffs.
α_j = intercept value of the inverse linear demand function in factory j
β_j = slope coefficient of the inverse linear demand function in factory j
γ_i = intercept value of the linear marginal production cost function in supply area i
η_i = slope coefficient of the linear marginal production cost function in supply area i
t_{ij} = unit transportation cost from supply area i to factory j.
PD_j $= \alpha_j - \beta_j Y_j$ inverse linear demand function in factory j
MC_i $= \gamma_i + \delta_i X_i$ linear marginal production cost function in supply area i

The model is specified as follows. Here we use quantity formulation, in which the decision variables are quantities, though we can alternatively use equivalent price formulation, in which the decision variables are prices.

Maximize

$$NSP = \sum_j \int (\alpha_j - \beta_j Y_j) dY_j - \sum_i \left[\int (\gamma_i + \delta_i X_i) dX_i + FC_i\right] - \sum_i \sum_j t_{ij} X_{ij}$$

subject to $\sum_i X_{ij} \geq Yj$ for all j, $X_i \geq \sum_j X_{ij}$ for all i, and all variables are non–negative.

Lagrangean of this maximization problem is specified as follows.

$$Ln = NSP + \sum_j P_j \left(\sum_i X_{ij} - Y_j\right) + \sum_i \varphi_i \left(X_i - \sum_j X_{ij}\right)$$

where P_j and φ_i are the corresponding nonnegative Lagrangean multipliers.

The Kuhn–Tucker conditions associated with this problem are both necessary and sufficient conditions for an optimal solution, under the assumptions of differentiability and concavity of the objective function, and in the presence of linear constraints. The Kuhn–Tucker conditions are specified as follows.

$$(4.a)\quad \frac{\partial L_n}{\partial X_{ij}} = P_j - t_{ij} - \varphi_i \le 0 \quad ; \; X_{ij} \ge 0 \quad ; \; \frac{\partial L_n}{\partial X_{ij}} X_{ij} = 0 \qquad \text{for all i and j,}$$

$$(4.b)\quad \frac{\partial L_n}{\partial Y_j} = \alpha_j - \beta_j Y_j - P_j \le 0 \quad ; \; Y_j \ge 0 \quad ; \; \frac{\partial L_n}{\partial Y_j} Y_j = 0 \qquad \text{for all j,}$$

$$(4.c)\quad \frac{\partial L_n}{\partial X_i} = -(\gamma_i + \delta_i X_i) + \varphi_i \le 0 \quad ; \; X_i \ge 0 \quad ; \; \frac{\partial L_n}{\partial X_i} X_i = 0 \qquad \text{for all i,}$$

$$(4.d)\quad \frac{\partial L_n}{\partial P_j} = \sum_i X_{ij} - Y_j \ge 0 \quad ; \; P_j \ge 0 \quad ; \; \frac{\partial L_n}{\partial P_j} P_j = 0 \qquad \text{for all j,}$$

$$(4.e)\quad \frac{\partial L_n}{\partial \varphi_i} = X_i - \sum_j X_{ij} \ge 0 \quad ; \; \varphi_i \ge 0 \quad ; \; \frac{\partial L_n}{\partial \varphi_i} \varphi_i = 0 \qquad \text{for all i,}$$

The Kuhn–Tucker conditions (4) imply the following corresponding statements (5):

$$(5.a)\quad X_{ij} > 0 \;\Rightarrow t_{ij} = P_j - \varphi_i \quad , \quad \frac{\partial L_n}{\partial X_{ij}} < 0 \;\Rightarrow\; X_{ij} = 0$$

$$(5.b)\quad Y_j > 0 \;\Rightarrow P_j = \alpha_j - \beta_j Y_j \quad , \quad \frac{\partial L_n}{\partial Y_j} < 0 \;\Rightarrow\; Y_j = 0$$

$$(5.c)\quad X_i > 0 \;\Rightarrow \varphi_i = \gamma_i + \delta_i X_i \quad , \quad \frac{\partial L_n}{\partial X_i} < 0 \;\Rightarrow\; X_i = 0$$

$$(5.d)\quad P_j > 0 \;\Rightarrow \sum_i X_{ij} = Y_j \quad , \quad \frac{\partial L_n}{\partial P_j} > 0 \;\Rightarrow\; P_j = 0$$

$$(5.e)\quad \varphi_i > 0 \;\Rightarrow X_i = \sum_j X_{ij} \quad , \quad \frac{\partial L_n}{\partial \varphi_i} > 0 \;\Rightarrow\; \varphi_i = 0$$

