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by

OKIMOTO Madoka

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OKIMOTO Madoka*

Although it is imperative that Food Security and Food Safety be ensured, the bias based on personal income makes the poor, who are sensitive to food prices, exposed to health hazard. Hence, each country should carry out 1) the policies that prevent health damage and 2) the policies that provide the food at low price, since low priced problematic food can nourish the poor.

By the analysis, the sources of the food price hike are revealed as (a) Economic growth, (b) Population growth with expansion of income gap and (c) Improvement of food safety. As for South, as *Kuznets's inverted U-curve hypothesis* implies that the economic growth expands income gap, the food price hike is considered inseparable from the economic development.

Keywords: Food security; Food price hike; Price competition; Income distribution; Population growth, Bounded rationality

JEL Classification: D81; D82; F12; I13; Q12; Q18

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* Graduate School of Economics, Nagoya University, Furo -cho, Chikusa-ku, Nagoya 464-8601

JAPAN, Tel: +81-568-84-9118, E-mail address: okimoto@soec.nagoya-u.ac.jp

I. Introduction

After 2006, the international price of grain has been clearly trending higher compared to the period between 1970 and 2006.[1)] What causes the international food price to become higher and unstable? In general, the source of such a price hike is considered to be, for example, abnormal whether conditions caused by environmental pollution in food exporting countries, a sudden rise in the energy price and a rapid growth of the global population.

In particular, it is worth analyzing how the recent population movements which are globally proceeding and the income gap which has expanded affect the food price, hand in hand with economic advancement. In 2011 United Nations Population Fund declared their forecast that world population would be over 100 billion and especially African population would increase threefold to be about 36 billion by the end of the century, while the increase in Asian population would turn to its decrease in around 2050.[2)] The rise in the population of those in poverty is also becoming serious problem in various countries over the last decades. Hence, taking account of the theories relating to demographic transition that express how economic growth influences population investigated by Stolnity(1964), Leibenstein(1974), Becker(1960) and so on, we develop demand functions affected by such changes in the social structure and incorporate it in the model of international Bertrand competition among a firm located in North and a firm that located in South, and capture the price determination.

In such a transition of economy, the issue that should be resolved is that soaring food prices forces the poor to select and to be nourished by low-priced food made in South, but the South food may involve faults with respect to its safety. Our model describes the market of a country where both the risky food made in South and the food made in North are provided. On this point, the most closely related research is Cardebat and Cassagnard (2010) that assumed Bertrand competition between the North firm and the South firm and asymmetric information about the production process in South, and analyzed exclusion of problematic South good by the North government. But in Cardebat and Cassagnard (2010), the South good did not cause suspected threat of health hazard. Calzolari and Immordino (2005) also investigated international trade in innovative food subject to uncertain health effects, and beautifully grasped decision of governments relating to the food safety through learning process with its solution concept, Perfect Bayesian Equilibrium. On the other hand, we owe the simple explanation of the food price hike under some risks to Nash Equilibrium, as our model is not established for analysis of governments' decision.

What make the problem concerning food safety more serious are consumers' behaviors. In our model, consumers are distributed over their income, and the lower income individuals are less sensitive to health damage. For the effect of income on behaviors, in the context of the choice of health plan prices by low income families, Chan and Gruber (2010) already empirically insisted that the higher income individuals were not more price sensitive and those who had chosen the lowest cost plan were more price sensitive. Although Cawley and Ruhm (2011) that provided an overview of risky health behavior, summarized that income could either increase or decrease unhealthy behaviors, how income affects behaviors should depend on the situation, and our setting that income promotes health consciousness is considered as more appropriate.[3)] Among the vigorous discussion on the bounded rationality, e.g. Herbert (1984), Gruber and Köszegi (2001) and many others, it is also important to note that McDermott et al. (2008) suggested that people could be harmed by their inherent preference toward food, which would tell us the existence of factor that diverts the attention to food safety of us.

In Section II, we organize our model of income and population. In Section III, we determine the demand functions and a game between food industries, completing and closing the model. With the full model in hand, Section IV analyzes nature of food price and Section V concludes(The Appendix reports detailed calculation process.).

II. A Model of Population Changes, Food Prices and Food Safety

We consider the world economy composed of North and South. Since income level and health awareness differ from person to person, it is natural to think that the food products are differentiated and tailored. Hence in the model, a representative North firm(N-firm) in North produces North food(N-food), and a representative South firm(S-firm) in South also produces South food(S-food). And both types of food are provided for the world market and appear easily distinguishable from each other. The problem we set is that the consumption of S-food may cause health damage but there is a demand for S-food as its price is sufficiently low. Hence we discuss at what levels the price of these two types of food are determined in the food market, according as how consumers react to health damage. First, we define the basic quality of food that is common to two types of food and the extent of health damage as q and D, which are to be given and constant.

II.1 Consumers and Health Awareness

Let us consider two levels of utility for the consumers, which depends on q, D and personal income level of each consumer. Namely, the utility obtained from one unit food is expressed as

$$U(q, D; I_i) = U^1(q) + U^2(D; I_i) = \sqrt{q} + (-I_i)D = \begin{cases} \sqrt{q} & for\ safe\ food \\ -I_i D & for\ unsafe\ food \end{cases}.$$

for the entire consumer. Here I_i denotes the personal income level of consumer i, and we suppose that all the N-food and $(1-m)$ percent of S-food are safe food with $q > 0$ and $D = 0$, while m percent of S-food is unsafe food with $D > 0$ and $q = 0$. As the comprehensive utility, $U(q, D; I_i)$ is measured by both $U^1(q)$ and $U^2(D; I_i)$, the concavity of $U^1(q) = \sqrt{q}$ implies that each consumer is risk averse as a whole and $U^2(D; I_i) = (-I_i)D$ expresses the health awareness that depends on personal income level and diminishes in proportion to the extent of his/her poverty. That is, this formula of utility is based on the cardinal behavior for food consumption: (i) when the value of health damage, D is positive, the basic quality, q can no longer make sense, (ii) the behavior relating to food consumption is risk averse, (iii) the lower income individuals are less sensitive to health damage.

