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Applying Mathematical Programming Food Supply Model for Improving Japan's Food Self-Sufficiency Ratio

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Abstract As the largest net import country of agricultural products in the world, Japan's food self-sufficiency ratio (SSR) on a calorie basis has significantly decreased from 73% in FY 1965 to about 40% in recent years. Improving the SSR has been or will be a very important policy issue for Japan. The latest Basic Plan for Food, Agriculture and Rural Areas has set a target of 50% as the SSR in FY 2020.

Using the mathematical programming food supply model, we investigate the policy strategies for improving the SSR. Our model is structurally a linear programming model aiming at a network flow optimization in order to maximize Japan's SSR. We analyze four scenarios on the policy strategies for improving the SSR; ⅰ)promoting consumption of rice, ⅱ) expanding the production of rice for feed, ⅲ) expanding the production of wheat and soybeans, and ⅳ) combination of the above-mentioned three strategies. Numerical results show that Japan's SSR could get to only 48% even if perfect import substitution of domestic product for imported one holds, given the constraint of calories consumed per day per capita per food item.

Keywords food self-sufficiency ratio; linear programming model; network flow optimization; optimal food supply; policy strategy

1 Introduction

Japan is the largest net import country of agricultural products and Japanese diet depends quite heavily on imported food and feed. Therefore, Japan's food self-sufficiency ratio (FSSR) on a calorie basis has significantly decreased to only 40% in recent years. Thus our present FSSR level is the lowest among all major OECD's countries. Global balance of food supply and demand has been influenced by continueing population growth in developing countries, increasing demand for biofuel, increasing imports of grains and oilseeds in China, the demand for agricultural products has been steadily increasing.

On the other hand, considering frequent unusual weather conditions around the world, shortage of water resources, and slowdown of growth in yield, global balance of food supply and demand would be getting tighter in the middle and long terms. In recent years, international prices of major agricultural products are soaring to record highs, while some countries control their export of agricultural products. In the short term, there are also uncertainties of supply of agricultural products. Japan cannot be optimistic about ensuring continuous and stable supply of food from abroad in the future.

Looking at Japan's agricultural situation, in 2010 the proportion of over 65 years and older farmers accounts for 62 percent of the agricultural workforce. Though we have the agricultural land area of 607 million ha in 1960, the area has reduced to 460 million ha in 2010. Abandoned field has reached 39 million ha. Thus Japan's agricultural productivity has seriously declined. According to the public opinion poll on the Role of Food, Agriculture and Rural conducted in 2008, 80 percent of respondents answered the current FSSR was "low" or "low if anything" while. 93 percent of respondents worried about the future of stable food imports.

Against the background of internal and external situation for the food supply, improvement of FSSR has long been positioned as the most important issues in agricultural policy. The Basic Plan for Food, Agriculture and Rural drawn up in March 2005, set a target of 45% as the FSSR on a calorie basis by FY2015 and the Basic Plan established in 2010 set a target of 50% by FY2020. In order to improve FSSR, both of the production and consumption approach has been promoted. In food production, as it is very important to make full use of paddy rice fields, the key to improving the FSSR is to grow more wheat, barley and soybeans as well as rice for paddy rice flour and rice for feed. It is also important to increase unit crop yields by introduction of new varieties and techniques and to promote effective use of upland fields. In food consumption, such policies have been implemented as follows. In order to improve the food self-sufficiency ratio, the following points are regarded as highly important and effective matters: (ⅰ) expanding the consumption of rice, including through the promotion of using rice flour, (ⅱ) improving the feed self-sufficiency ratio, (ⅲ) restricting and moderating the excessive intake of oils and fats, (ⅳ) expanding the production of vegetables to meet demand in the processing and food service sectors, (ⅴ) promoting Shokuiku (food education) further, and (ⅵ) promoting strategic advertising in order to develop a national movement. Such efforts should be reinforced from both production and consumption as part of a national movement.

However, since 1998, FSSR has remained around 40 percent (39% in 2006, 41% in 2008). There is considerable divergence between goals and reality. Although improving FSSR is the most important issue in agricultural policy and many Japanese are concerned about extremely low FSSR, there are only few studies executed on quantitatively investigating FSSR so far. In particular, we cannot find any studies which formulate a mathematical network programming model for food supply systems in Japan and analyze the FSSR improvement strategy. Most of studies on FSSR in Japan, as referred by Morita (2006), are qualitative analyses on improving of FSSR and also on goal-setting of FSSR. As quantitative analyses of FSSR, there are a few studies as follows; a regression analysis on the determinants of FSSR by Hirasawa (2004), an analysis of process and factors that decrease the FSSR by Chino (2005), an analysis on movement of FSSR on a calorie basis by calculating changes in FSSR by food item and total of domestic supplied calories by Yoshii and Oyama(2007) and Yoshii et al. (2009), an analysis of the relationship between labor force growth rate and FSSR by Motegi (2008), an analysis of the optimal cereal self-sufficiency by using characteristic approach by Motegi (2011), and so on. Looking at the literature on FSSR in other countries, we can only find the studies on food aid and poverty in developing countries, and increasing food production in China.

In this paper, we develop a mathematical programming network flow model, which represents Japan's food flow system from supply side to demand side, in order to make a quantitative analysis on strategic policies to improve FSSR on a calorie basis. By using the network model, we try to find optimal solution (flow) in order to maximize the FSSR, investigate the effect of current policy measures on FSSR quantitatively, then derive policy implications from the results. The paper is organized as follows. First, we define FSSR in Section 2, and analyze FSSR on a calorie basis and food supply-demand situation in Japan. Next, in Section 3 we explain the details of mathematical programming network flow model. In Section 4, we obtain optimal solution to maximize FSSR and in Section 5, we analyze the numerical results of sensitivity analysis on the four FSSR improvement strategies. Conclusions and future work are described in Section 6 at the end.

2 Japan's FSSR and Food Supply-demand

2.1 Definition of FSSR

There are several definitions of FSSR. In this study, we analyze the FSSR on a calorie basis. The total FSSR on a calorie basis is calculated by using 'calorie' as a common unit of food items, by the following equation.

$$R = \frac{\sum_{i\in N} p_i q_i}{\sum_{i\in N} q_i} \qquad (2.1)$$

In a general mathematical term, food self-sufficiency ratio is defined as:
where

R: food self-sufficiency ratio (FSSR)

p_i: self-sufficiency ratio (SSR) of food item i, $i \in N$

q_i: kilo-calorie quantity of consumption of food item i, $i \in N$

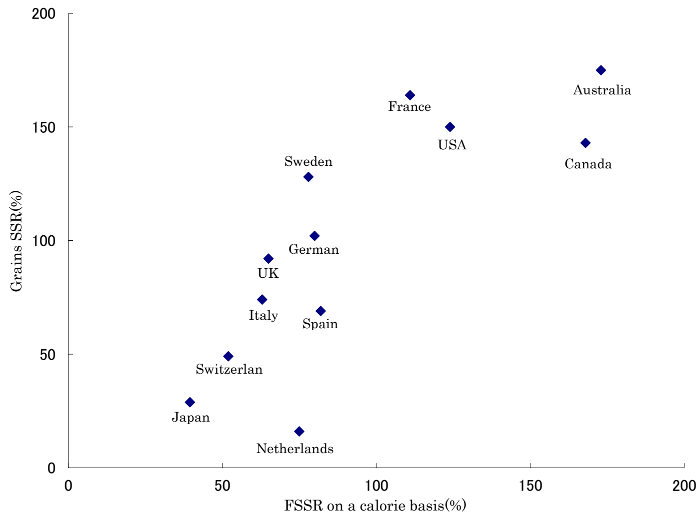
N: set of concerned food items

The reason why we focus on FSSR on a calorie basis is that calorie is a basic and necessary nutrient for the ratio human survival of human beings and FSSR on a calorie basis shows that Japan is capable of improving the self-sufficiency. In addition, by using calorie based FSSR on a, we can forecast completely our self-sufficient capability of livestock products and vegetable fats and oils which are highly dependent on imported feed and oilseeds. FSSR on a calorie basis has been used Japan as well as Korea, Taiwan, Switzerland and Norway.