The Lagrangean multipliers are interpreted as shadow prices in competitive equilibrium. Namely φ_i is interpreted as producer price in supply region i, and P_j is interpreted as market price in factory j. Statement (4.a) and (5.a) indicate that the price difference between supply and demand regions (factories) is less than or equal to the unit transportation cost. Whenever trade takes place, the price difference is exactly equal to the unit transportation cost. Statement (4.b) and (5.b) imply that if there is any demand in region j, the market price equals the demand price in factory j. Statement (4.c) and (5.c) indicate that the producer price is equal to the marginal cost, whenever the

Table 9. Tableau of Kuhn–Tucker conditions

			PD1	PD2	PD3	···	PD33	MC1	MC2	MC3	···	MC14	X1.1	X2.1	X3.1	···	X14.1	X1.2	X2.2	X3.2	···	X14.2	X1.3	X2.3	X3.3	···	X14.3	···	X1.33	X2.33	X3.33	···	X14.33
	$-\alpha 1/\beta 1$	Vp1	$-1/\beta 1$										-1	-1	-1	···	-1																
	$-\alpha 2/\beta 2$	Vp2		$1/\beta 2$														-1	-1	-1	···	-1											
B	$-\alpha 3/\beta 3$	Vp3			$-1/\beta 3$																		1	-1	-1	···	-1						
	:	:				···																						···					
	$\alpha 33/\beta 33$	Vp33					$-1/\beta 33$																						-1	-1	-1	···	-1
	$-\gamma 1/\delta 1$	Vm1						$-1/\delta 1$					1					1					1						1				
	$-\gamma 2/\delta 2$	Vm2							$-1/\delta 2$					1					1					1						1			
C	$-\gamma 3/\delta 3$	Vm3								$-1/\delta 3$					1					1					1						1		
	:	:									···					···					···					···						···	
	$-\gamma 14/\delta 14$	Vm14										$-1/\delta 14$					1					1					1						1
	t1.1	Y1.1	1					-1																									
	t2.1	Y2.1	1						-1																								
	t3.1	Y3.1	1							-1																							
	:	:	:								:																						
	t14.1	Y14.1	1									-1																					
	t1.2	Y1.2		1				-1																									
	t2.2	Y2.2		1					1																								
	t3.2	Y3.2		1						-1																							
	:	:		:							:																						
A	t14.2	Y14.2		1								-1																					
	t1.3	Y1.3			1			-1																									
	t2.3	Y2.3			1				-1																								
	t3.3	Y3.3			1					-1																							
	:	:			:						:																						
	t14.3	Y14.3			1							-1																					
	:	:																															
	t1.33	Y1.33					1	-1																									
	t2.33	Y2.33					1		-1																								
	t3.33	Y3.33					1			-1																							
	:	:					:				:																						
	t14.33	Y14.33					1					-1																					

Part A corresponds to formula (4.a), part B corresponds to formila (4.d), and part C corresponds to formula (4.e).
Vpj, Vmi and Yij are slack variables. All variables cannot be nagative, and satisfy the conditions $PjVpj = 0, \varphi_i Vmi = 0, XijYij = 0$.
To clearly present, PDj instead of Pj, and MCi instead φ_i.

production is positive.

Lastly, the remaining statements (4.d), (5.d) and (4.e), (5.e) reproduce the linear constraints of the optimization problem, implying the market clearing condition. In each region, production has to be greater than or equal to the domestic use plus exports to other regions (4.e), and consumption has to be less than or equal to domestic production plus imports from other regions (4.d). When the Lagrange multipliers (shadow prices) are positive, the conditions above hold with equality. On the other hand, if markets do not clear, then the shadow prices are equal to zero.