For consumer i with I_i, the difference between the utilities and the price of corresponding food give two consumer surpluses:

$$CS^N = \sqrt{q} - p^N, \tag{1}$$

$$CS_i^S = (1-m)\sqrt{q} - mI_i D - p^S. \tag{2}$$

Here p^j (j= N, S) denotes the price of j-food. Comparing two levels of consumer surplus, consumer i chooses N-food or S-food and demands at most one j-food (j= N, S). Here we suppose that consumer i has incentive to purchase a food, if the consumer obtains the non-negative consumer surplus by that food:

$$CS^N \geq 0 \Leftrightarrow \sqrt{q} - p^N \geq 0, \tag{3}$$

$$CS_i^S \geq 0 \Leftrightarrow \frac{(1-m)\sqrt{q} - p^S}{mD} \geq I_i \,. \tag{4}$$

We also suppose that consumer i prefers and chooses the type of food which gives the consumer higher consumer surplus. Accordingly, the income level of marginal consumers is expressed as

$$CS^N = CS_i^S \Leftrightarrow I_i = \frac{p^N - p^S - m\sqrt{q}}{mD}. \tag{5}$$

As to Eq.s(3)-(4), we note that both types of food are provided only after $\sqrt{q} \geq p^N$ and $\sqrt{q} \geq p^S$ are ensured. In addition if $p^N \leq p^S$ held, not only $CS^N > CS_i^S$ would hold for the entire consumer but also, in regards to Eq.(5), $\frac{p^N - p^S - m\sqrt{q}}{mD}$ would be negative. Hence in order to focus on the circumstance that both types of food are provided, we put

Condition1: $\sqrt{q} \geq p^N > p^S$.

Under Condition1, all the consumers can obtain consumer surplus from N-food, while only the poor can obtain consumer surplus from S-food. Lastly, $\frac{(1-m)\sqrt{q} - p^S}{mD} - \frac{p^N - p^S - m\sqrt{q}}{mD} = \frac{\sqrt{q} - p^N}{mD} > 0$ concludes that the income level where the incentive to purchase S-food vanishes is above the marginal income indicated by Eq.(5) as in Figure1. Consequently, we define the threshold of the demand as $I^{TD} \equiv \frac{p^N - p^S - m\sqrt{q}}{mD}$.

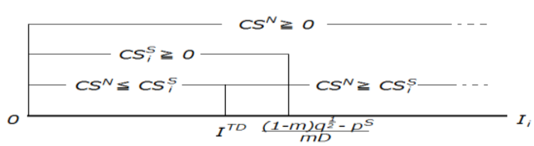

FIGURE 1 Threshold of Demand over the Personal Income Level

II.2 Link between Population Growth and Income

For a country, we suppose that μ denotes the income level of the country and g denotes the income gap of the country so that $\mu - \frac{g}{2}$ represents the bottom income and $\mu + \frac{g}{2}$ represents highest income. We also assume that consumers in the country are distributed continuously, according to the level of I_i over $\left[\mu - \frac{g}{2},\ \mu + \frac{g}{2}\right]$ where $\mu - \frac{g}{2} \geq 0$ and $\mu + \frac{g}{2} > 0$. While μ and g are determined by industrial development, cycle change of economy, etc., we deal with μ and g as given for simplicity.

In addition, as well as Stolnity (1964), Leibenstein (1974) and Becker (1960), at the drawn of economic growth, a rise in μ in general causes the rate of population growth to increase, and after that, the rate turns to fall at the maturation period of the economic growth. This is based on the fact as rule of thumb that the higher μ becomes, the lower the birth rate gradually becomes and the lower the death rate drastically becomes. Accordingly the population in a country tends to rise in most of South developing countries, while many advanced economies are faced with reduce in the population. Taking the above, we develop a function that characterizes the population in each level of I_i as

$$L(I_i) = \begin{cases} xI_i & if \quad 0 \leq I_i \leq I^T \\ \bar{L} - yI_i & if \quad I^T \leq I_i, \end{cases} \tag{6}$$

where $x > 0$ and $y > 0$. Since we disregard other factors that may affect the population, $L(0) = 0$ holds. Note that $\bar{L}$ is not highest income level. Hence according to given μ, g and $L(I_i)$, the total population of the country is determined as $TL(\mu, g) = \int_{\mu-\frac{g}{2}}^{\mu+\frac{g}{2}} L(I_i)dI_i$.

Here we suppose that if $\mu - \frac{g}{2} < I^{TD} < \mu + \frac{g}{2} \leq I^T$ holds, the said country is South developing country, while if $I^T \leq \mu - \frac{g}{2} < I^{TD} < \mu + \frac{g}{2}$ holds, the said country is North developed country. Hence, as in Figure2, $TL(\mu, g)$ in South and North are expressed as

$$TL^{South}(\mu,g)=\int_{\mu-\frac{g}{2}}^{\mu+\frac{g}{2}}(xI_i)dI_i=\left[\frac{1}{2}xI_i{}^2\right]_{\mu-\frac{g}{2}}^{\mu+\frac{g}{2}}=x\mu g,$$

$$TL^{North}(\mu,g)=\int_{\mu-\frac{g}{2}}^{\mu+\frac{g}{2}}(\bar{L}-yI_i)dI_i=\left[\bar{L}I_i-\frac{1}{2}yI_i{}^2\right]_{\mu-\frac{g}{2}}^{\mu+\frac{g}{2}}=(\bar{L}-y\mu)g.$$

Note $\frac{\partial TL^S(\mu,g)}{\partial\mu}>0$ and $\frac{\partial TL^N(\mu,g)}{\partial\mu}<0$ mean that the economic growth in a South(North) country makes the total population increase(decrease), while $\frac{\partial TL^j(\mu,g)}{\partial g}>0$ ($j=N,\ S$) is obvious, since a rise in g means the population growth with expansion of income gap.

