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—Research Paper—

A System Analysis and Simulation of the Korean Dairy Industry Sector —Milk Supply Component—

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I. Problems and Policy Issue to Be Analyse

In Korea, the traditional main food is rice There is a shortage of food, though the land is uesd intensively. The Koreans produce mainly rice its yield is very much higher than other crops. This leads to the comsumption of one type of food and, hence, to an unbalanced diet.

Since 1962, Korean income has been going up rapidly, and the demand for animal protein has also increased.

In order to solve the probem, the government decided to deveiop the dairy industry, because this would enable the population to consume more animal protein, and there is weak competion between rice and milk production.

In development planning, one of the most important things is how to increase the efficiency of the given resources. In this study, the question of what proportion of nationaI resources should be allocated to the development of the dairy industry, increasing its effciency nation-wide, will not be treated. Various alternatives which will keep the balanced growth between milk demand and suply will be sought, merely in order to increases the efficiency of the scarce resources for the dairy industry. Scarce resonrces, here, mean the given land, manpower, cows, quantity of feed, time, etc. These can be thought of as money value, or cost of dairy the management of the dairy industry. In other words, the idea is to try to find optimum levels of dairy industry production on a time path.

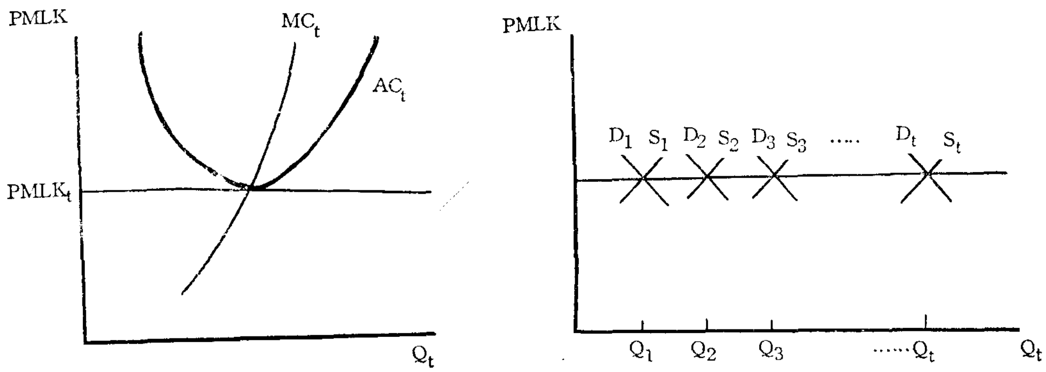

Figure I-1 Milk Demand, Supply and Its Price on Time Path

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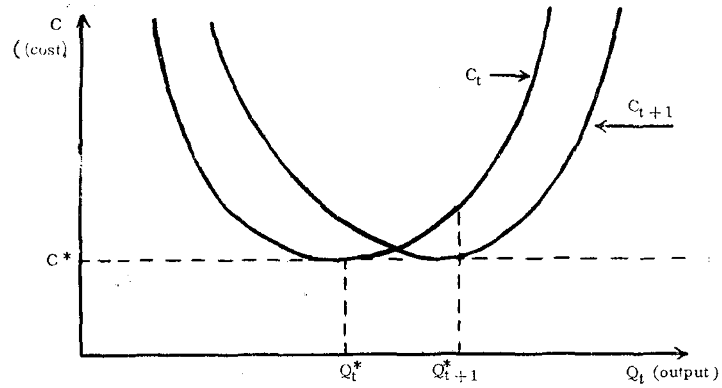
If we suppose that the supply is increased by increasing the number of dairy farms rather than increasing the number of head at each farm, the farmes' cost function will not be changed according to the shifted demand curves. We can also suppose that the demand will be increased by income effect, and the government will want to control the prices of milk to match the demand with its domestic supply facilities. The government may want to increase the number of head (number of dairy farmers) to increase its facilities, and the farmers may want to get positive net profits. In Figure I −1, min. AC_t may not equal P_{milk}. We will study this later.



where: Q_t=amount of milk output (MT/yr)

C_t=average cost of Q_t (₩/MT)

Q_t^*=Optimum capacity of milk industry at time t(MT/yr)

C_t^*=minimum average cost at time t (₩/MT)

Figure I-2 An Postulated Dary Industry Cost Curve on Time Path

Q_t also can be thought of as the amount of milk demanded. If the dairy industry is designed to produce the Q_t at the minimum cost, it can be said that the industry is in an optimum saize. The development should plan on the desired time path. This means that the efficiency planning should minimize the amount realized in the difference between the optimum size of the industry and the demand for its production at a time period through the planning stage, since the cost function is a convex function, *i.e.*,