In addition to calorie-based FSSR, FSSR on a monetary basis, which is calculated by dividing total value of domestic food production by total value of domestic food consumption, and grain self-sufficiency ratio on a weight basis (GSSR), which is calculated by dividing total volume of domestic grain production volume by total volume of domestic grain consumption, have been used. FSSR on a monetary basis appropriately reflects the importance of vegetables and fruits which are relatively low in calories but play an important role in maintenance and promotion of health. Numerical targets of both calorie based FSSR and money based FSSR are established in the Basic Plan.

As for GSSR, we can easily obtain GSSR data of many countries because of a weight basis and make international comparisons of GSSR.

In Figure 1, the horizontal axis represents FSSR on a calorie basis and the vertical axis represents GSSR. Figure 1 shows that the higher GSSR, the higher FSSR on a calorie basis, generally. As Japan strongly depends on imported grains, namely wheat for food and corn for feed, its low GSSR causes low FSSR. In contrast, the Netherlands' GSSR is lower than Japan's but the Netherlands' FSSR is higher than Japan's because the Netherlands' feed self-sufficiency ratio is considerably high and FSSR of livestock products on a calorie basis is also high.



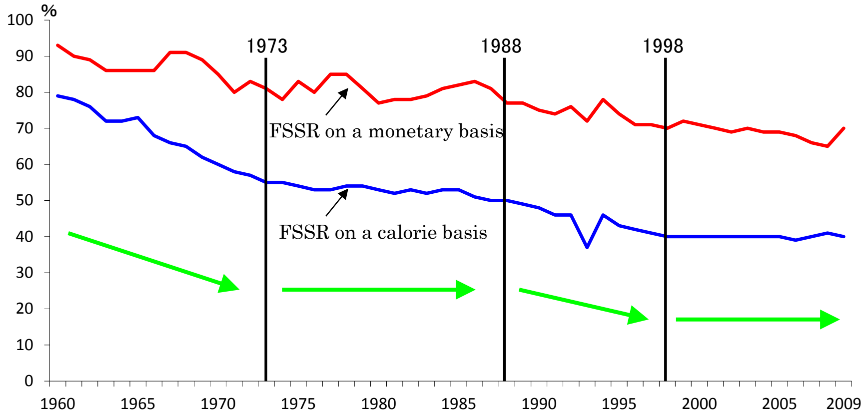
Source : Food Supply-demand Table (Ministry of Agriculture, Forestry and Fishery)

Figure1: FSSR in Japan and other countries

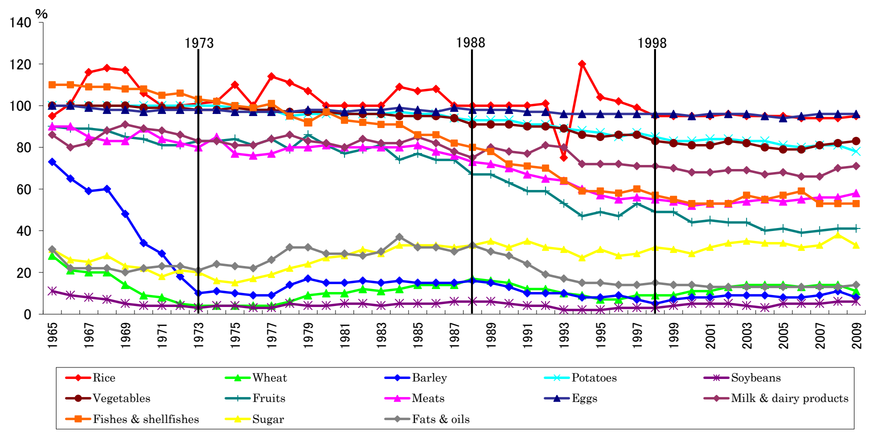
2.2 Change in calorie-based FSSR

Figure 2 shows the change in Japan's FSSR on a calorie basis and on a monetary basis from (fiscal year) 1960 to FY 2009. The calorie-based FSSR, as indicated by the arrows in Figure 2, decreased from 79% in FY 1960 to 55% in FY 1973 and then remained stable at around 53% to FY 1985. However the FSSR decreased again from 53% in FR 1985 to 41% in FY1997 and since FY1998, has remained flat at around 40%. Although the monetary-based FSSR has also been declining from 93% in FY 1960 to 70% in FY 2009, its decline is smaller than the FSSR on a calorie basis.

We show the relationship between change in calorie based FSSR and FSSR by food item. As shown in Figure 3, a drop in FSSR to FY 1973 was mainly caused by a decrease in SSR of wheat, barley and soybeans. The SSR of wheat decreased from 28% in FY 1965 to 4% in FY 1973, barley decreased from 73% to 10% and soybeans decreased from 11% to 3%. Next a drop in FSSR from FY 1985 to FY 1997 was mainly caused by a decrease in SSR of meats, seafood and oils & fats. The SSR of meats decreased from 81% in FY 1985 to 55% in FY 1997, barley decreased from 86% to 57% and soybeans decreased from 32% to 15%.



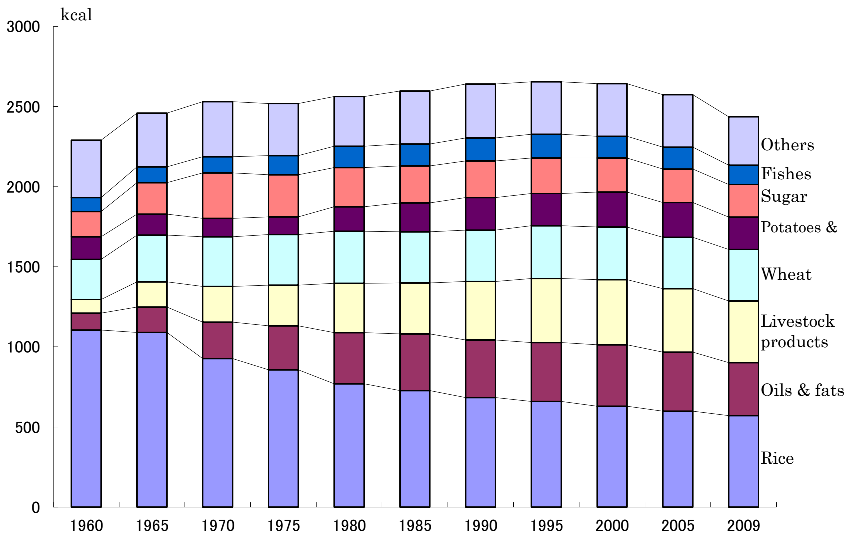
Source : Food Supply-demand Table (Ministry of Agriculture, Forestry and Fishery)
Figure2: Change in Japan’s FSSR on a calorie basis and a monetary basis