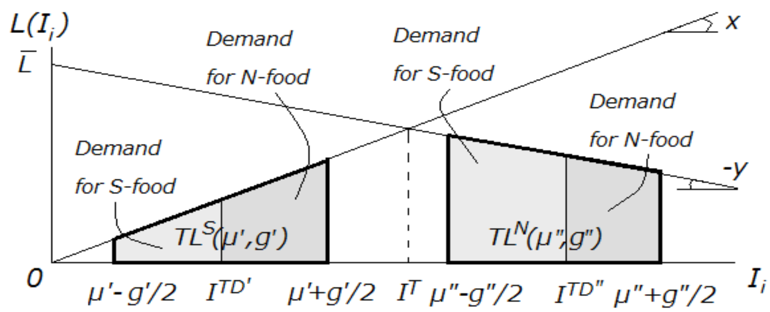

FIGURE 2 Population Growth and Income

Note: Even if the foods provided in North are identical with those provided in South, severer food standard can reduce the ultimate level of m and D in North, and cause I^{TD} in North to be above I^{TD} in South.

III. Timing of Game

To clearly analyze the equilibrium food price, we focus on and suppose the Bertrand competition among N-firm and S-firm in the intestine food market in one country where both types of food are provided as in Figure3. In the model, the said country is consisted of two types of country: (i) Developed country in North, (ii) Developing country in South. The reason why we discriminately treat two types of county is that the demand in South differs from that in North.

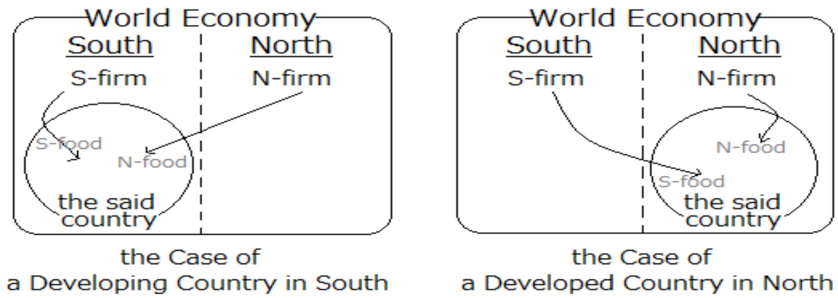

FIGURE 3 Intestine Food Market

III.1 Demands and Producers in the Case of a Developed Country in North

Since we already modeled how consumers were distributed and where the threshold was, the demand functions of j-food ($j= N,\ S$) in a North country are expressed as follows:

$$
\begin{aligned}
x^N &= \int_{I^{TD}}^{\mu+\frac{g}{2}} \left(\overline{L} - yI_i\right) dI_i \\
&= \overline{L}\left(\mu + \frac{g}{2}\right) - \frac{1}{2} y \left(\mu + \frac{g}{2}\right)^2 \\
&- \left[\overline{L}\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right) - \frac{1}{2} y \left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right)^2\right],
\end{aligned} \tag{7}
$$

$$
\begin{aligned}
x^S &= \int_{\mu-\frac{g}{2}}^{I^{TD}} \left(\overline{L} - yI_i\right) dI_i \\
&= \overline{L}\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right) - \frac{1}{2} y \left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right)^2 \\
&- \left[\overline{L}\left(\mu - \frac{g}{2}\right) - \frac{1}{2} y \left(\mu - \frac{g}{2}\right)^2\right].
\end{aligned} \tag{8}
$$

Here x^j ($j = N$, S) denotes the demand for j-food ($j = N$, S). Hence, the decision-makings of N-firm and S-firm under Bertrand competition are displayed as

$$max_{p^N}\pi^N = max_{p^N}(p^N - c^N)x^N,$$

$$max_{p^S}\pi^S = max_{p^S}(p^S - c^S)x^S,$$

where x^N and x^S are characterized by Eq.s(7)-(8) and c^j (j= N, S) expresses the unit cost for food production of j-firm (j= N, S). Then we obtain *F.o.c.*s as

$$\overline{L}\left(\mu+\frac{g}{2}\right)-\frac{1}{2}y\left(\mu+\frac{g}{2}\right)^2-\left[\overline{L}\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)-\frac{1}{2}y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)^2\right]$$
$$+\frac{(p^N-c^N)}{mD}\left[-\overline{L}+y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]=0, \tag{9}$$

$$\overline{L}\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)-\frac{1}{2}y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)^2-\left[\overline{L}\left(\mu-\frac{g}{2}\right)-\frac{1}{2}y\left(\mu-\frac{g}{2}\right)^2\right]$$
$$-\frac{(p^S-c^S)}{mD}\left[\overline{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]=0. \tag{10}$$

Here we put the condition that guarantees *S.o.c.* of N-firm as

Condition2: $\overline{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)-y\left(\frac{p^N-c^N}{mD}\right)>0.$

Hence, we obtain $\frac{d^2\pi^N}{dp^{N2}}=-\frac{1}{mD}\left\{2\left[\overline{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]-y\left(\frac{p^N-c^N}{mD}\right)\right\}<0$. Likewise $\overline{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)=\overline{L}-yI^{TD}>0$ that should hold to construct a plausible analysis demonstrates $\frac{d^2\pi^S}{dp^{S2}}<0$. Additionally, the slopes of reaction function for j-firm (j= N, S), or $\left.\frac{dp^N}{dp^S}\right|_N=\frac{\overline{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)-y\left(\frac{p^N-c^N}{mD}\right)}{2\left[\overline{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]-y\left(\frac{p^N-c^N}{mD}\right)}>0$ and $\left.\frac{dp^N}{dp^S}\right|_S=\frac{2\left[\overline{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]+y\left(\frac{p^S-c^S}{mD}\right)}{\overline{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)+y\left(\frac{p^S-c^S}{mD}\right)}>0$, provide the strategic complementary relationship so that the stability condition, $\left.\frac{dp^N}{dp^S}\right|_S>$

$\left.\frac{dp^N}{dp^S}\right|_N > 0$ is satisfied (See Appendix A.).