All these statements taken together characterize an equilibrium solution for the traditional spatial equilibrium problem in perfectly competitive market. The Kuhn–Tucker conditions in the case of Taiwanese raw milk market is formulated as in Table 9. In Table 9, the equality $P_j=\alpha_j-\beta_j Y_j$ and $\varphi_i=\gamma_i+\delta_i X_i$ are used to omit the variables Y_j and X_i, assuming Y_j and X_i are both positive in practice. The optimal solution is obtained by Quadratic Programming Method.

RESULT AND DISCUSSION

According to above quantitative method, we can solve perfectly competitive spatial equilibrium problem by utilizing estimated supply and demand functions as well as unit transportation cost of raw milk (Table 10). The result (Table 11) includes raw milk supply in each supply county, demand in each factory, trade flows, and prices in producing counties and factories. As long as trade takes place between producing county i and factory j, the difference between the price in factory j and the marginal production cost in county i is equal to the transportation cost. Otherwise, no trade occurs when price difference is smaller than transportation cost. This kind of price relation is the feature of perfectly competitive spatial equilibrium.

We also forecast the future situation of raw milk market in twenty years presented in Table 12~15 based on income increase and under the assumption of unchangeable demand and supply structure of raw milk. The average income increasing rate of last twenty years calculated is around five percent per year. Surely this rate would not be stable at five percent every year in real world, but to the objective of the study, it dose not matter to precisely forecast future situation. Therefore, we assume that income increases at five percent each year in twenty years, then raw milk supply and demand will increase as well as those prices will rise every year. Under this condition, what kind of problems dairy industry may face to, and how to solve them are future important issues of concern.

First, to take the example of factory's side, as above mentioned, we consider some factories, which raw milk demand increases even more than twice during twenty years, may have to purchase machines or enlarge facilities. On the other hand, some small factories may not compete with other big factories under the future more difficult environment. In fact, some small factories which share of total raw milk processing is under one percent shown in Table 16 had met the problem of shutting down or seriously decreasing on raw milk demand during past six years. On the other side of dairy farmers, if the trend is toward as the forecast of raw milk supply increase and price rise, farmers should consider some problems such as improvement of farm management and feeding technology and so on. Thus, production supply structure of raw milk may vary in some

Table 10. Unit raw milk transportation cost in 1996

Unit: NT$/ton

Factory / Area(Hsien)	1[a]	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1 Taipei	400	1200	1400	400	1400	400	1200	400	1000	900	1000	1000	400	400	1400	1400	1000
2 Taoyuan	400	1000	1400	400	1200	400	1200	400	900	650	900	900	400	400	1400	1400	900
3 Hsinchu	650	900	1200	650	1200	650	1000	650	650	400	650	650	650	650	1200	1400	650
4 Miaoli	900	900	1200	650	1000	650	900	650	650	400	650	650	650	650	1200	1400	650
5 Taichung	1000	650	1000	900	900	900	650	900	400	650	400	400	900	900	1000	1400	400
6 Changhwa	1000	400	1000	900	900	900	650	900	400	650	400	400	900	900	1000	1400	400
7 Nantou	1000	400	1000	1000	900	1000	650	1000	650	900	650	650	1000	1000	1000	1400	650
8 Yunlin	1200	400	900	1000	650	1000	400	1000	650	900	650	650	1000	1000	900	1400	650
9 Chiayi	1200	400	650	1200	650	1200	400	1200	650	900	650	650	1200	1200	650	1400	650
10 Tainan	1400	650	400	1200	400	1200	650	1200	900	1000	900	900	1200	1200	400	1400	900
11 Kaohsiung	1400	900	400	1400	400	1400	650	1400	1000	1200	1000	1000	1400	1400	400	1200	1000
12 Pingtung	1400	900	400	1400	400	1400	650	1400	1000	1200	1000	1000	1400	1400	400	1200	1000
13 Taitung	1400	1400	1200	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1200	0	1400
14 Hwalien	1400	1400	1400	1400	1400	1400	1400	1400	1200	1400	1200	1200	1400	1400	1400	1200	1200