Source : Food Supply-demand Table (Ministry of Agriculture, Forestry and Fishery)
Figure 3: Trends in Japan’s by food item

2.3 Food supply and consumption

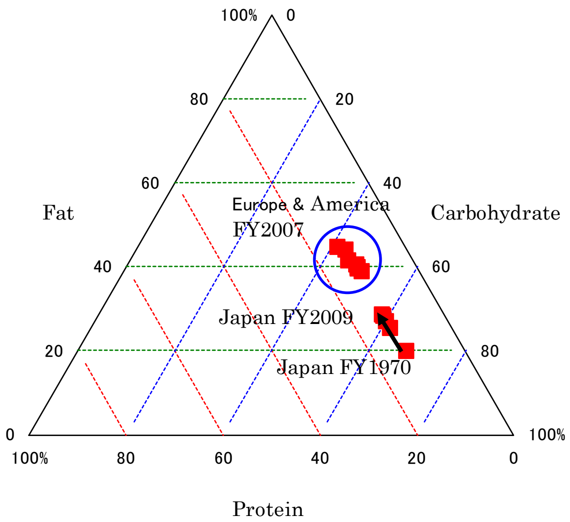
Japanese diet has significantly changed over the long term, as shown in Figure 4. The consumption of rice, which is the staple food in Japan, has decreased, and on the other side, the consumption of livestock products and oils & fats has increased. The calories supplied per capita per day reached its peak, 2,670 kcal in FY 1996 and are recently decreasing to 2436 kcal in FY 2009.



Source : Food Supply-demand Table (Ministry of Agriculture, Forestry and Fishery)

Figure 4: Composition of calories supplied per day per capita

Thus, because of reducing share of rice and growing share of the livestock products and oils & fats in calories supplied, present Protein-Fat-Carbohydrate (PFC) balance, which shows percentage of protein, fat and carbohydrate in total calories supplied, has been deviating from the optimal value (P:13%, F:25.5%, C:61.5%) for Japanese, which was realized in FY 1980. As shown in Figure 5, the value of PFC balance in Japanese diet has been approaching to Western-type diet with low carbohydrate and low fat. However, compared with Western countries, Japan's PFC balance still keeps higher-carbohydrate and lower-fat. In Figure 5, Europe America includes those date for US, Germany, Spain, France, Italy, UK and Australia in FY2007. As for Japan these data imdicate FY1970, 1980, 1990, 2000 and 2009.



Source : Food Supply-demand Table (Ministry of Agriculture, Forestry and Fishery)

Figure 5: PFC-balance in Japan and other countries

We explain the impact of these dietary changes on FSSR. We show FSSR on a calorie basis and percentage of volume of calories supplied by food item of FY 1965 in Figure 6 and of FY 2009 in Figure 7. In Figures 6 and 7, the horizontal axis represents percentage of volume of calories supplied by food item, which is calculated by dividing calories supplied by food item by total calories supplied and the vertical axis represents FSSR on a calorie basis by food item.

To explain how to read the Figure 6 and 7, let us look at the rice case as an example. As shown in Figure 6, in FY 1965, FSSR of rice was 100% (horizontal axis) and percentage of volume of calories supplied by rice was 44% (vertical axis). In Figure 7, FSSR of rice declined to 96% and percentage of volume of calories supplied by rice also declined to 23% in FY 2009. By comparing Figure6 and Figure 7, as calories supplied by rice, which supported high FSSR(73%) in FY 1965 have decreased and percentage of volume of calories supplied by livestock products, oils & fats and wheat, whose FSSR were low has increased, FSSR on a calorie basis has declined to 40%.

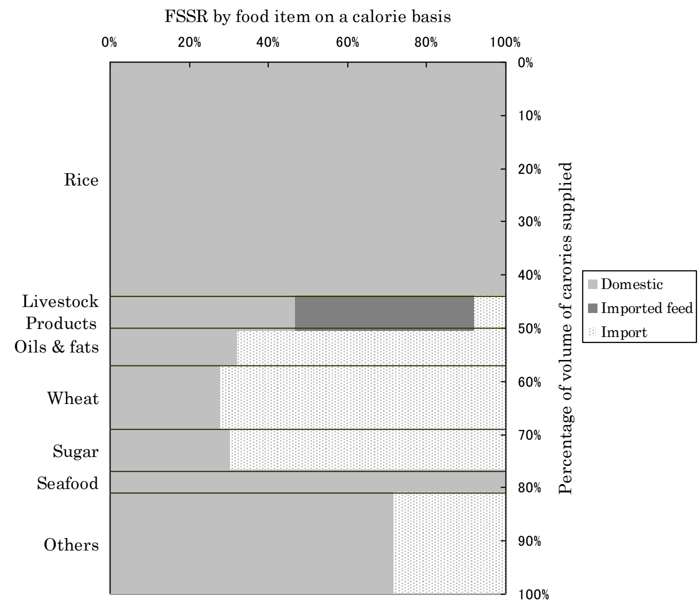


Figure 6: FSSR on a calorie basis and percentage of volume of calories supplied by food item (FY 1965)

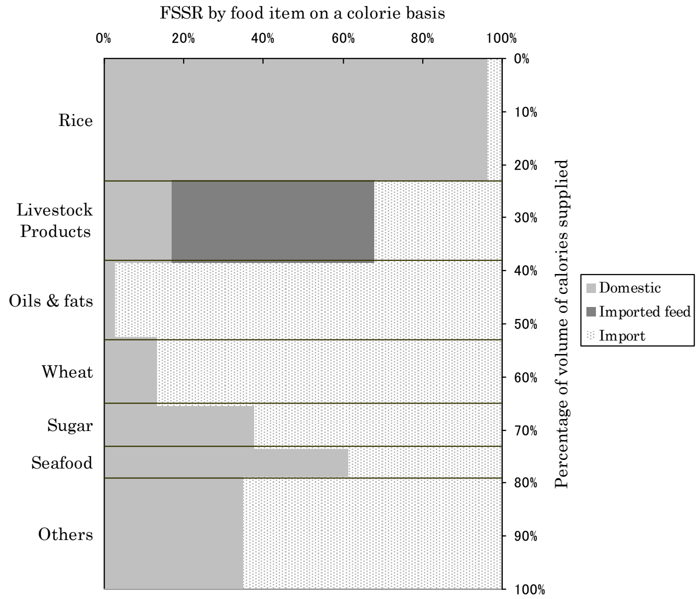


Figure7: FSSR on a calorie basis and percentage of volume of calories supplied by food item (FY 2009)

Here, let us explain the imported feed used in livestock production. In FY 1965, as shown in Figure 6, 2.8% of calories supplied per day per capita was dependent on imported feed as the percentage of calories supplied by livestock products was 6.4% and the dependence on imported feed in calories supplied by livestock products was 45%,. In FY 2009, 8.2% of calories supplied per day per capita depended on imported feed. As thepercentage of calories supplied was 15.8% and the dependence on imported feed in calories supplied by livestock products was 52% as shown in Figure 7 nearly half of the calories supplied by domestic livestock is dependent on imported feed in FY 2009, "the apparent domestic livestock production" and "domestic livestock production in calculation of FSSR on a calorie basis" is different. In addition, if livestock products were provided without entirely importing feed in FY 2009, calorie based FSSR could be improved by about 8%. As well as corn which accounts for the major part of livestock feed, wheat whose consumption has increased in changing diet, and soybeans which are raw materials for vegetable oils are produced very little in Japan, thus dependent on import from a just few of countries.