III.2 Demands and Producers in the Case of a Developing Country in South

The demand functions of j-food (j= N, S) in a South country are expressed as follows:

$$X^N = \int_{I^{TD}}^{\mu+\frac{g}{2}} (xI_i)dI_i = \frac{1}{2}x\left(\mu+\frac{g}{2}\right)^2 - \frac{1}{2}x\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right)^2, \quad (11)$$

$$X^S = \int_{\mu-\frac{g}{2}}^{I^{TD}} (xI_i)dI_i = \frac{1}{2}x\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right)^2 - \frac{1}{2}x\left(\mu-\frac{g}{2}\right)^2. \quad (12)$$

Here X^j (j= N, S) denotes the demand for j-food (j= N, S). The decision-makings of N-firm and S-firm are also displayed as

$$max_{P^N}\pi^N = max_{P^N}(P^N - c^N)X^N,$$

$$max_{P^S}\pi^S = max_{P^S}(P^S - c^S)X^S,$$

where X^N and X^S are characterized by Eq.s(11)-(12) and c^j (j= N, S) expresses the unit cost for food production of j-firm (j= N, S). To distinguish the price in the case of South from that of North, we capitalize the price in the case of South as P^j (j= N, S). Subsequently we have *F.o.c.*s, the reaction functions, of N-firm and S-firm from the top, as

$$\frac{1}{2}\left(\mu+\frac{g}{2}\right)^2 - \frac{1}{2}\left(\frac{P^N - P^S - m\sqrt{q}}{mD}\right)^2 - \frac{(P^N - c^N)}{mD}\left(\frac{P^N - P^S - m\sqrt{q}}{mD}\right) = 0, (13)$$

$$\frac{1}{2}\left(\frac{P^N - P^S - m\sqrt{q}}{mD}\right)^2 - \frac{1}{2}\left(\mu-\frac{g}{2}\right)^2 - \frac{(P^S - c^S)}{mD}\left(\frac{P^N - P^S - m\sqrt{q}}{mD}\right) = 0. (14)$$

Here, our utilizing the reduced form of Eq.(14) that provides $\left(\frac{P^N - P^S - m\sqrt{q}}{mD}\right) - \frac{(P^S - c^S)}{mD} =$

$\left(\mu-\frac{g}{2}\right)^2\left(\frac{mD}{P^N-P^S-m\sqrt{q}}\right)+\frac{(P^S-c^S)}{mD}>0$, *S.o.c.*s are calculated as $\frac{d^2\pi^N}{dP^{N2}}<0$ and $\frac{d^2\pi^S}{dP^{S2}}=-\frac{x}{mD}\left[2\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)-\frac{(P^S-c^S)}{mD}\right]<0$. Additionally, the slopes of Eq.(13) and Eq.(14), $\left.\frac{dP^N}{dP^S}\right|_N=\frac{\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)+\left(\frac{P^N-c^N}{mD}\right)}{2\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)+\left(\frac{P^N-c^N}{mD}\right)}>0$ and $\left.\frac{dP^N}{dP^S}\right|_S=\frac{2\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)-\left(\frac{P^S-c^S}{mD}\right)}{\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)-\left(\frac{P^S-c^S}{mD}\right)}>0$, conveys to us that the stability condition, $\left.\frac{dP^N}{dP^S}\right|_S>\left.\frac{dP^N}{dP^S}\right|_N>0$ is satisfied (See Appendix A.).

IV. Comparative Statics

As in Figure4, the equilibrium prices in a North country are characterized by Eq.s(9)-(10) and denoted by p^{j*} ($j=N,\ S$) from here. Likewise for a South country, the prices at the equilibrium are characterized by Eq.s(13)-(14) and denoted by P^{j*} ($j=N,\ S$) from here (See Appendix B for the calculation process of the comparative statics and see Appendix C for the derivation of the natures of reaction functions.).

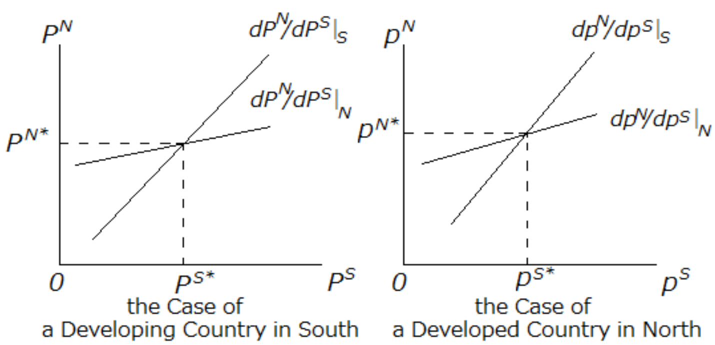

FIGURE 4 Bertrand Equilibrium Prices

IV.1 Population Movement

In the model, the higher level of x (of y) corresponds to the higher growth rate (the more serious negative growth rate) of population, and the higher level of $\bar{L}$ means the later timing that the population takes a downward turn. Since the results with respect to $\bar{L}$ and y are $\frac{dp^{j*}}{d\bar{L}}>(<)0$ and $\frac{dp^{j*}}{dy}<(>)0$ ($j=N,\ S$), if the values of g, c^N and c^S are sufficiently high(low), and the result with respect to x is $\frac{dP^{j*}}{dx}=0$ ($j=N,\ S$), we reach

Theorem 1

I) The population growth rate in a South country has nothing to do with the food price.

II) In a North country, if the income gap of the country and the production costs for North and South firm are large and high, i) as the timing that the population reaches the hit becomes later, the price of North and South food rises, ii) as the negative growth rate of population is more serious, the price of North and South food falls.

First, I) is obtained, since there is no direct effect on the price, or the firms do not mind the population growth rate in South. Comparing the demand functions in the North case with those of the South case, we find that after the economy experiences the transformation in properties of the population growth, the population growth rate begins to influence the food price. This implies that the history of change in population and demand affects the current level of demand, and the reason why the level of the growth rate does not affect the price in South is that the state of population change is before a peak for the population.

As to II), the direct effects are obtained as $\frac{dp^j}{d\bar{L}} > 0$ and $\frac{dp^j}{dy} < 0$ ($j = N,\ S$), if the values of g, c^N and c^S are high, and have a decisive influence on the result. Although the plausible result concerning a North country stated in II) can be reversed by the smaller income gap and the operation at lower costs that implies lower prices, the reversed result is too counterintuitive and can be an exception that corresponds to prices that is too low.