$$\text{Minimum Cost}=MIN_n \sum_{t=0}^{n} (f(Q_t^*) - f(Q_t))$$

$$C_t=f(Q_t)$$

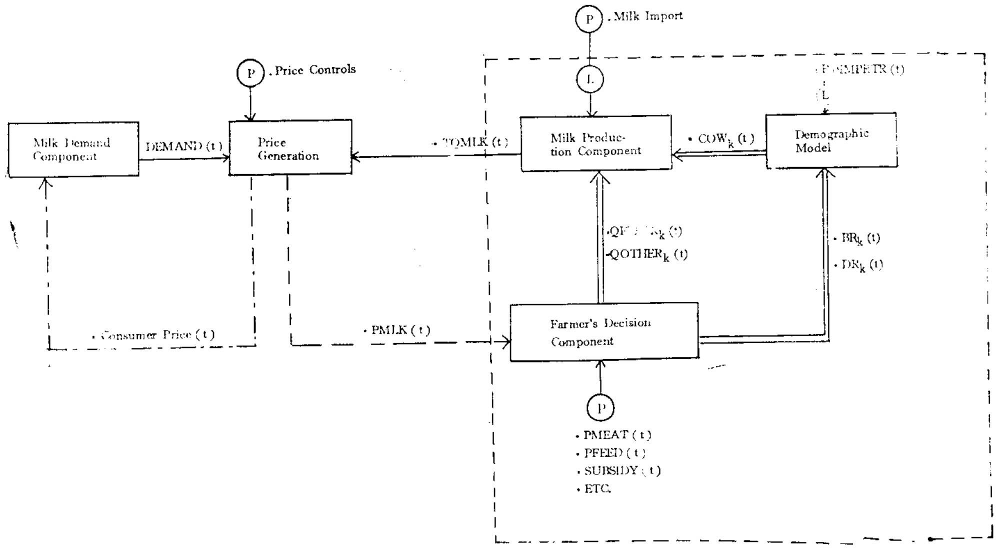
In this way, the demanded output can be produced with minimum cost.

In this study, the increasesed efficiency through development of the farmer's techniques (for instance, changes of each farmer's head size and/or feeding technique, etc.) will be excluded during the planning period.

To better Korean dairy development planning, more accurate information is needed on the demand for milk production and the types of investments with they can obtain an appropriate supply/demand ratio. Therefore, the system will be designed in two parts, demand, and supply.

II. An Overall Description of the Milk Supply Model

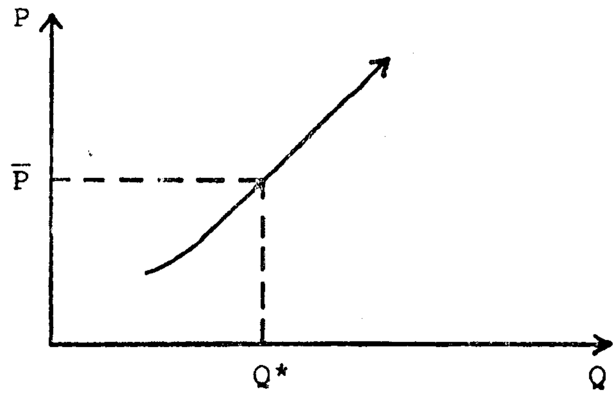
At this time, since studying time is limited, a description of the demand side will be postponed, and the supply side only will be studied. Therefore, the prices (milk price, feed price, and meat price) will be given; then output will be determined uniquely at a given time.



Key:

——•——→Forward Flows
——•——→Price Information
Ⓟ————→Policies
——Ⓛ———Lagged
* Campital letters mean variables used in mathematical description.

Figure I-3 Korean Dairy Industry Sector Model: System Linkage Diagram



$\bar{P}$ means given prices

Figure I -4. A Supply curve with a given scale

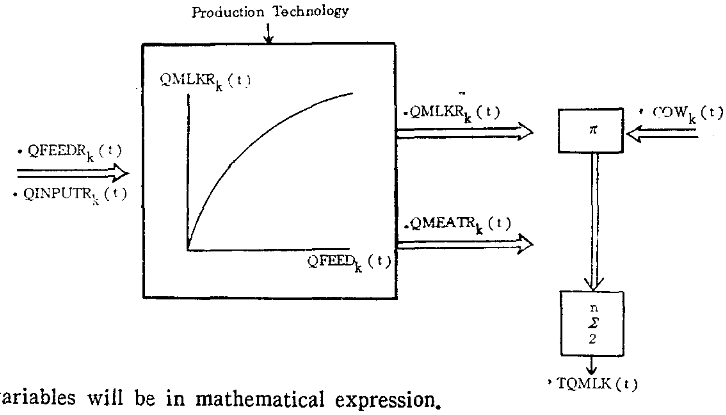
The dairy cow is living thing. This animal not only produces milk, but also grows, propagating the calves. Furthermore, the milk yield varices according to the cow's age, though it be the same cow. For this reason, even though the prices are given, the total milk production may be different from to time. This will be discussed later in detail.

The objective of this study of the supply model is to see the variation of milk production and the dairy industry size which will be changing on a time path.

The milk supply model consists of three components: production component (Ⅱ.1), demographic component (Ⅱ.2), and farmer's decisionen component(Ⅱ.3).

II. 1. The Production Component

In this part, mainly milk production rates per cow will be calculated. The component system is shown in Figure Ⅱ-1.



*Definitions of variables will be in mathematical expression.

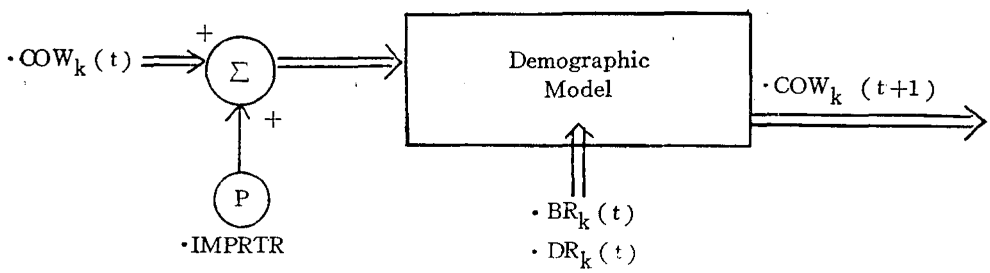
Figure II-1 Internal Structure of the Prouduction Component

II. 2 The Demographic Component

In this study, only the female dairy cow will be treated, since the main objective of this study is to see the amount of milk production annually, and only the female cows can produce it. Of course, a certain number of bulls are necessary for breeding, but they will exist only as long as the farmer wants to keep female dairy cows and feed them.