As shown in Figure 8, Japan imports wheat from the U.S. Australia and Canada, soybeans from the U.S., Brazil and Canada, most of the corn from the U.S. Thus, Japan is highly dependent on the United States. Japan relies on 12.45 million hectares of agricultural land overseas, which is equivalent to 2.7 times the total area of agricultural land in the country.

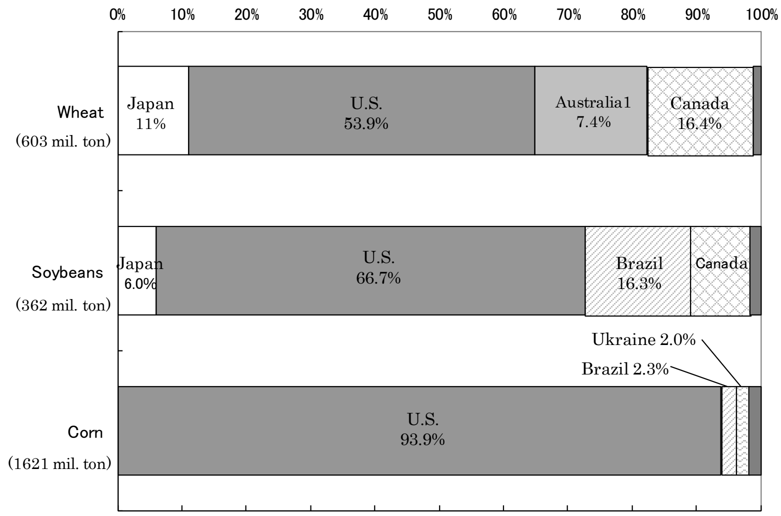


Figure8: Japan’s major imported crops

3 Mathematical network programming model for food supply

3.1 Structure of the Model

The Japan's food supply and demand system accomodating food commodity flows from various supply regions to final demand sectors is shown as a network-structured system in Figure 9. The supply sector consists of seventeen nodes, corresponding to sixteen supplying countries/regions and domestic supply. The domestic supply node is our most concern as it is used in calculation of FSSR. Food commodities are represented in twenty-one most common food items in Japan, and are partly used to feed livestock, and/or transformed into intermediate food commodities like miso (Japanese fermented soybean paste), soy sauce and liquor. The final demand sector consists of three components, namely eating-out/home-meal replacement, food-processing and household consumption.

In Table 1, we show elements of a supply region set; I, a food item set; J, a demand sector set; K, an intermediate product set; T. One of the characteristics of our network model is that it includes special constraints on feed, considering calories of imported feed is deducted from calories supplied by domestic livestock products in calculation of FSSR on a calorie basis.

Table 1: Elements of subsets

		Elements					
Subsets	I	1 U.S.	2 Canada	3 Brazil	4 Chile	5 Argentina	6 Australia
		7 New Zealand	8 China	9 S. Korea	10 Thailand	11 Philipines	12 Malaysia
		13 EU	14Russia	15 S. Africa	16 Others	17 Japan	
	J	1 Rice	2 Wheat	3 Barley	4 Corn	5 Millet	6 Sweet potatoes
		7 White potatoes	8 Starch	9 Soybeans	10 Vegetables	11 Fruits	12 Beef
		13 Pork	14 Chicken	15 Eggs	16 Milk	17 Dairy products	18 Seafood
		19 Sugar	20 Vegtable Oils	21 Animal Oils			
	K	1 Eating-out & home-meal replacement	2 Food-processing	3 Household consumption			
	T	2 Miso	3 Soysauce	4 Liquor			

3.2 Mathematical Formulation

A feasible food flow in the network needs to satisfy future food demand under various supply constraints, physical and engineering constraints. The food flows on the arcs of the network correspond to unknown variables of the model, and network constraints are linear equalities and inequalities using those variables. Consequently, our problem of finding an optimal flow can be formulated as a linear programming problem. Our objective is to obtain a feasible food flow that satisfies future food demand and maximizes domestic supply, which implies a maximized FSSR.

In our model, there are five decision variables {xij, yjk, ujt, vjt1, and $w_{t_1 j}$ } corresponding to food flows, as shown in Figure 9. The $w_{t_1 j}$ variable indicates the particular “returning” flow from “livestock feed” node to its beneficiary subset, namely beef, pork, chicken, milk, and dairy products.

3.2.1 Decision variables

xij: Calories of a food item j supplied by a supply region i, where i∈I and j∈J.

yjk：Calories of a food item j consumed in a demand sector k, where j∈J and k∈K.

ujt：Calories of a food item j consumed in an intermediate product t, where j∈J and t∈T.

vjt1：Calories of a food item j consumed as feed, where j∈J and t1 means "feed".

$w_{t_1 j}$: Calories of feed t1 consumed to produce livestock product j, j∈J, t1 means "feed".

3.2.2 Constraints

Constraints in our model are expressed as follows:

i) Upper and lower bounds of final demand

$$D_k^L \le \sum_{j \in J} a_{jk} y_{jk} + \sum_{t \in T} d_{tk} v_{jt_1} \le D_k^U, k \in K \qquad (2)$$

where D_k^U and D_k^L are upper and lower bounds of final demand in the demand sector k.

ii) Flow conservation constraints

$$\sum_{i \in I} x_{ij} = \sum_{k \in K} a_{jk} y_{jk} + \sum_{t \in T} b_{jt} u_{jt} - \sum c_{t_0 j} w_{t_0 j}, j \in J \qquad (3)$$

$$\sum_{j \in J} b_{jt} u_{jt} = \sum_{j \in J} c_{tj} w_{tj}, t = 1 \qquad (4)$$

$$\sum_{j \in J} b_{jt} u_{jt} = \sum_{k \in K} d_{tk} v_{tk}, 2 \le t \le 4 \qquad (5)$$

where (2) are flow conservation constraints at the node of a food item j∈J, (4) are flow conservation constraints of a food item j∈J in feed sector(τ=1) and (5) are flow conservation constraints in intermediate sectors (τ=2,3,4).

iii) Flow conservation constraints of feed

$$\left(1 - m_k\right) x_{sk} = m_k \sum_{i \in I} x_{ik}, k \in K \qquad (6)$$

where mk are domestic SSR of a food item k∈K.

iv) Upper and lower bounds of calories supplied by food item

$$q_{ij}{}^L \le x_{ij} \le q_{ij}{}^U, i \in I_0 \subset I, j \in J_0 \subset J \qquad (7)$$

Where q_{ij}^U and q_{ij}^L are upper and lower bounds calories of a food item j∈J supplied by a supply region i∈I.

v) Objective function

Maximize $z = \dfrac{1}{\sum_{k \in K} D_k} \left(\sum_{j \in J_1} x_{i_1 j} + \sum_{j \in J_2} k_{t_1 j} x_{i_1 j} \right), J = J_1 \cup J_2, J_1 \cap J_2 = \varnothing$ （7）

where denominator is calories supplied per day per capita, numerator is calories by domestic production and J1 and J2 are food items.