IV.2 Economic Growth and Income Gap

With respect to μ, the result for a North country is $\frac{dp^{j*}}{d\mu} > (<) 0$ ($j = N,\ S$) if the values of c^N and c^S are sufficiently low(high), while the result for a South country is $\frac{dp^{j*}}{d\mu} > (<) 0$ ($j = N,\ S$) if the values of g, c^N and c^S are sufficiently high(low). Here, a rise in μ means a rise in income level in the country. Taking these into account, we have

Theorem 2

For a North(South) country, an economic growth raises the price of both North and South food, if the production costs of North firm and South firm are low (if the income gap *of the country and the production costs for North firm and South firm are large).*

As for Theorem 2, from the direct effects, $\frac{dp^N}{d\mu} > 0$, $\frac{dp^S}{d\mu} < 0$, $\frac{dP^N}{d\mu} > 0$ and $\frac{dP^S}{d\mu} < 0$, it is said that the economic development leads an affluent life, increases the ratio of the rich who have a preference for safer food to the poor, prevents more people from demanding questionable low priced food and makes N-firm want to sell safe food at a higher price and S-firm try to sell questionable food at a lower price. At the same time, the indirect effect through the strategic complementarity of price competition makes the price of N-food lower and the price of S-food higher. Such a strategic pricing disturbs the consumer psychology to obtain safer food and makes the direction of price change unclear.

What transmit a safe food price hike to questionable food and cause an increased price of questionable food are the followings: (i) In North, lower production costs which imply a lower price, (ii) In South, higher production costs which imply a higher price, and large income gap. This implies that, in North(South) where the population decline(population growth) will not stop by the economic growth, a food price hike is caused by the economic growth, due to the price originally low(due to the production at a high cost).

With respect to g, since the results are $\frac{dp^{j*}}{dg} > 0$ and $\frac{dP^{j*}}{dg} > 0$ ($j = N,\ S$), and a rise in g means a population growth accompanied by the expansion of income gap, we arrive at

Theorem 3

Regardless of whether the country belongs to North or South, a population growth with the expansion of income gap raises the price of both North and South food.

Theorem 3 is caused by the direct effects, $\frac{dp^j}{dg} > 0$ and $\frac{dP^j}{dg} > 0$ ($j = N,\ S$) and is a likely consequence by the population growth. The reason why the result is obvious, despite the expansion of income gap, is constant level of μ, or stable income level of the said country.

IV.3 Health Hazard

With respect to m and D, the effects on the price of N-food are $\frac{dp^{N*}}{dm} > 0$, $\frac{dP^{N*}}{dm} > 0$,

$\frac{dp^{N*}}{dD} > 0$ and $\frac{dp^{N*}}{dD} > 0$. Likewise, the effects on the price of S-food are $\frac{dp^{S*}}{dm} < (>)0$, $\frac{dp^{S*}}{dD} < (>)0$, $\frac{dP^{S*}}{dm} < (>)0$ and $\frac{dP^{S*}}{dD} < (>)0$, if p^S is low(high) so that the difference between p^N and p^S is sufficiently large(small). Accordingly, we arrive at

Theorem 4

Regardless of whether the country that belongs to North or South,

I) A rise in the probability or the extent of health damage raises the price of North food.

II) A rise in the probability or the extent of health damage reduces the price of South food, if the price difference between North food and South food is large.

First, the direct effects in a North country are $\frac{dp^N}{dm} > 0$ and $\frac{dp^N}{dD} > 0$, but the signs of $\frac{dp^S}{dm}$ and $\frac{dp^S}{dD}$ are unclear, and the direct effects in a South country are $\frac{dP^N}{dm} > 0$, $\frac{dP^S}{dm} < 0, \frac{dP^N}{dD} > 0$ and $\frac{dP^S}{dD} < 0$. This implies that an increase in health hazard basically makes the people prefer safe food more, N-firm sell safe food at a higher price and, at least in the South case, S-firm sell questionable food at a lower price. Thus a safe food price hike seems to reflect those plausible direct effects; a price hike of questionable food is likely based on the indirect effect by the strategic complementarity that makes S-food high-priced. In addition, a higher price of S-food that corresponds to a smaller price differentiation may be based on smaller health hazard that leads more complemental relation among both types of food.

Finally with respect to q, the results are $\frac{dp^{N*}}{dq} > 0, \frac{dp^{S*}}{dq} < 0, \frac{dP^{N*}}{dq} > 0$ and $\frac{dP^{S*}}{dq} < 0$. Subsequently we find out

Theorem 5

Regardless of whether the country belongs to North or South, a rise in the extent of basic quality of food rises the price of North food, while it reduces the price of South food.

It is said that Theorem 5 reflects the direct effects, $\frac{dp^N}{dq} > 0$, $\frac{dp^S}{dq} < 0$, $\frac{dP^N}{dq} > 0$ and

$\frac{dP^S}{dq} < 0$, and the indirect effects through Bertrand competition are small and of little importance. That is, even though the basic quality of food bears no relation to health hazard prima facie, it influences the food price as if it were an index of safety. The assumed reason for this is that the basic quality is one attraction for the consumer who chooses safe food but is not so important for the consumer of S-food who is found of cheaper goods.

V. Policy Implications

Since the poor tend to be sensitive to the food prices, they are apt to disregard and be exposed to health hazard. Hence, as long as the low priced food made in South can cause health damage, each country should carry out 1) the policies that prevent the expansion of health damage through domestic distribution or international trade: e.g. (i) Monitoring at the distribution channel or at the border, (ii) Certification system of the operation.

Of course, the extreme policy that excludes the food made in South is considered unsuitable from the viewpoint of not only the spirit of the WTO, diplomatic relations but also food security. This is because even if the food made in South has safety problem, such a food bears the important role to provide food for the poor at low price. However the food price hike hinders the full supply of low priced food. Hence at least, it is desirable that the price of food made in South does not rise, and facing the food price hike, the government should carry out 2) the policies that provide the food for the poor at low price: e.g. (i) A flexible reduction in tariff rate on a food product that faces the price hike, (ii) To make the level of income support linked to a surge in food prices.