Factory / Area(Hsien)	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
1 Taipei	1000	1400	1400	1200	1400	1000	1400	1000	400	650	1400	1000	1000	1000	900	1400
2 Taoyuan	900	1400	1400	1000	1400	900	1400	900	400	650	1400	900	900	1000	650	1400
3 Hsinchu	650	1200	1200	900	1400	650	1400	650	650	400	1200	650	650	900	400	1200
4 Miaoli	650	1200	1200	900	1400	650	1400	650	900	400	1200	650	650	900	400	1200
5 Taichung	400	1000	1000	650	1200	400	1200	400	1000	650	1000	400	400	650	650	1000
6 Changhwa	400	1000	1000	400	1400	400	1400	400	1000	650	1000	400	400	650	650	1000
7 Nantou	650	1000	1200	400	1400	650	1400	650	1000	900	1000	650	650	400	900	1000
8 Yunlin	400	900	900	400	1400	650	1400	400	1200	900	900	650	400	400	900	900
9 Chiayi	650	650	650	400	1400	650	1400	650	1200	1000	650	650	650	650	900	650
10 Tainan	900	400	400	650	1400	900	1400	900	1400	1200	400	900	900	900	1000	400
11 Kaohsiung	1000	400	400	900	1200	1000	1200	1000	1400	1200	400	1000	1000	1000	1200	400
12 Pingtung	1000	400	400	900	1200	1000	1200	1000	1400	1200	400	1000	1000	1200	1200	400
13 Taitung	1400	1200	1200	1400	1200	1400	1200	1400	1400	1400	1200	1400	1400	1400	1400	1200
14 Hwalien	1400	1400	1400	1400	0	1200	0	1400	1400	1400	1400	1200	1400	1400	1400	1400

Source: 1998 Taiwan Walking Internet, for data of road distances.
The data of unit transportation cost is through factories survey.
[a] The number from 1 to 33 represents the factories, here we do not include the name of factory (company) because of privacy.
When the factory is in the same place of supply area (factory owns its own dairy farms) we consider that the unit raw milk transportation cost is "0".

way according to above conditions as well as leading to the problem of factory's relocation.

One more problem should be considered is regarding the liberalization of fluid milk trade. If the price of raw milk rise constantly as we forecast, accompanying the pressure of liberalization and international competition, it may stimulate the import of fluid milk. Therefore, it should be another important issue that what kind of effects on dairy industrial organization in Taiwan will be under the liberalized fluid milk market in future, such as how much of raw milk demand and supply will decrease and how the raw milk price will drop down and so on.

Table 11. Equilibrium raw milk trade flows and prices in 1996 under perfectly competitive spatial equilibrium

Unit: ton and NT$/kg

Factory / Area(Hsien)	1[a]	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	1[b]	8	11	2	10	2	9	2	5	4	5	5	2	2	11	13	5
1 Taipei	2,650																
2 Taoyuan	19,912																
3 Hsinchu	7,194																
4 Miaoli				784				4,029		10,889				329			
5 Taichung									6,753			772					
6 Changhwa						25,861			15,042		1,344						6,300
7 Nantou																	
8 Yunlin							25,300										
9 Chiayi		10,936					4,435										
10 Tainan			4,735	19,233		1,478	19,634						10,259		1,544		
11 Kaohsiung			22,046														
12 Pingtung			7,456		33,059												
13 Taitung																3,756	
14 Hwalien	3,902															278	
Total	33,658	10,936	34,237	20,017	33,059	27,339	49,369	4,029	21,795	10,889	1,344	772	10,259	329	1,544	4,034	6,300
%	10.7%	3.5%	10.9%	6.4%	10.5%	8.7%	15.7%	1.3%	6.9%	3.5%	0.4%	0.2%	3.3%	0.1%	0.5%	1.3%	2.0%