3.2.3 Assumptions and input data

We set the following assumptions to obtain the optimal solutions by using our model:

- The FY2002 is the base year and the FY 2012 is the target year. The upper limit of total of food demand decreases by 4% decrease compared to the base year, because food demand is predicted to decrease by 0.4% per year.
- The upper bounds of calories supplied by import products are fixed at the level of base year and the lower bounds are set at 90% (80% in case of soybeans) of the base year. The lower limit of corn is not set. The minimum-access rice import (800 thousand tons) keeps unchanged.
- The upper bounds of calories supplied by domestic products are fixed at the level of base year and the lower bounds are not set.
- The three demand sectors, which consist of eating-out/home-meal replacement, food-processing and household consumption, are treated as one sector.
-Considering recent consumption trends, the lower limit of calories consumed by food item is set at 90% or 95% of the base year.
- The network of import feed is included in our model and calories of imported feed are deducted from calories supplied by domestic livestock products in calculation of FSSR on a calorie basis.

Starch, vegetable oils and sugar are treated similarly because of their high import-dependence.

-Some food items whose statistical data are difficult to obtain, are excluded from our model.

Input data for the model are extracted from MAFF's Food Balance Sheets of FY 2002, various MAFF's statistical data and other business data.

3.2.4 Reference case analysis

Under the above assumptions, we get a set of optimal solution by putting numerical data from the Japan's Food Balance Sheet for FY 2002 as the initial values into the model. Let us call the solution obtained as reference solution. We compare initial values and reference solution on calorie basis supplied by domestic production and show Table 2. Compared with initial values and reference solution, total of calories supplied on a net-calorie basis decreases from 1.12579 × 10-14 kcal in FY 2002 to 1.16571×10-14 kcal in FY 2012. By using the moderate prediction of the population in 2012 (126,605 thousand persons), calories supplied per day per capita in FY 2012 is 2,436 kcal.

When we calculate using the initial values, FSSR on a calorie basis is 40.3%. On the other hand, in calculation of using the reference solution, FSSR is 41.1%, as shown in Table 2. The calories domestically supplied by rice, which represents the largest share, decline by 3.4 percent, compared with initial values and reference solution, because in case of the initial values there are 3% gap between calories supplied and calories consumed considering rice inventory and the gap is adjusted and gone by calculating the reference solution. While the 'number' of calories domestically supplied by rice decreases,share of rice to total of calories domestically supplied slightly increases from 30.2% to 30.4%. Domestic production of wheat, potatoes, fruits, vegetables and milk/dairy products is maintained at the current level, but calories domestically supplied of meat and eggs, which are highly dependent on imported feed, and vegetable oil and starch which depends heavily on imported raw materials greatly reduce. As a result, total of calories domestically supplied in case of reference solution decline by 4.1% compared with initial values.

In Table 3, let us see changes in calories supplied by import. Calories supplied by import of major items such as wheat and soybeans decline to lower bounds set by assumptions. The total of calories supplied by import declines by 13.1%, because of the decrease in domestic production of starch, meat and eggs, which greatly depend on foreign raw materials and feed.

Table 2: Initial values and reference values on a calorie basis by domestic production

			(unit: mil kcal)
	Initial value(A)	Optimal solution(B)	B/A
Rice	28,670,225	27,705,842	96.6
	(30.2)	(30.4)	
Wheat	2,379,562	2,379,562	100.0
	(2.5)	(2.6)	
Potatoes	3,326,256	3,326,256	100.0
	(3.5)	(3.7)	
Starch	10,168,608	8,405,370	82.7
	(10.7)	(9.2)	
Vegatables & fruits	5,019,592	5,019,592	100.0
	(5.3)	(5.5)	
Meat & eggs	7,365,892	6,482,384	88.0
	(7.8)	(8.1)	
Milk & dairy products	5,363,200	5,363,200	100.0
	(5.7)	(5.9)	
Seafood	3,860,472	3,771,131	97.7
	(4.1)	(4.1)	
Oils & Fats	15,408,630	14,318,947	93.0
	(16.2)	(15.7)	
Others	13,357,085	13,357,088	100.0
	(14.1)	(14.7)	
Total	94,919,525	91,012,880	95.9
	(100)	(100)	
FRRS on a calorie bases	40.3%	41.1%	

Table 3: Initial values and reference values on a calorie basis by import

(unit: mil.kcal)

	Initial value (A)	Optimal solution (B)	B／A
Wheat	14,274,499	12,847,021	90.0
	(13.9)	(13.9)	
Corn	32,790,322	27,055,983	82.5
	(30.9)	(29.3)	
Soybeaans	21,501,413	17,201,123	80.0
	(20.2)	(18.6)	
Meat & eggs	3,834,773	3,451,295	90.0
	(3.6)	(3.7)	
Seafood	5,015,491	4,513,939	90.0
	(4.7)	(4.9)	
Oils & fats	5,441,524	4,897,373	90.0
	(5.1)	(5.3)	
Others	23,404,133	22,372,332	96.2
	(22.0)	(24.2)	
Total	106,262,155	92,339,066	86.9
	(100)	(100)	

Shadow price for the lower bounding constraint (2) are given in Table 3. The values indicate the increase of SSR corresponding to the unit increase of domestic consumption for each food item. Table 4 shows the shadow prices and import for each food item. These values imply the increase of SSR corresponding to the unit increase of the lower bounding constraint (6) for corresponding to domestic production and imports.

Table 4: Shadow price for the lower bounding constraint

Food item	Shadow price
Feed	0.0
Starch	0.110
Beef	0.0945
Pork	0.0611
Chicken	0.0689
Egg	0.0824
Milk	0.150
Dairy	0.110
Sugar	0.150
Vegetal oil	0.116

Food item	Domestic production	Import
Wheat	0.00705	-0.110
Barley	0.0690	.0
Corn	0.0771	-
Sweet potato	0.0	0.135
Potato	0.0	0.135
Starch	0.0401	0.110
Soy bean	0.109	0.0410
Vegetable	0.0	0.129
Fruit	0.0	0.110
Beef	0.0	0.0945
Pork	0.0334	0.0611
Chicken	0.0377	0.0689
Egg	0.0451	0.0825
Dairy	0.0401	0.110
Seafood	0.0	0.558
Sugar	0.0	0.150
Vegetal oil	0.0	0.116
Animal oil	0.0	0.110
Miso	0.110	-
Liquor	0.110	-

4 Sensitivity analysis on the Strategy for improving food self-sufficiency

4.1.1 Setting scenarios

As stated in Section 1, both the production side and consumption side efforts have not given good results to improving Japan's FSSR. However, as strategies for improving FSSR are limited, we try to analyze quantitatively what percentage could be increased by each scenario, by using our model.