The cows are divided into one-year age cohorts. The main reason for division into age groups is that the distributons by each age are different, and the milk yields per cow are also different.

In this part, the main output is the number of cows grouped by age ($COW_k(t)$).



*Variable definitions will be in mathematical expression.

Figure II-2 Demographic Component

II. 3 Farmer's Decision Component

The size of the dairy industry is the summation of each farm size. The farm size (the number of cows by age cohort) can be determined by changing the birth rate, death rate, and import rate of the cows. For instance, farmers would want to increase their farm size if excess profits were expected; if not, they would not want to increase their farm size. In this study, each farm size will not be treated. Instead, an average of the above concept will be dealt with.

III. A Mathematical Description of the Milk Supply Model

In this section, mathematical expression for the simulation will be shown

III. 1 The Production Component

During one time period, Total amount of milk production will be determined by population of dairy cows and their yields distributed by age at this time.

$$TOMLK(t) = QMLKP_k(t) * COW_k(t) \tag{1}$$

where:

$TQMLK(t)$ = total milk production at time t (kg/yr)

$QMLKR_k(t)$ = average yield per cow in K-age cohort at time t (kg/head-yr)

$COW_k(t)$ = the number of cows in K-age cohort at time t (head)

A simplified production function is postulated. The feed is assumed as a dominant variable.

$$QMLKR_k(t) = C2_k * QFEEDR_k(t)\, EXP(ALPHA_k) \tag{2}$$

where:

$C2_k$ = production scale coefficient of a K-age cow

$QFEEDR_k(t)$ = amount of feed supplied to a K-age cow at time t (kg/head-yr)

$ALPHA_k$ = the production elasticity of the supplied feed to a K-age cow

III. 2 The Demographic Model

In this system, only the female cows will be studied, as mentioned earlier.

The number of cows at time, t+dt, is depend upon the of cows the year before, $COW_k(t)$, and imported cows at time, t.

$$\frac{dCOW_k(t)}{dt} = \sum_j a_{kj} * COW_j(t) + b_k * \ IMARTR\ (t) \tag{3}$$

Equation (3) can be derived as a discrete form

$$COW_k(t+1) = \sum_j \ a_{kj}(t) * COW_j(t) + b_k(t)\ IMPRTR(t) \tag{3}$$

where;

$$a_{kj} = \begin{bmatrix} 0. & 0, & BR_3(t).. & BR_k(t).... & BR_n(t) \\ 1.-DR_1(t) & 0. & ... & 0. .... & 0. \\ 0. & 1.-DR_2(t) & 0. ... & 0. .... & 0. \\ 0. & 0. & 1.-DR_3(t). & 0. .... & . \\ 0. & & & & 0. \\ 0. & & & & 0. \\ 0. & & & & . \\ 0. & 0. & 0. ... & 0..1\text{-}DR_{n-1}(t) & 0. \end{bmatrix}$$

$$b_k(t) = \begin{bmatrix} B_1(t) \\ B_2(t) \\ \cdot \\ \cdot \\ \cdot \\ B_n(t) \end{bmatrix}$$

where;

$BR_k(t)$ =average birth rate per cow in K-age cohort (/had-yr)

$DR_k(t)$ =average death rate per cow in K-age cohort (/head-yr)

$B_k(t)$ =age proportion of cows imported (Prop tion)

$IMPRTR(t)$ =total importal dairy cowas at head (head/yr)

III. 3 The Farmer's Decision Comonent

In this part, the size of the industry will be determined. The change of the industry size is obviously dependent upon the birth and death rates, of the current dairy cows, sex ratio of culves born, and imported cows. The outputs of this component will be the birth and death rates in each age cohort.

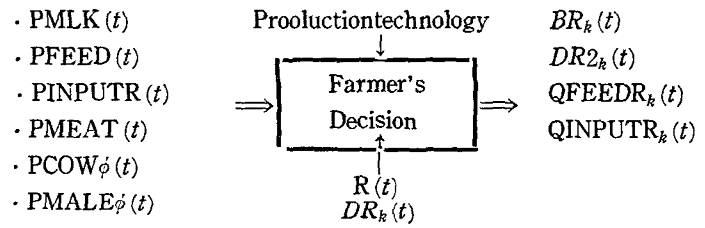


Figure III-1 Farmer's Decision Component

It will be assumed that every dairy farmer wants to maximize the profits realized on his farm.

In this study, it was assumed that if the age of a cow was different from the others, the average profit in the aged cow would be different from cows of other aged. The average profits by age are postulated in Figure Ⅲ-4.

From the production function, the marginal productivity ($MPQFR_k(t)$) is that:

$$\frac{\partial QMLKP_k(t)}{\partial QFEEDR_k(t)} = C2_k{*}\ ALPHA_k{*}QFEED_k(t)\ EXP\ (ALPHA_k - 1.) \qquad (4)$$

Then, the reciprocal of the price ratio between milk price and feed price at time t would be equal to the marginal productivity, i. e.,

$$MPQFR_k(t) = 1./PRATIO(t)$$

$$PRATIO(t) = PMLK(t)/PRATIO(t)$$

where:

PRATIO (t) =price ratio between milk price and feed price at time t

PMLK (t) =milk price at time t (₩/kg)

PFEED (t) =feed price at time t (₩/kg)

then,

$$QEEEDR_k(t) = ((1./PRATIO(t))/(C2_k{*}ALPHA_k))\ EXP\ (1./ALPHA_k - 1.)) \qquad (5)$$

This rlationship is explained in Figures Ⅲ-2 and Ⅲ-3. It is assumed that a more aged cow is less efficient.