Factory / Area(Hsien)	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	Total	%
	6	11	12	8	14	5	14	6	1	3	11	5	6	7	4	11		
1 Taipei									2,701								5,351	1.7%
2 Taoyuan																	19,912	6.3%
3 Hsinchu																	7,194	2.3%
4 Miaoli										436					284		16,751	5.3%
5 Taichung						181											7,706	2.5%
6 Changhwa												170					48,717	15.5%
7 Nantou									3,640					211			3,851	1.2%
8 Yunlin	2,118							370					38	4,719			32,545	10.4%
9 Chiayi				5,988													21,359	6.8%
10 Tainan			10,224													1,698	68,805	21.9%
11 Kaohsiung																	22,046	7.0%
12 Pingtung		2,191									4,168						46,874	14.9%
13 Taitung																	3,756	1.2%
14 Hwalien					506		564										5,250	1.7%
Total	2,118	2,191	10,224	5,988	506	181	564	370	6,341	436	4,168	170	38	4,930	284	1,698	310,117	100%
%	0.7%	0.7%	3.1%	2.0%	0.2%	0.1%	0.2%	0.1%	2.0%	0.1%	1.3%	0.1%	0.0%	1.6%	0.1%	0.5%	100%	

Supply Regions	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Pooled Price	19.66	19.66	19.41	19.36	19.11	19.11	19.06	19.1	19.06	18.81	18.8	18.8	19.86	18.7

Factories	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Paid Price	20.06	19.46	19.21	20.01	19.21	20.01	19.46	20.01	19.51	19.76	19.51	19.51	20.01	19.21	19.21	19.86	19.51
Factories	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	
Paid Price	19.46	19.21	19.21	19.46	18.66	19.51	18.66	19.46	20.01	19.76	19.21	19.51	19.46	19.46	19.76	19.21	

[a] The number from 1 to 33 represents the factories, here we do not include the name of factories (company) because of privacy.

[b] The number in this raw indicates the area which factory is located in, and same as the number represented in the column of Area.

[c] The number of area from 1 to 4 indicates the north of Taiwan.
The number of area from 5 to 9 indicates the middle of Taiwan.
The number of area from 10 to 12 indicates the south of Taiwan.
The number of area from 13 to 14 indicates the east of Taiwan.

Table 12. Forecasted raw milk demand quantities for 33 Taiwanese dairy factories from the year of 2001 to 2016

Unit: ton

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
2001	40,119	12,986	40,590	23,850	39,211	32,575	58,638	4,801	25,887	12,954	1,596	917	12,223	392	1,830	4,803	7,484	2,515	2,598
2006	48,627	15,663	48,891	28,850	44,234	39,402	70,726	5,807	31,234	15,654	1,926	1,106	14,786	474	2,205	5,811	9,029	3,033	3,130
2011	59,142	18,999	59,232	35,096	57,260	47,935	85,833	7,064	37,892	19,011	2,337	1,341	17,987	576	2,672	7,064	10,956	3,679	3,793
2016	72,839	23,345	72,703	43,223	70,301	59,033	105,483	8,700	46,566	23,388	2,872	1,647	22,152	710	3,280	8,745	13,465	4,521	4,656

Year	20	21	22	23	24	25	26	27	28	29	30	31	32	33	Total
2001	12,128	7,109	598	215	666	440	7,557	519	4,943	202	45	5,855	337	2,013	368,596
2006	14,609	8,575	719	259	801	530	9,154	627	5,954	244	54	7,062	407	2,425	442,008
2011	17,714	10,398	869	314	966	643	11,137	762	7,216	296	66	8,568	495	2,939	540,252
2016	21,750	12,774	1,063	386	1,182	790	13,715	937	8,859	363	81	10,528	609	3,608	664,274

Table 13. Forecasted raw milk demand prices for 33 Taiwanese dairy factories from the year of 2001 to 2016