We describe the basic idea of setting the scenarios. To improve FSSR, in other words, to increase the capacity of domestic agricultural food supply, it is necessary to make good use of paddy fields which is peculiar to Japan and have high productivity. Currently, as demand for the staple rice has reduced, about 40 percent of paddy fields has not been used to grow rice, in part of which has been the "abandoned cultivated land". With the aging and declining population, it is expected to decrease further demand for the staple rice and to expand acreage of paddy fields which will not be used to grow rice, in future. Thus, it is necessary to promote low-FSSR wheat and soybean production in paddy fields and expand rice for rice-flour and rice for feed in paddy fields which is not suitable to growing wheat and soybeans.

Based on these ideas, we set the following four scenarios. The first scenario is to expand the consumption of rice. Although there are long-term trends in decreasing rice consumption, by improving from skipping breakfast to rice-based breakfast in diet and promoting the use of rice-flour for making rice-flour bread and rice-flour noodles. Also increasing consumption of rice contributes to improving the PFC balance. The second scenario is to expand the production of rice for feed. Providing concentrated feed such as corn is indispensable for raising hog, poultry and beef cattle. However Japan relies on import for most of concentrated feed. Japan's SSR of feed is about 25% and especially its SSR of concentrated feed is only 10%. Low SSR of feed is one of reasons that Japan’s FSSR on a calorie basis still remains low.

Now, against the background of growing demand for biofuels, international prices of corn are skyrocketing and it is also important to improve the SSR of feed to save feed costs. Therefore by expanding the production of rice for feed in paddy fields and substituting domestic feed-rice for imported feed-corn, we try to improve FSSR on a calorie basis. From a viewpoint of making full use of paddy fields, raising lower FSSR of wheat and soybeans (FSSR of wheat is 11%, soybeans is 6%) is most important strategy for improving Japan's FSSR. The fourth scenario is a combination strategy of the above three scenarios, namely to expand the consumption of rice and the production of rice for feed, wheat and soybeans. In the numerical calculation of each scenario, we add the constraint that the total of calories supplied is 1.12579 ×10-14 kcal, which is the same calories as in reference solution and is 2,436 kcal per day per capita, in order to make sensitivity analysis under the same condition.

4.1.2 Numerical results of expanding consumption of rice

In this scenario, we calculated what percentage of FSSR on a calorie basis would be improved, compared with the reference solution, if the consumption of rice increased by 1% to 8%. 8% is equivalent to Japan's minimum access quantity of rice imported under the WTO Agreements on Agriculture. Also we set the upper limit of domestic rice supply to the FY 2002 production level.

The results are shown in Figure 10. As mentioned above, for rice, the upper limit of calories supplied is greater than consumed by about 3%. As the consumption of rice was increasing and domestically produced rice was consumed, the FSSR was improving by 0.55% at the maximum. However, even if any more consumption of rice increased, the FSSR would be no longer improved because of the upper limit of calories supplied by rice.

Next, we calculated the FSSR under no upper limit of calories supplied and unlimited domestic rice supply. In this case, even if the consumption of rice increased by more than 5%, the FSSR would not be improved by more than 0.66%, because of the constraint of calories consumed per day per capita, namely 2,436 kcal. This means that 'I am full now, so I cannot any more rice'.

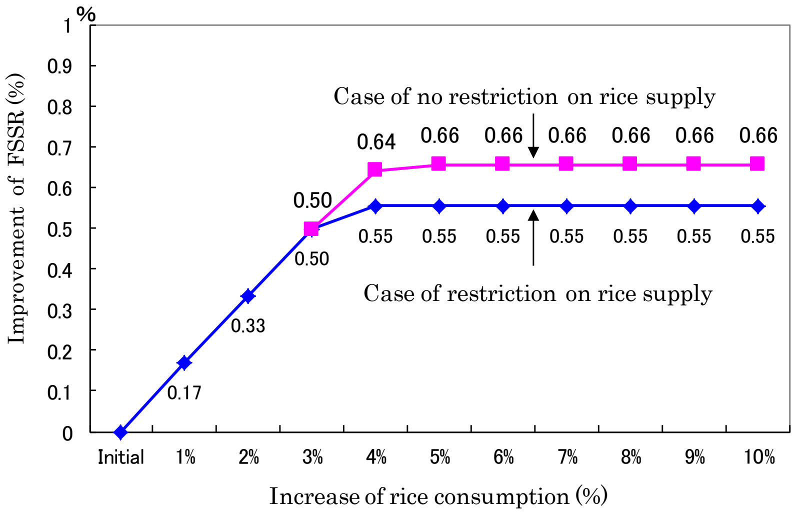


Figure 10 Increase in Rice consumption and FSSR

4.1.3 Numerical results of expanding production of rice for feed

In fiscal 2002, domestic rice for feed is supplied 9,000 tons in Japan. We calculated what percentage of FSSR on a calorie basis would be improved if the production of rice for feed increased by ten times of the current level to two hundred times. We assumed the yield of rice for feed was 600kg/10a, which is the same as rice for food. As the total of calories supplied was larger than calories supplied in the reference case with production of rice for feed, we modified the model to match the reference case with this case. Because we set the upper limit to the calories supplied by domestic livestock and those calories reached the limit, increasing production of rice for feed would not increase the supply of domestic livestock products. Assuming that domestic rice for feed perfectly substituted for imported corn for feed as concentrated feed, FSSR would be improved by 0.05% per 100 thousand ton. Therefore, in order to improve FSSR by 1%, we would need to increase production of rice for feed by two million tons. Currently, for hog and chicken it is possible to substitute domestic rice for feed for imported corn to a certain extent, but for beef cattle in the experimental stage.

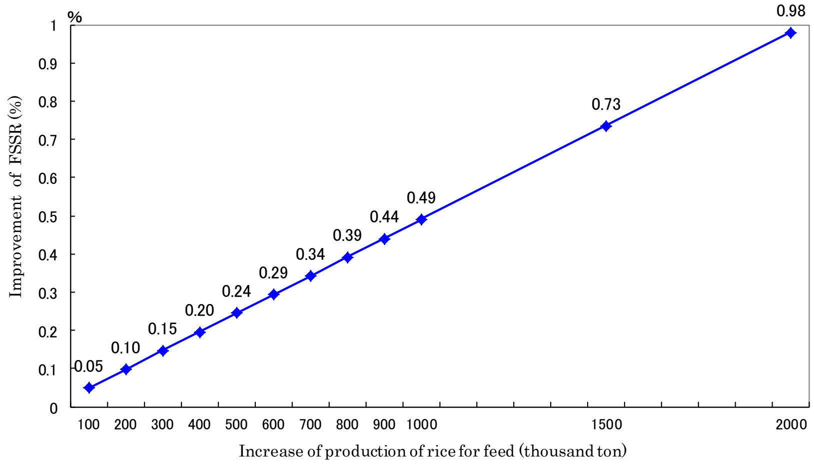


Figure 11 Increase in Livestock Rice production and FSSR

4.1.4 Numerical results of expanding production of wheat and soybeans

In this scenario, we set the following two cases; perfect substitution of domestic wheat and soybeans for imported ones, and no substitution of domestic wheat and soybeans for imported ones.

First, for wheat, we calculated what percentage of FSSR on a calorie basis would be improved by expanding domestic production of wheat under perfect substitution of domestic wheat for imported one.