Here, by the analysis, regardless of whether a country belongs to North or South, the sources of the food price hike are supposed to be the followings: (a) Economic growth (See Theorem 2; Note that the price hike in North is not that big of a deal, because it is implied that the negative population growth can suppress the soaring food prices by Theorem 1), (b) Population growth accompanied by expansion of income gap (See Theorem 3), (c) Improvement of food safety (See Theorem 4; Note that the improvement of safety makes the price of food made in North fall).

First, it is supposed that the food price hike in South is basically caused by (a) and (b), suppressing the life of people. It is because, based on *Kuznets's inverted U-curve hypothesis*: the income gap expands at an early stage of economic development, as China and India have experienced in recent years, and the income gap turns to shrink at a later stage(See Kuznets (1955)), we can consider (a)(Economic growth) triggers (b)(Expansion of income gap with population growth) in South countries. Namely it is said that, in South *what causes the food price hike is the process of economic development itself*. Hence in South, since the food price hike is inseparable from the economic growth, there is no sweeping countermeasure against the price hike and the policies that provide the food for the poor at low price are needed all the more.

Secondly, (c) shows the unexpected but natural cause of the food price hike especially in North. As shown in Theorem 4, if the safety of the South food is improved through policy tools, the price of the South food rises and the price of the North food falls, so that the price difference among foods reduces. This might appear good result but, in fact, such uniformed food prices is a burden to the poor, which is a noteworthy fact. Viewed from the opposite side, the deterioration in health hazard causes the price surge in the North food, but the true nature of that issue is not the price hike but health hazard and we should attach importance to the policies that prevent the expansion of health damage.

In the last place, the depopulation in North and the population growth in South imply the shrinkage of the North food market and the expansion of the South food market. Hence looking ahead to the future, we might financially need to assist the food industry in North to export the safe food to South countries that face the serious food price hike.

Appendix

A. The Stability Conditions

1 the Case of a Developed Country in North

Thanks to Condition2, the sign of the stability condition is obtained as

$$\left.\frac{dp^N}{dp^S}\right|_S - \left.\frac{dp^N}{dp^S}\right|_N \Leftrightarrow \frac{2\left[\bar{L} - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right)\right] + y\left(\frac{p^S - c^S}{mD}\right)}{\bar{L} - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right) + y\left(\frac{p^S - c^S}{mD}\right)} - \frac{\bar{L} - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right) - y\left(\frac{p^N - c^N}{mD}\right)}{2\left[\bar{L} - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right)\right] - y\left(\frac{p^N - c^N}{mD}\right)}$$

$$\Leftrightarrow \left[\bar{L} - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right)\right]\left\{3\left[\bar{L} - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right)\right] - y\left(\frac{p^N - c^N}{mD}\right) + y\left(\frac{p^S - c^S}{mD}\right)\right\} > 0.$$

2 the Case of a Developed Country in South

The sign of the stability condition is obtained as

$$\left.\frac{dP^N}{dP^S}\right|_S - \left.\frac{dP^N}{dP^S}\right|_N \Leftrightarrow \frac{2\left(\frac{P^N - P^S - m\sqrt{q}}{mD}\right) - \left(\frac{P^S - c^S}{mD}\right)}{\left(\frac{P^N - P^S - m\sqrt{q}}{mD}\right) - \left(\frac{P^S - c^S}{mD}\right)} - \frac{\left(\frac{P^N - P^S - m\sqrt{q}}{mD}\right) + \left(\frac{P^N - c^N}{mD}\right)}{2\left(\frac{P^N - P^S - m\sqrt{q}}{mD}\right) + \left(\frac{P^N - c^N}{mD}\right)} > 0.$$

B. The Comparative Statics

1 the Case of a Developed Country in North

$$\frac{1}{mD}\begin{bmatrix} -\left\{2\left[\bar{L} - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right)\right] - y\frac{(p^N - c^N)}{mD}\right\}, & \bar{L} - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right) - y\frac{(p^N - c^N)}{mD} \\ \bar{L} - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right) + y\frac{(p^S - c^S)}{mD}, & -\left\{2\left[\bar{L} - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right)\right] + y\frac{(p^S - c^S)}{mD}\right\} \end{bmatrix}\begin{bmatrix} dp^N \\ dp^S \end{bmatrix}$$

$$= \begin{bmatrix} \frac{1}{2}\left(\mu + \frac{g}{2}\right)^2 - \frac{1}{2}\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right)^2 - \frac{(p^N - c^N)}{mD}\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right) \\ -\frac{1}{2}\left(\mu - \frac{g}{2}\right)^2 + \frac{1}{2}\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right)^2 - \frac{(p^S - c^S)}{mD}\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right) \end{bmatrix} dy + \begin{bmatrix} -\left[\bar{L} - y\left(\mu + \frac{g}{2}\right)\right] \\ \bar{L} - y\left(\mu - \frac{g}{2}\right) \end{bmatrix} d\mu$$

$$-\frac{1}{2}\begin{bmatrix} \bar{L} - y\left(\mu + \frac{g}{2}\right) \\ \bar{L} - y\left(\mu - \frac{g}{2}\right) \end{bmatrix} dg + \frac{1}{2D\sqrt{q}}\begin{bmatrix} -\left[\bar{L} - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right) - y\frac{(p^N - c^N)}{mD}\right] \\ \bar{L} - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right) + y\frac{(p^S - c^S)}{mD} \end{bmatrix} dq$$

$$-\frac{1}{m}\begin{bmatrix} \frac{(p^N - p^S)}{mD}\left[\bar{L} - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right) - y\frac{(p^N - c^N)}{mD}\right] + \frac{(p^N - c^N)}{mD}\left[\bar{L} - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right)\right] \\ -\frac{(p^N - p^S)}{mD}\left[\bar{L} - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right) + y\frac{(p^S - c^S)}{mD}\right] + \frac{(p^S - c^S)}{mD}\left[\bar{L} - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right)\right] \end{bmatrix} dm$$

$$+\frac{1}{D}\begin{bmatrix} -\left\{\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right)\left[\bar{L} - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right) - y\frac{(p^N - c^N)}{mD}\right] + \frac{(p^N - c^N)}{mD}\left[\bar{L} - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right)\right]\right\} \\ \left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right)\left[\bar{L} - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right) + y\frac{(p^S - c^S)}{mD}\right] - \frac{(p^S - c^S)}{mD}\left[\bar{L} - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right)\right] \end{bmatrix} dD$$

$$-\begin{bmatrix} \left(\mu + \frac{g}{2}\right) - \left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right) - \frac{(p^N - c^N)}{mD} \\ \left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right) - \left(\mu - \frac{g}{2}\right) - \frac{(p^S - c^S)}{mD} \end{bmatrix} d\bar{L}.$$