Unit: NT$/kg.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
2001	23.85	23.25	23.00	23.80	23.00	23.80	23.25	23.80	23.30	23.55	23.30	23.30	23.80	23.80	23.00	23.65	23.30	23.25	23.00
2006	28.58	28.03	27.78	28.58	27.78	28.58	28.03	28.58	28.08	28.33	28.08	28.08	28.58	28.58	27.78	28.38	28.08	28.03	27.78
2011	34.95	34.40	34.15	34.95	34.15	34.95	34.40	34.95	34.45	34.70	34.45	34.45	34.95	34.95	34.15	34.75	34.45	34.40	34.15
2016	43.01	42.46	42.21	43.01	42.21	43.01	42.26	43.01	42.51	42.76	42.51	42.51	43.01	43.01	42.21	42.43	42.51	42.46	42.21

Year	20	21	22	23	24	25	26	27	28	29	30	31	32	33
2001	23.00	23.25	22.45	23.30	22.45	23.25	23.85	23.55	23.00	23.30	23.25	23.25	23.55	23.00
2006	27.78	28.03	27.18	28.08	27.18	28.03	28.58	28.33	27.78	28.08	28.03	28.03	28.33	27.78
2011	34.15	34.40	33.55	34.45	33.55	34.40	34.95	34.70	34.15	34.45	34.40	34.40	34.70	34.15
2016	42.21	42.26	41.61	42.51	41.61	42.46	43.01	42.76	42.21	42.51	42.46	42.46	42.76	42.21

Table 14. Forecasted raw milk supply quantities for 14 Taiwanese dairy supply regions from the year of 2001 to 2016

Unit: ton

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
2001	6,839	25,515	9,259	21,420	8,537	54,047	4,269	36,117	23,655	83,869	26,863	57,112	4,595	6,499	368,596
2006	8,691	32,488	11,830	27,293	9,583	60,751	4,794	40,610	26,544	102,820	32,922	69,989	5,639	8,054	442,008
2011	11,191	41,901	15,299	35,136	10,980	69,704	5,495	46,611	30,402	128,131	41,014	87,188	7,048	10,152	540,252
2016	14,349	53,791	19,681	45,045	12,744	81,014	6,381	54,191	35,275	160,104	51,237	108,915	8,745	12,802	664,274

Table 15. Forecasted raw milk supply prices for 14 Taiwanese dairy supply regions from the year of 2001 to 2016

Unit: NT$/kg.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14
2001	23.45	23.45	23.20	23.15	22.90	22.90	22.85	22.85	22.85	22.60	22.60	22.60	23.65	22.45
2006	28.18	28.18	27.93	27.93	27.68	27.68	27.63	27.63	27.63	27.38	27.38	27.38	28.38	27.18
2011	34.55	34.55	34.30	34.30	34.05	34.05	34.00	34.00	34.00	33.75	33.75	33.75	34.75	33.55
2016	42.61	42.61	42.36	42.36	42.11	42.11	42.06	42.06	42.06	41.81	41.81	41.81	42.43	41.61

Table 16. Transition of raw milk demand in small–scale dairy factories

Unit: ton

	YP	AM	KS	ZK	KT	CC	HT	TC	SM	DS	SC	CF	DM	CS	CT	SF	CH
1992	2385	1836	1390	540	1359	328	743	1588	372	456	648	167	57	78	360	–	–
1993	2298	1710	2338	431	1527	–	–	1206	147	402	588	194	56	427	1431	–	79
1994	2282	1211	2299	432	1640	–	–	367	135	566	489	266	56	458	823	230	104
1995	1664	532	1881	367	2007	–	–	588	148	585	448	353	30	163	–	440	97
1996	1370	347	1547	187	2187	–	–	503	200	587	376	432	–	–	–	291	38
1997	1449	342	1463	235	2280	–	–	126	202	639	497	443	–	–	–	426	–

Source: same as in table 3

REFERENCES

Dantzig, G. B. 1949 Programming of Interdependent Activities, II, Mathematical Model. *In* "Activity Analysis of Production and Allocation". ed. by T. C. Koopmans, John Wiley and Sons, New York, 1951, pp. 19–32