As shown in Figure 12, under the perfect substitution, FSSR on a calorie basis would be improved by one-quarter to one percent if domestic production of wheat increased by a hundred thousand tons. However, if domestic wheat were no match for imported one in price and quality, and the amount of imported wheat unchanged, FSSR on a calorie basis would be improved by only 0.66% even though the domestic production of wheat increased by more than 500 thousand tons. That reason is the same as a case of expanding consumption of rice in 5.2－ that we set the constraint to calories consumed per day per capita, namely 2,436 kcal.

For soybeans, we also calculated under the same assumption. As shown in Figure 13, under the perfect substitution, FSSR on a calorie basis would be improved by 0.38 percent if domestic production of soybeans increased by a hundred thousand tons. On the other hand, without substitution, FSSR on a calorie basis would be improved by only 0.16 percent even though the domestic production of soybeans increased by more than 60 thousand tons.

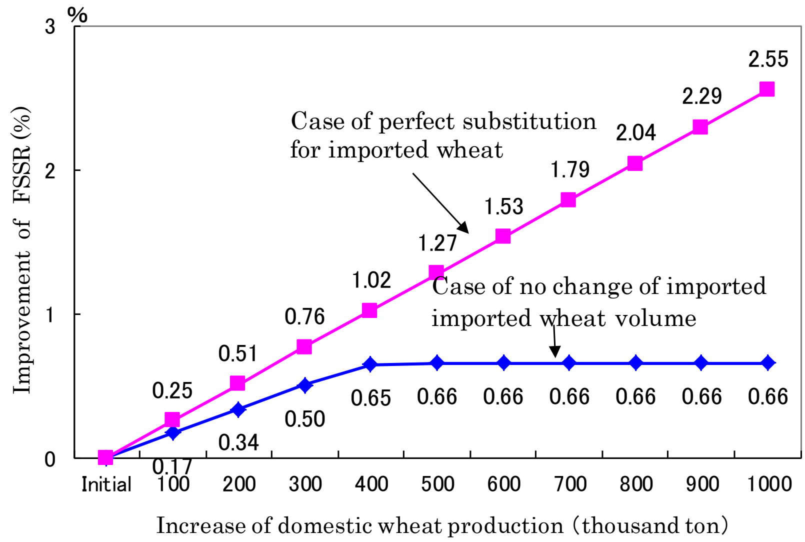


Figure 12 Increase in Wheat production and FSSR

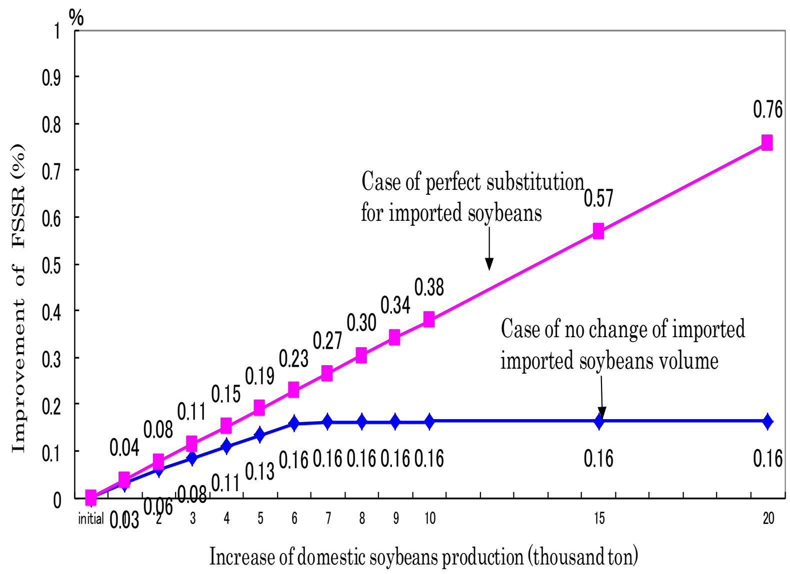


Figure 13 Increase in Soybean production and FSSR

4.1.5 Numerical results of combination of above scenarios

Let us consider what percentage of FSSR would be improved by a combination strategy of expanding consumption of rice and production of rice for food and feed, wheat and soybeans. As these crops are land-extensive, we have to take account of the cropland constraint for increasing production. Suppose we could use 600 thousand ha of surplus cropland which is composed of 200 thousand ha of controlled paddy rice fields ready for rise planting and 400 thousand ha of abandoned cultivated land. Comparing calories per ha supplied by each crop, rice is the greatest and wheat is greater than soybeans. We should grow rice in the whole surplus cropland, to improve FSSR maximally. Is that correct? The answer is 'No.", because we only improve FSSR by 0.66% by expanding consumption and production of rice, as mentioned in 5.2. Under perfect substitution of domestic wheat for imported one, an impact of expanding wheat on FSSR is larger than rice for feed. Therefore we conclude that we should grow wheat in the whole surplus cropland, to get highest FSSR. However, in Japan, the suitable areas to grow wheat are considerably limited. In addition, improving SSR of feed is also very important issue in agricultural policy.

As a second-best strategy, we calculated what percentage of FSSR would be improved by growing wheat and rice for feed in the whole surplus cropland. The results are shown in Figure 14. If it were possible to grow wheat in the whole surplus cropland, FSSR on a calorie basis would be improved by 7%. The more production of rice for feed, the less improvement of FSSR. If rice for feed were expanded by three million tons, FSSR would be improved by only 3.38%.

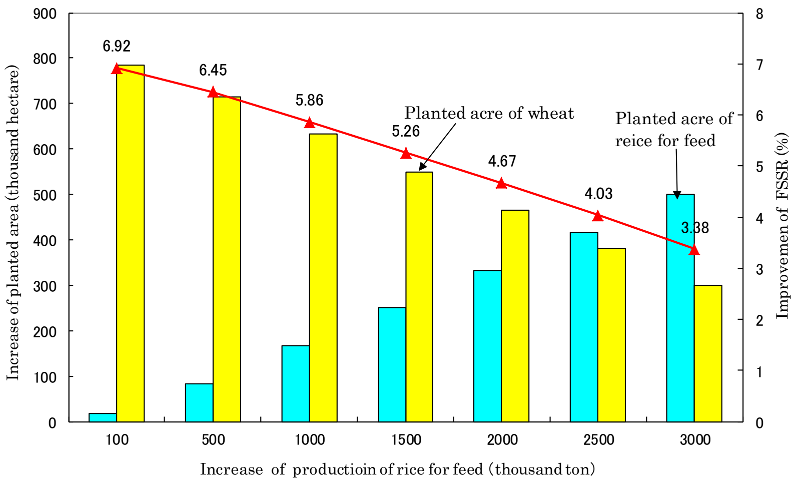


Figure 14 Increase in Rice production and FSSR

5 Conclusion and Future Problems

By using our mathematical programming network flow model, we obtained the following results for Japan's FSSR improvement strategies:

- Expanding consumption of rice would improve FSSR on a calorie basis by only up to 0.66% because of the constraint of calories consumed per day per capita.
- Expanding domestic production of rice for feed would improve FSSR by 0.05% per 100 thousand ton.
- Expanding domestic production of wheat would improve FSSR by 0.25% by

100 thousand tons under the perfect substitution of domestic wheat for imported one. And by growing wheat in the whole surplus cropland (600 thousand ha), FSSR on a calorie basis would be improved by 7%.