The dairy farmers would want to keep a cow as long as the cow makes an actual positive profit within a given time period. The explicit expression of the relationship by the assumption is:

$$\mathrm{EPRF}_k(t) = \mathrm{ETR}_k(t) - \mathrm{ETC}_k(t) \tag{6}$$

where:

$\mathrm{EPRE}_k(t)$ = the expected average profit made by a K-age cow at time t (₩/head-*yr*)

$\mathrm{ETR}_k(t)$ = the average total return made by a a K-age cow at time t (₩/head-*yr*)

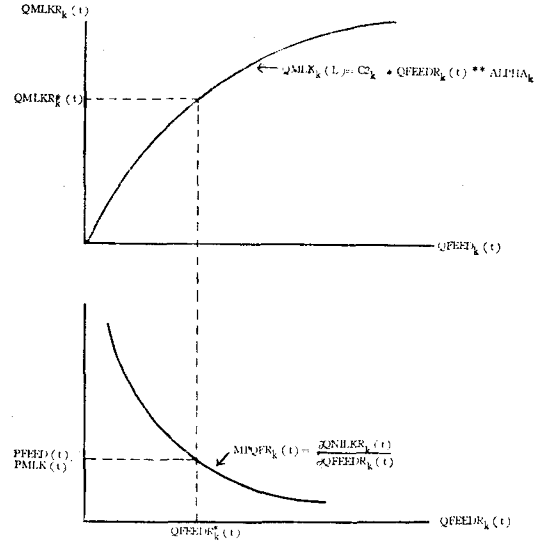


Figure III-2 Typical Milk production Curve and Its Marginal Productive Curve

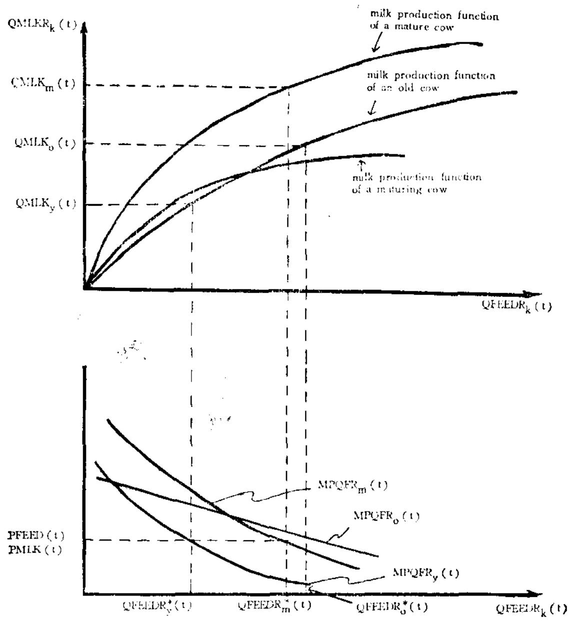
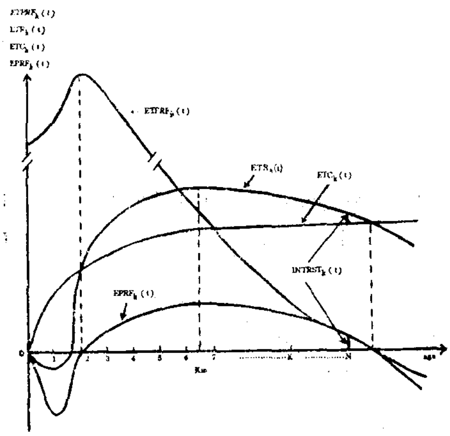


Figure III-3 Milk Production Curves and Their Marginal Productive Curves of Various Aged Cows



*1. $ETR_k(t)$, $ETC_k(t)$, and $EPRF_k$(t are pictured in the same scale.
*2. $ETPRE_k(t)$ is in a different scale from $ETR_k(t)$, $ETC_k(t)$, and $EPE_k(t)$.

Figure III-4 Expecetd Cost, Revenue, Profit on Each Aged Cow and Integrated Expected Profit Curves with respect to the Rest of her Life

$$\frac{dETR_k(t)}{dt} = (1. - DR1_k(t)) * (QMLKR_k(t) * PMLK(t) + QMEATR_k(t) * MRATE2_k(t) * PMEAT(t) + BR_k(t) * (PCOW♀(t) + PMALE♀(t))/2.) \quad (7)$$

where:

$DR1_k(t)$ = natural average death rate per K-age cow at time t (/head-yr)

$QMEATR_k(t)$ = the weight rate being increased from (k-1) age cow to K-age cow during an increment time dt (kg/head-yr)

$MRATEI_k(t)$ = the meat proportion of $QMEATR_k$ (proportion)

BR_k(t) = the average brith rate per k-age cow at time t (/head-yr)

$$\frac{dETC_k(t)}{dt} = (1. - DR1_k(t)) * TC_k(t) + DR1_k(t) * LOSS_k(t) \quad (8)$$

where:

$TC_k(t)$ = total cost, with the exception of the interest of $PCOW_k(t)$, of feeding a K-age cow at time t (₩/head-yr)

$LOSS_k(t)$ = the dairy farmer's loss by natural death of a K-age cow at time t (w/head-yr)

$$TC_k(t) = VC_k(t) + FC_k(t) \quad (9)$$

where:

$VC_k(t)$ = variable cost for a K-age cow at time t (₩/head-yr)

$FC_k(t)$ = foxed cost for a K-age cow except the interestof the cow value, at time t (₩/head-yr)

$$VC_k(t) = FEEDC_k(t) + OTHERC_k(t) \quad (10)$$

where;