Durham, C. A., Sexton, R. J. and J. H. Song 1996 Spatial Competition, Uniform Pricing, and Transportation Efficiency in the California Processing Tomato Industry. *Amer. J. Agr. Econ.*, **78**: 115–125

Halvorson, Harlow W. 1955 The Supply Elasticity for Milk in the Short Run. *J. Farm Econ.*, **37–II** (1955): 1186–1197

Harker, Patrick T. 1986 Alternative Models of Spatial Competition. *Operations Research*, **34–3** (May–June 1986): 410–425

Hashimoto, H. 1985 A Spatial Nash Equilibrium Model. *In* "Spatial Price Equilibrium: Advances in Theory, Computation and Application (Lecture Notes in Economics and Mathematical Systems Vol. 249)". ed. by P. T. Harker, Springer–Verlag, Berlin Heidelberg, pp. 20–40

Hayenga, Marvin L. and Duane Hacklander 1970 Monthly Supply–Demand Relationships for Fed Cattle and Hogs. *Am. J. Agr. Econ.*, **52–4**: 535–544

Kawaguchi, T., Suzuki, N., and H. M. Kaiser 1997 A Spatial Equilibrium Model for Imperfectly Competitive Milk Markets. *Am. J. Agr. Econ.*, **79**: 851–859

Koopmans, T. C. 1949 Optimum Utilization of the Transportation System. *Econometrica (Supplement)*, **17**: 136–146

Kottke, Marvin 1970 Spatial, Temporal and Product–Use Allocation of Milk in an Imperfectly Competitive Dairy Industry. *Am. J. Agr. Econ.* **52–1**: 33–40

Kuhn, H. W. and A. W. Tucker 1951 Nonlinear Programming. *In* "Proceedings of the Second Berkely Symposium on Mathematical Statistics and Probabilities". ed. by J. Neyman, University of California Press, California, pp. 481–492

Ladd, George W. and George R. Winter 1961 Supply of Dairy Products by Iowa Farmers. *J. Farm Econ.*, **43–I**: 113–122

Levins, Richard A. 1982 Price Specification in Milk Supply Response Analysis. *Am. J. Agr. Econ.*, **64–2**: 286–288

Lin, Lily and T. Kawaguchi 1998 Study on Reducing Raw Milk Transportation Cost in Taiwanese Dairy Industry. *J. Fac. Agr., Kyushu Univ.*, **43**(1·2): 269–280, Nov. 1998

Lio, Huei Ming 1997 The introduction of producing and marketing situation in Taiwanese fluid milk industry. *Food Marketing News*, **8607**: 10–12 (in Chinese)

Lio, Yao Chung 1996 *An economic analysis of dairy farmer's milk production cost in Taiwan.* MA Thesis. National Chung Hsing University, Taiwan (in Chinese)

Milligan, Robert A. 1978 Milk Supply Response in California: Effects of Profitability Variables and Regional Characteristics. *West. J. Agr. Econ.*, **3**: 157–164

Nerlove, Marc 1956 Estimate of the Elasticities of Supply of Selected Agricultural Commodities. *J. Farm Econ.*, **38**: 496–509

Nerlove, Marc 1979 The Dynamics of Supply: retrospect and Prospect *Am. J. Agr. Econ.*, **61–3**: 874–888

Rockafellar, R. T. 1980 Lagrange Multipliers and Variational Inequalities. *In* "Variational Inequalities and Complementarity Problems–Theory and Applications". ed. by R. W. Cottle et. al., John Wiley, pp. 303–322

Samuelson, P. A. 1952 Spatial Price Equilibrium and Linear Programming. *The American Economic Review*, **42**: 283–303

Takayama, T. and G. G. Judge 1964 Spatial Equilibrium and Quadratic Programming. *J. Farm Econ.*, **46**: 67–93

Takayama, T. and G. G. Judge 1971 *Spatial and Temporal Price and Allocation Models.* North Holland Publishing Co., Amsterdam.