Taken Condition2 into account, we have

$$|J^N| = \frac{1}{(mD)^2}\left[\bar{L} - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right)\right]\left\{3\left[\bar{L} - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right)\right] - y\frac{(p^N - c^N)}{mD} + y\frac{(p^S - c^S)}{mD}\right\} > 0.$$

If the values of g, c^N and c^S are sufficiently high(low), the results with respect to $\bar{L}$ and y are as follows.

$$(mD)|J^N|\frac{dp^{N*}}{d\bar{L}} = \left[\left(\mu+\frac{g}{2}\right)-\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)-\frac{(p^N-c^N)}{mD}\right]\left\{2\left[\bar{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]+y\frac{(p^S-c^S)}{mD}\right\}$$

$$+\left[\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)-\left(\mu-\frac{g}{2}\right)-\frac{(p^S-c^S)}{mD}\right]\left[\bar{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)-y\frac{(p^N-c^N)}{mD}\right]$$

$$=\frac{y}{\bar{\bar{L}}}\left[\boldsymbol{\frac{1}{2}\left(\mu+\frac{g}{2}\right)^2-\frac{1}{2}\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)^2}\right.$$

$$\left.-\boldsymbol{\frac{(p^N-c^N)}{mD}\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)}\right]\left\{2\left[\bar{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]+y\frac{(p^S-c^S)}{mD}\right\}$$

$$+\frac{y}{\bar{\bar{L}}}\left[\boldsymbol{\frac{1}{2}\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)^2-\frac{1}{2}\left(\mu-\frac{g}{2}\right)^2-\frac{(p^S-c^S)}{mD}\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)}\right]\left[\bar{L}\right.$$

$$\left.-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)-y\frac{(p^N-c^N)}{mD}\right]>(<)0, \qquad (\because Eq.(9), Eq.(10))$$

$$(mD)|J^N|\frac{dp^{S*}}{d\bar{L}} = \left[\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)-\left(\mu-\frac{g}{2}\right)-\frac{(p^S-c^S)}{mD}\right]\left\{2\left[\bar{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]-y\frac{(p^N-c^N)}{mD}\right\}$$

$$+\left[\left(\mu+\frac{g}{2}\right)-\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)-\frac{(p^N-c^N)}{mD}\right]\left[\bar{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)+y\frac{(p^S-c^S)}{mD}\right]$$

$$=\frac{y}{\bar{\bar{L}}}\left[\boldsymbol{\frac{1}{2}\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)^2-\frac{1}{2}\left(\mu-\frac{g}{2}\right)^2}\right.$$

$$\left.-\boldsymbol{\frac{(p^S-c^S)}{mD}\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)}\right]\left\{2\left[\bar{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]-y\frac{(p^N-c^N)}{mD}\right\}$$

$$+\frac{y}{\bar{\bar{L}}}\left[\boldsymbol{\frac{1}{2}\left(\mu+\frac{g}{2}\right)^2-\frac{1}{2}\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)^2-\frac{(p^N-c^N)}{mD}\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)}\right]\left[\bar{L}\right.$$

$$\left.-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)+y\frac{(p^S-c^S)}{mD}\right]>(<)0, \qquad (\because Eq.(9), Eq.(10))$$

$$-(mD)|J^N|\frac{dp^{N*}}{dy} = \left[\frac{1}{2}\left(\mu+\frac{g}{2}\right)^2-\frac{1}{2}\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)^{\mathbf{2}}\right.$$

$$\left.-\frac{(p^N-c^N)}{mD}\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]\left\{2\left[\bar{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]+y\frac{(p^S-c^S)}{mD}\right\}$$

$$+\left[\frac{1}{2}\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)^{\mathbf{2}}-\frac{1}{2}\left(\mu-\frac{g}{2}\right)^2-\frac{(p^S-c^S)}{mD}\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]\left[\bar{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right.$$

$$\left.-y\frac{(p^N-c^N)}{mD}\right]>(<)0,$$

$$
\begin{aligned}
-(mD)|J^N|\frac{dp^{S*}}{dy} = &\left[\frac{1}{2}\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right)^{\mathbf{2}} - \frac{1}{2}\left(\mu - \frac{g}{2}\right)^2\right. \\
&\left. - \frac{(p^S - c^S)}{mD}\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right)\right]\left\{2\left[\bar{L} - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right)\right] - y\frac{(p^N - c^N)}{mD}\right\} \\
&+ \left[\frac{1}{2}\left(\mu + \frac{g}{2}\right)^2 - \frac{1}{2}\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right)^{\mathbf{2}} - \frac{(p^N - c^N)}{mD}\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right)\right]\left[\bar{L}\right. \\
&\left. - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right) + y\frac{(p^S - c^S)}{mD}\right] > (<)0.
\end{aligned}
$$

If the values of c^N and c^S are sufficiently low(high),the results with respect to μ are as follows.

$$
\begin{aligned}
(mD)|J^N|\frac{dp^{N*}}{d\mu} = &\left[\bar{L} - y\left(\mu + \frac{g}{2}\right)\right]\left\{2\left[\bar{L} - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right)\right] + y\frac{(p^S - c^S)}{mD}\right\} \\
&- \left[\bar{L} - y\left(\mu - \frac{g}{2}\right)\right]\left\{\left[\bar{L} - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right)\right] - y\frac{(p^N - c^N)}{mD}\right\} > (<)0,
\end{aligned}
$$

$$
\begin{aligned}
(mD)|J^N|\frac{dp^{S*}}{d\mu} = &-\left[\bar{L} - y\left(\mu - \frac{g}{2}\right)\right]\left\{2\left[\bar{L} - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right)\right] - y\frac{(p^N - c^N)}{mD}\right\} \\
&+ \left[\bar{L} - y\left(\mu + \frac{g}{2}\right)\right]\left\{\left[\bar{L} - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right)\right] + y\frac{(p^S - c^S)}{mD}\right\} > (<)0.
\end{aligned}
$$