$FEEDC_k(t)$ = feeding cost for a K-age cow at time t (₩/head-yr)

$OTHERC_k(t)$ = the others of the variable cost (₩/head-yr)

$$LOSS_k(t) = d(PCOW_k(t) - VBEEF_k(t))/dt \qquad (11)$$

where:

$PCOW_k(t)$ =the value of a K-age cow at time t (₩/head)

$VEEF_k(t)$ =the beef value of a K-age cow at time t (₩/head)

$PCOW_k(t)$ is calculated by comparing the total present valus of total expected profit which can be produced by a K-age cow during her life with her present beef value. If the total expected profit is bigger then her physical beef value, the price of the cow will be the total expected profit. If the beef value is bigger than the total expected pr fit, then the beef va ue will be the pric of the cow. Therefore.

$$PCOW_k(t) = AMAX1(ETPRF_k(t),\ VBEEF_k(t)) \qquad (12)$$

where:

$ETPRF_k(t)$ =the total expected profit of a K-age cow at time t (₩/head)

$VBEEF_k(t)$ =the beef valve of a K-age cow at time t (₩/head)

The $ETPRE_k(t)$ and the $VBEEF_k(t)$ are calculated as follows:

$$EPTREF_k(t) = \int_k^n [EPRE_k(i, t)/((1. + R(t)\, EXP(K-i+dt))]dt \qquad (13)$$

$$VBEEF_k(t) = WEIGHT_k * MRATE1_k * PMEAT(t) \qquad (14)$$

where:

$WGHEIT_k$=the weight of a K-age cow (Kg/head)

$MRATE1_k$=the meat proportion

$R(t)$ =the interest rate (prorportion/yr)

Now, it is time to discuss how the farmer decides to sell his cows as beef cows.

If the farmer wants to make maximum profit with his dairy farm, he hopes to keep his cow as long as the expected profit of the cow in a certain time period is bigger than the inte rest of the price of the cow. If the profit is below the interest, it is better to sell his aged cow and to invest in others, rather than keep it. The cow is too old to be kept for the farmer's profit. Since the $EPRF_k(t)$ is a decreasing function with respect to age after K_m (maximum production age), and the interest is a constant or increasing function by $PCOW_k(t)$ and interest rate, the farmer's selling rate can be calculated by comparing the expected profit with the interest at a time period, not horizontal time period.

$$INTRST_k(t) = PCOW_k(t) \ * R(t) \qquad (15)$$

where:

$INTRST_k(t)$ =the interest which the farmer can obtain when the value of a K-age cow would be invested in the others (₩/head-yr)

The age, N, in which the actual profit is zero (or near zero) can be found by simulation.

A K-age cow, up until now, was thought of as an average cow of K-age which was aggregated. If the production abilities of the K-age cows are distributed as a symmetric bell shape, the farmers will give up keeping the low ability cows (this will be half of the N-age cows) and they will keep the other half. The assumption that this is a reasonable death rate for each age cohort can be postulated as in Figure Ⅲ-6.

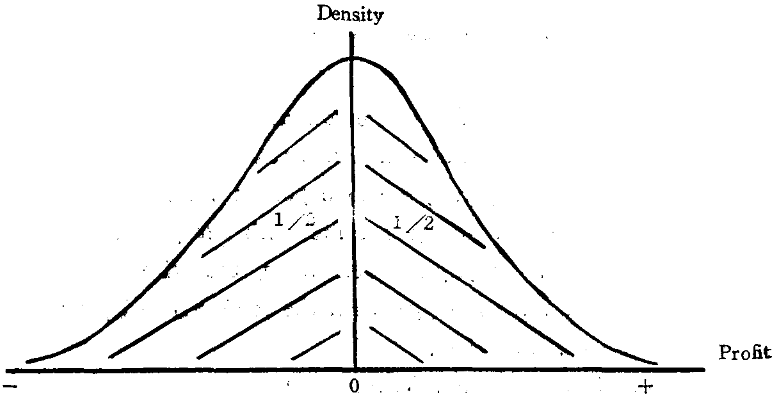


Figure III-5 N-Age Cows' Distribution with Respect to Actual Profit

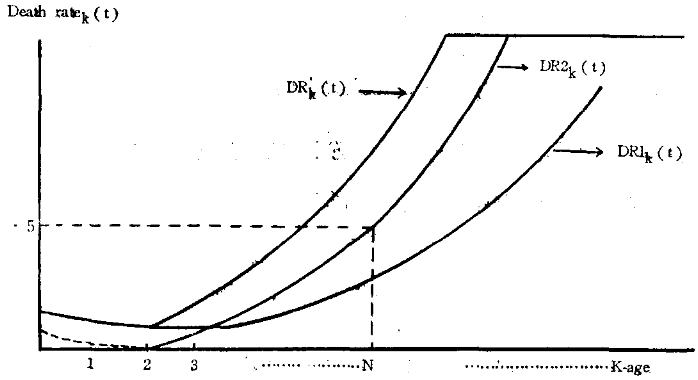


Figure III-6 Death Rate for Age

Up to this time, QFEEDR$_k(t)$ and DR2$_k(t)$ have been discussed among the factors, i.e., QFEEDR$_k(t)$, DR$_k$(t) and BR$_k(t)$, which are decided by the farmers. The remaining one is BR$_k(t)$.

An explantion of this may require an understanding of the nature of the dairy cow. If we assume the techniques given, one mature cow can breed only one calf (excluding the case of twins) in a period, and the techniques cannot reduce the period. At the present time, one relatively possible thing is to increaes the fecundation rate. This is also limited by technogy. This means that even if the farmer wants to increase the birth rate of his cows, he is highly limited by biological factors. The only thing he can do is to reduce the brith rate, but no farmer wants to do that. In order for a cow to produce milk, the cow must breed calves continuously, since a higher birth rate can produce more milk. The current birth rate is the maximum birth rate which can be reached by the present Korean farmers' techniques.