- Expanding domestic production of soybeans would improve FSSR by 0.04% by 10 thousand tons under the perfect substitution of domestic soybeans for imported one.

It is necessary to note that improving Japan's FSSR is connected with the substitution of domestic food for imported one. Therefore it is very important to reduce production costs of domestic crops and food and to product high quality food. When considering Japan's future food supply and demand, one of most important factors is a change in food consumption patterns due to transition to a society with a low birthrate and an aging population. For example, by dividing one consumption sector into three sectors in our model, which consist of eating-out/home-meal replacement, food-processing and household consumption, if a low birthrate and an aging population increase a demand for eating-out/home-meal replacement, we can analyze an effect of the change in food demand on future FSSR. As stated above, because of changes in Japanese eating habits by reducing consumption of rice and increasing of livestock products and oil & fats, the current PFC balance becomes far from the ideal PFC balance. If the PFC balance is improved by further promoting Shokuiku (food education), we can also analyze its impact on FSSR.

Notes

(1) Survey results in 2000 and 2006 showed that corresponding percentages for those who responded current Japan’s FSSRs are low were 53％ and 70％ respectively.

(2) Refer to Morita（2006）pp.9-10

(3) Shogenji（2008）argues the contrast between value-added type agriculture and land use type one from the viewpoint of the gap between calorie-based SSR and money-based SSR.

(4) Kayano（2005）investigate recent decreasing factors of FSSR into two periods such as relatively shrinking period from Showa 45 to Showa48, and absolutely shrinking period from Showa 60 to Heisei 10.

(5) Kayano（2005）decompose SSR into $R=\Sigma\, \omega c \cdot ri$ where thermal SSR(R), food item SSR(r) and thermal share(R)

(6) Our estimates are passed upon such data as per capita per day food supply calorie during the period from 1999 to 2008 in food supply and Demand table using population data from 2002 to 2011.

(7) “Depicting a Desirable Food Consumption in Heisei 27”(Ministry of Agriculture, Forestry and Fishery) shows that very few food items exceed Heisei 15 data.

(8) Computational work has been conducted on Express MP2008A.

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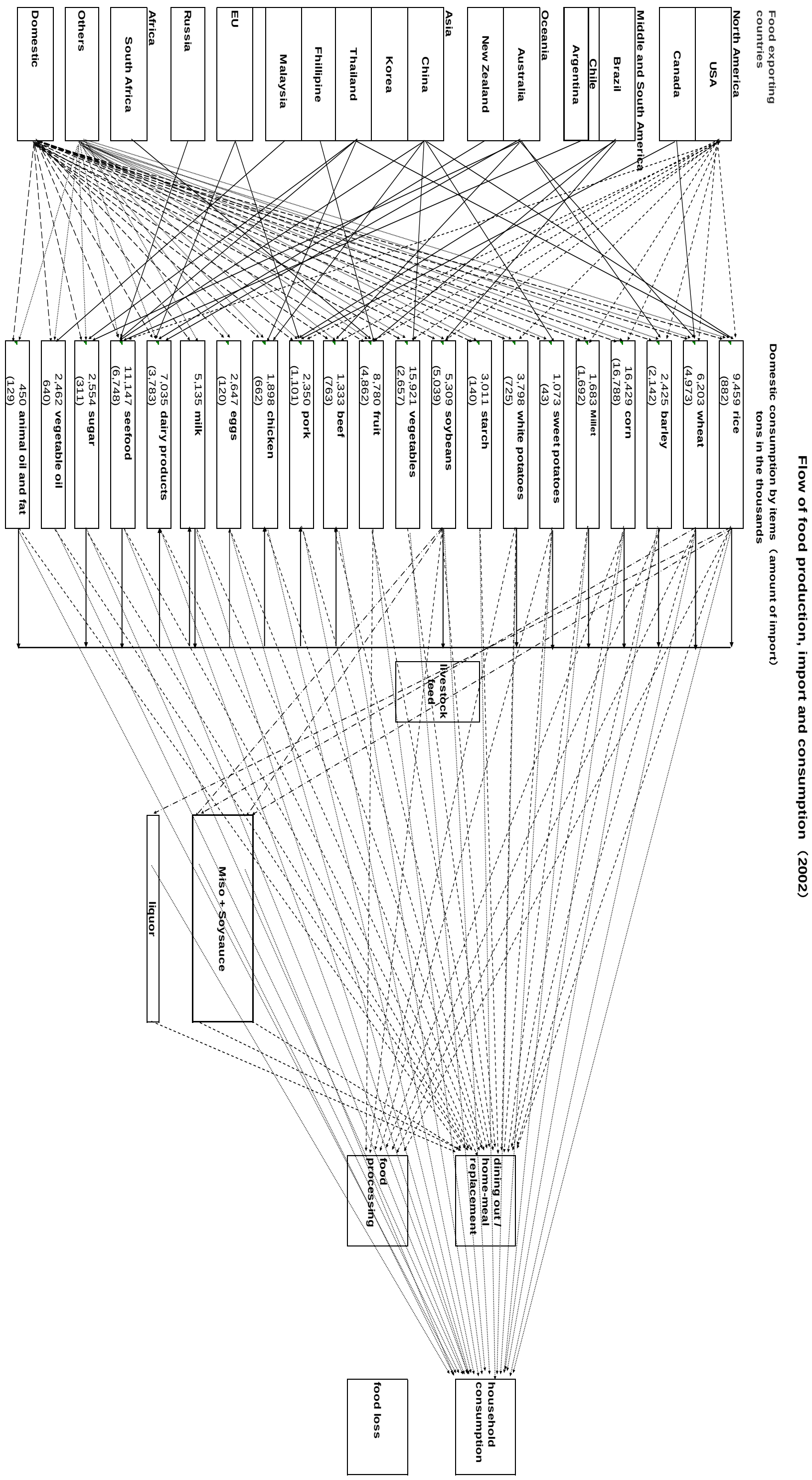
Flow of food production, import and consumption (2002)
Food exporting countries
North America
USA
Canada
Middle and South America
Brazil
Chile
Argentina
Oceania
Australia
New Zealand
Asia
China
Korea
Thailand
Fhilipine
Malaysia
EU
Russia
Africa
South Africa
Others
Domestic
Domestic consumption by items (amount of import)
tons in the thousands
9,459 rice (882)
6,203 wheat (4,973)
2,425 barley (2,142)
16,429 corn (16,788)
1,683 Millet (1,692)
1,073 sweet potatoes (43)
3,798 white potatoes (725)
3,011 starch (140)
5,309 soybeans (5,039)
15,921 vegetables (2,657)
8,780 fruit (4,862)
1,333 beef (763)
2,350 pork (1,101)
1,898 chicken (662)
2,647 eggs (120)
5,135 milk
7,035 dairy products (3,783)
11,147 seefood (6,748)
2,554 sugar (311)
2,462 vegetable oil 640)
450 animal oil and fat (129)
livestock feed
Miso + Soysauce
liquor
food processing
dining out / home-meal replacement
food loss
household consumption