Up until now, the farmers' behaviors according to input and output price have been discussed. Now the focus will be upon the behaviors of the dairy industry nation-wide.

In Cection Ⅱ the milk production has been shown to be different from time to time, even though the prices remain the same during that time, because the dairy cow is a living animal, and the number of cows on the scale, and the quality of the cows, will be changed. These relationships can be explained in Figure Ⅲ-7.

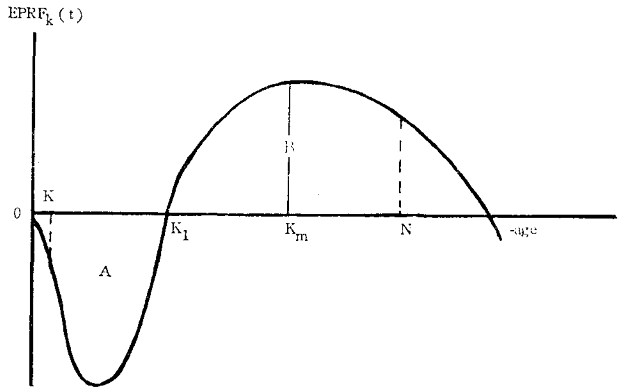


Figure III-7 A Typical Expected Profit Curve on Age

In Figure Ⅲ-7, K_m is the age at which the cow produces maximum profit during her life. N is the age at which the cow produces the actual zero profit: when N is greater or equal to K_m.

The farmer will keep the K-age cow as long as ETPRF$_k$(t) is positive. If a zero-age cow will not, however, make ETPRF$_k$(t) positive, i.e. area A is smaller then area B in Figure Ⅲ-7 and if no imported cows are assumed, then eventually the farmer will give up his dairy farm after (N-K) years. If no imported cows are assumed, there will be no commercial dairy in this country after (N-K) years. This means that if the farmer wants to keep K-age cows at t-year, he must have (K-1)-age cows at (t-1) year. However, during this period (N-K), the output will also be variable because the distributions of the milk cows by their abilities in each age cohort are not the same. An expected total milk production (TQMLK(t)) with respect to time during (N-K) yeers cen be postulated as follows (the dotted line in Figure Ⅲ-8). But as long as the K equals zero and ETPRF$_0$(t) is greater than or equal to zero, the scale of the dairy industry and the output will be increasing monotonically (solid line in Figure Ⅲ-8). The slope is dependent upon the milk production rate (QMLKR$_k$(t)) and the distribution of cows by age: that will depend upon the birth and death rates, which are determined by profit, which is in turn determined by the input and output prices.

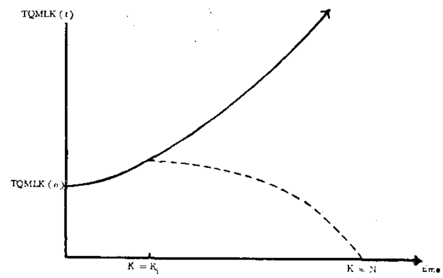


Figure III-8 On Time Path Expected Milk Production with Respect to a Typical Expected Profit Curve (Figure III-7)

Ⅳ. The Government Decision Role

The development planner will want to get the output which fits the nation-wide demand at a certain price in the planning time period. For this, the government can enact a certain degree of subsidy, taxation, rationing policy, and so on, in relation to input and/or output. The government can also import a number of cows from outside the country. The optimum import rate level of the cows will be discussed, after that the damand component is finished.

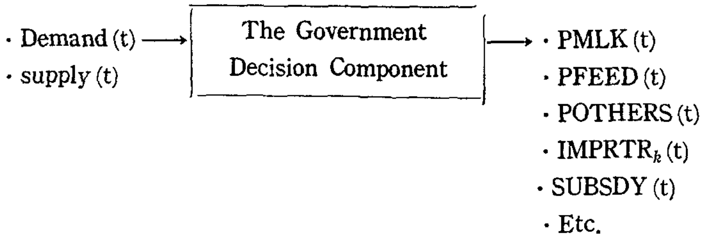


Figure IV-1

A detailed discussion of what the mechanism of these policies will not be treated. This part is one of the future studies. In this study, it is merely assumed, implicitly, that the government can control the input and output prices by its policy role.

V. Conclusion

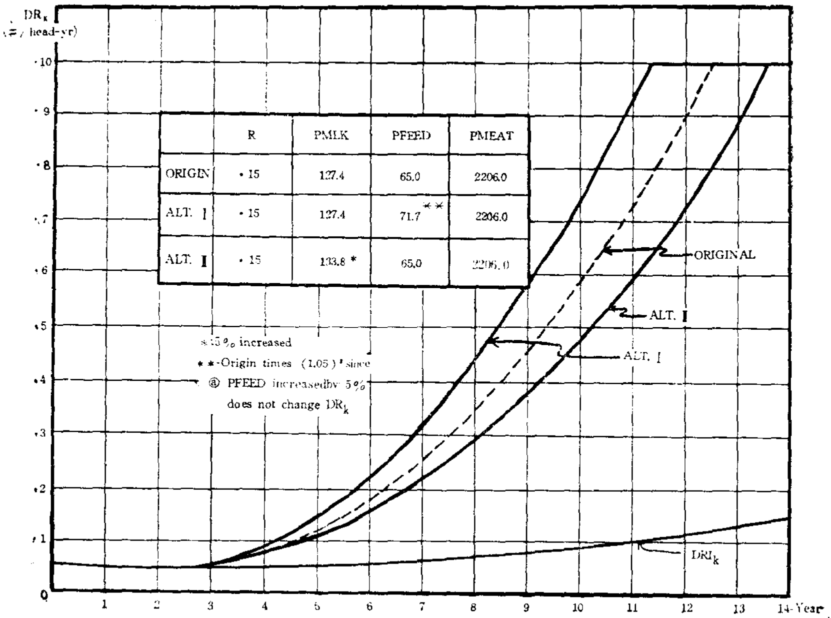
To construct a comprehensive model for the dairy industry, there should be at least two parts, supply and demand. In this study, some of the supply part was discussed. The simulation model of this part worked as it was expected. It was shown in the simulation results. (Appendix A) However, the production equations look so simple. These must be refined, as well as the data of the base year.

The demand part must be built for the decision makers: so they can decide on the optimal size of the dairyr industry on planning time path. A computerized nonlinear optimization techniques can help this anlysis.

APPENDIX. A.

Simulation Results For a Test of Internal Consistency.

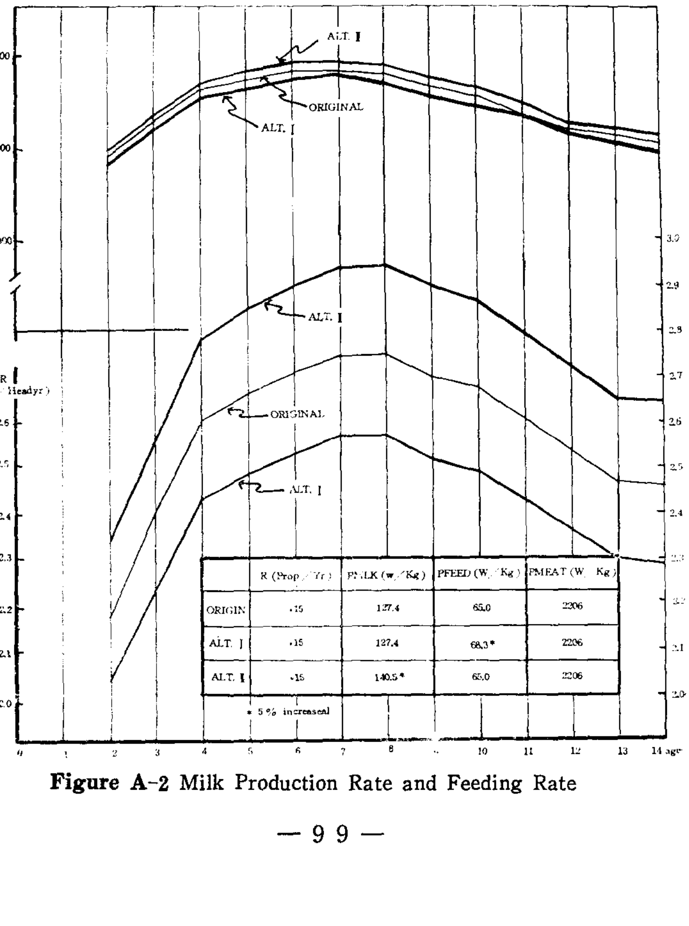
1. Death Rate: DRK (t)
2. Milk Production Rate and Feeding Rate: QNLKR$_k$(t) &QFEEDR$_k$(t)
3. Expected Revenue, Cost, Porfet on each Aged Cow, Integrated Profit Curves with respect to the Rest of her Life, and Price of a K-age Cow: ETR$_k$(t), ETC$_k$(t), EPRF$_k$(t), ETPRF$_k$(t) & PCOW$_k$(t)
4. Prices of a K-age Cow for Various Alternatives: PCOW$_k$(t).
5. Sensitive Tests for Possible Policies.



	R	PMLK	PFEED	PMEAT
ORIGIN	.15	127.4	65.0	2206.0
ALT. I	.15	127.4	71.7**	2206.0
ALT. II	.15	133.8 *	65.0	2206.0

*: 5% increased
**-Origin times (1.05)² since
@ PFEED increasedby 5%
does not change DR_k

A-1 Figure A-1 Death Rate



	R (Prop/Yr)	PMLK (W/Kg)	PFEED (W/Kg)	PMEAT (W/Kg)
ORIGIN	.15	127.4	65.0	2206
ALT. I	.15	127.4	68.3*	2206
ALT. II	.15	140.5*	65.0	2206

* 5% increased

Figure A-2 Milk Production Rate and Feeding Rate

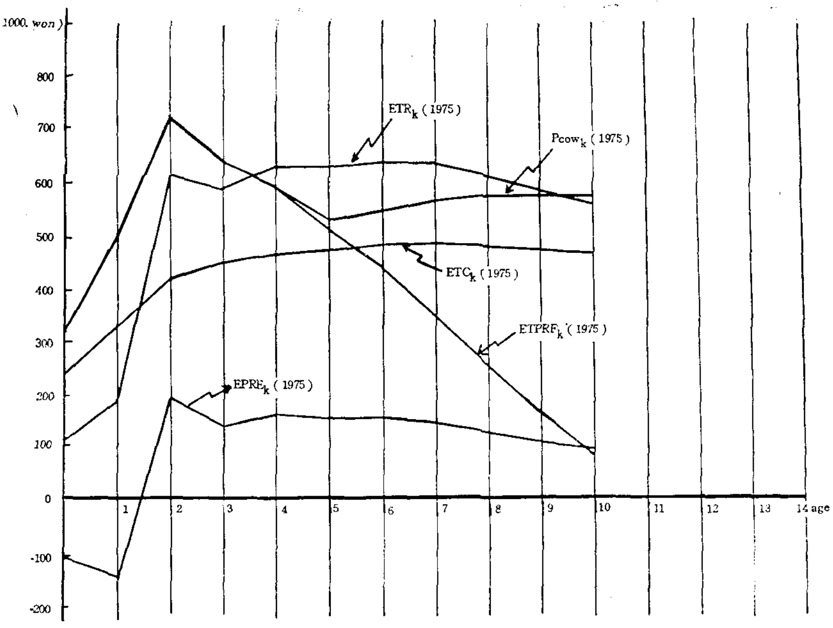
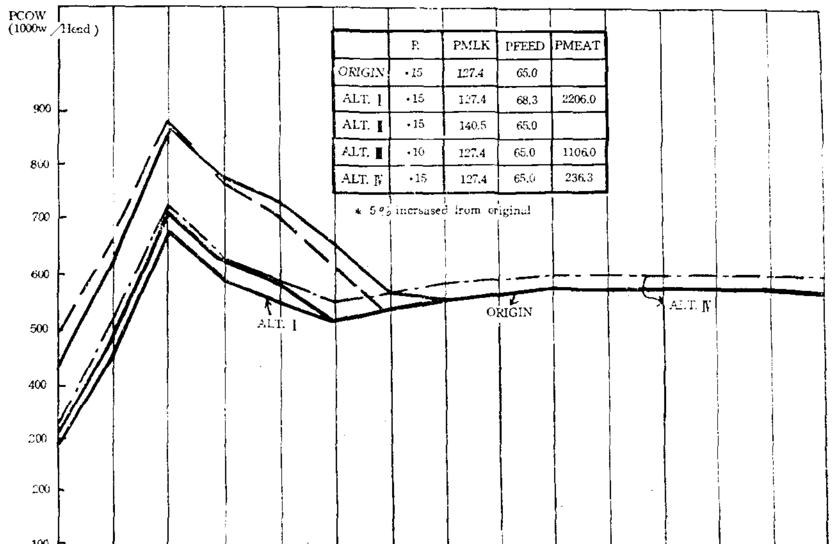


Figure A-3: The Results of $ETR_k(t)$, $ETC_k(t)$, $ETC_k(t($ $ETPRF_k(t)$ and $PCOW_k(t)$ at t=1975

※ compare this with Figure Ⅲ-3

The reason why the simulation results are less smooth is that these are combined two profits, from milk and from weight increased while in Figure Ⅲ-3 those are considered only milk profit.



	R	PMLK	PFEED	PMEAT
ORIGIN	·15	127.4	65.0	
ALT. I	·15	127.4	68.3	2206.0
ALT. II	·15	140.5	65.0	
ALT. III	·10	127.4	65.0	1106.0
ALT. IV	·15	127.4	65.0	236.3

* 5% incrsased from original

Figure A-4 The Results of the Expected Pcow

A-5 Sensitive Tests for Tossible Policies

Test No.	R	PMEAT	PFEED	PMEAT	$IMPORT_2$
Original	.15	127.4	65.0	2206.0	0
Alt. I	.10				
Alt. II		PMLK (1+05)^t			
Alt. III			PFEED (1+05)^t		
Alt. IV				PMENT (1.05)^t	
Alt. V					5000 t

@ Blank nease same Value ok original

Original

Iterm \ Year	1976	1977	1978	1979	1980
R (prop/rr)	.15	.15	.15	.15	.15
PMLK (w/kg)	127.4	127.4	127.4	127.4	127.4
PFEED (w/kg)	65.0	65.0	65.0	65.0	65.0
PMENT (w/kg)	2206.0	2206.0	2206.0	2206.0	2206.0
IMPRTR (head/rr)	—	—	—	—	—
TCOW (head)	101161.	108482.	116502.	125142.	134425.
TQFEED (MT/yr)	187432.	201777.	216925.	232874.	250249.
TQMLK (MT/yr)	276919.	299106.	322870.	346151.	371903.
TQNEAT (MT/yr)	2427.	2618.	2795.	2985.	3205.

Test	Item \ Year	1976	1977	1978	1979	1980
Alt. I	R	.10	.10	.10	.10	.10
	TCOW	102353	110853	119989	129695	140106
	TQFEED	187432	204976	222633	240709	260188
	TQMLK	276919	304645	332397	358400	387164
	TAMEAT	2127	2402	2651	2890	3137
Alt. II	PMLK	133.8	140.5	147.5	154.9	162.6
	TCOW	102353	112561	123576	135207	147555
	TQFEED	198568	230367	271323	316205	367176
	TQMLK	282463	316974	361182	403678	449250
	TQMEAT	2127	1970	2291	2606	2917
Alt. III	PFEED	68.3	71.7	75.2	79.0	83.0
	TCOW	101161	106625	110467	116021	122397
	TQFEED	177034	180056	178863	174238	173902
	TQMLK	271484	287478	296120	295970	306517
	TQMAET	2427	3086	3717	3373	3442
Alt. IV	$IMPORT_2$	5000	5000	5000	5000	5000
	TCOW	106161	119478	134572	151114	169099
	TQFEED	187432	212644	239919	269940	303268
	TQMLK	276919	318384	362295	406164	455559
	TQMEAT	2427	2670	2911	3200	3567

Alt. V	PMENT	2316. 3	2432. 1	2553. 7	2681. 4	2815. 1
	TCOW	101161	108482	114523	121587	529435
	TQFEED	187432	201777	216925	227573	124787
	TQMLK	276919	299106	322870	336973	357812
	TQMEAT	2427	2618	3294	3244	3359

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