The results with respect to g are as follows and the signs are determinate.

$$
\begin{aligned}
(mD)|J^N|\frac{dp^{N*}}{dg} = &\frac{1}{2}\left[\bar{L} - y\left(\mu + \frac{g}{2}\right)\right]\left\{2\left[\bar{L} - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right)\right] + y\frac{(p^S - c^S)}{mD}\right\} \\
&+ \frac{1}{2}\left[\bar{L} - y\left(\mu - \frac{g}{2}\right)\right]\left[\bar{L} - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right) - y\frac{(p^N - c^N)}{mD}\right] > 0,
\end{aligned}
$$

$$
\begin{aligned}
(mD)|J^N|\frac{dp^{S*}}{dg} = &\frac{1}{2}\left[\bar{L} - y\left(\mu - \frac{g}{2}\right)\right]\left\{2\left[\bar{L} - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right)\right] - y\frac{(p^N - c^N)}{mD}\right\} \\
&+ \frac{1}{2}\left[\bar{L} - y\left(\mu + \frac{g}{2}\right)\right]\left[\bar{L} - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right) + y\frac{(p^S - c^S)}{mD}\right] > 0.
\end{aligned}
$$

The results with respect to m and D are as follows.

$$
\begin{aligned}
m^2D|J^N|\frac{dp^{N*}}{dm} = &\left[\bar{L} - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right)\right]\left\langle\left[\frac{(p^N - p^S)}{mD} + \frac{(p^S - c^S)}{mD}\right]\left[\bar{L} - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right) - y\frac{(p^N - c^N)}{mD}\right]\right. \\
&\left. + \frac{(p^N - c^N)}{mD}\left\{2\left[\bar{L} - y\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right)\right] + y\frac{(p^S - c^S)}{mD}\right\}\right\rangle > 0,
\end{aligned}
$$

$$(m^2D)|J^N|\frac{dp^{S*}}{dm}=\left[\bar{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]\langle\frac{(p^S-c^S)}{mD}\left\{2\left[\bar{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]-y\frac{(p^N-c^N)}{mD}\right\}$$

$$-\left[\frac{(p^N-p^S)}{mD}-\frac{(p^N-c^N)}{mD}\right]\left[\bar{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)+y\frac{(p^S-c^S)}{mD}\right]\rangle,$$

$$m(D)^2|J^N|\frac{dp^{N*}}{dD}=\langle\left[\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)+\frac{(p^S-c^S)}{mD}\right]\left[\bar{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)-y\frac{(p^N-c^N)}{mD}\right]$$

$$+\frac{(p^N-c^N)}{mD}\left\{2\left[\bar{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]+y\frac{(p^S-c^S)}{mD}\right\}\rangle\left[\bar{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]>0,$$

$$m(D)^2|J^N|\frac{dp^{S*}}{dD}=\left[\bar{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]\langle\frac{(p^S-c^S)}{mD}\left\{2\left[\bar{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]-y\frac{(p^N-c^N)}{mD}\right\}$$

$$-\left[\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)-\frac{(p^N-c^N)}{mD}\right]\left[\bar{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)+y\frac{(p^S-c^S)}{mD}\right]\rangle.$$

The condition that determines the sign of $\frac{dp^{S*}}{dm}$ and that of $\frac{dp^{S*}}{dD}$ are as follows.

$$\frac{dp^{S*}}{dm}<0\Leftrightarrow(p^S-c^S)\frac{2\left[\bar{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]-y\frac{(p^N-c^N)}{mD}}{\bar{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)+y\frac{(p^S-c^S)}{mD}}+(p^N-c^N)<(\boldsymbol{p^N}-\boldsymbol{p^S}),$$

$$\frac{dp^{S*}}{dD}<0\Leftrightarrow(p^S-c^S)\frac{2\left[\bar{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]-y\frac{(p^N-c^N)}{mD}}{\bar{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)+y\frac{(p^S-c^S)}{mD}}+(p^N-c^N)<(\boldsymbol{p^N}-\boldsymbol{p^S}-m\sqrt{q}).$$

The results with respect to q are as follows and the signs are determinate.

$$2m\sqrt{q}(D)^2|J^N|\frac{dp^{N*}}{dq}=\left[\bar{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)-y\frac{(p^N-c^N)}{mD}\right]\left[\bar{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]>0,$$

$$2m\sqrt{q}(D)^2|J^N|\frac{dp^{S*}}{dq}=-\left[\bar{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)+y\frac{(p^S-c^S)}{mD}\right]\left[\bar{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]<0.$$

2 the Case of a Developing Country in South

$$\frac{1}{mD}\begin{bmatrix}-\left[2\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)+\frac{(P^N-c^N)}{mD}\right], & \left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)+\frac{(P^N-c^N)}{mD} \\ \left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)-\frac{(P^S-c^S)}{mD}, & -\left[2\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)-\frac{(P^S-c^S)}{mD}\right]\end{bmatrix}\begin{bmatrix}dP^N\\ dP^S\end{bmatrix}$$

$$=\begin{bmatrix}0\\0\end{bmatrix}dx+\begin{bmatrix}-\left(\mu+\frac{g}{2}\right)\\ \left(\mu-\frac{g}{2}\right)\end{bmatrix}d\mu-\frac{1}{2}\begin{bmatrix}\left(\mu+\frac{g}{2}\right)\\ \left(\mu-\frac{g}{2}\right)\end{bmatrix}dg+\frac{1}{2D\sqrt{q}}\begin{bmatrix}-\left[\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)+\frac{(P^N-c^N)}{mD}\right]\\ \left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)-\frac{(P^S-c^S)}{mD}\end{bmatrix}dq$$

$$-\frac{1}{m}\left[\begin{array}{l}\left[\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)+\frac{(P^N-c^N)}{mD}\right]\frac{\sqrt{q}}{D}+2\left[\frac{1}{2}\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)^2+\frac{(P^N-c^N)}{mD}\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)\right]\\-\left\{\left[\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)-\frac{(P^S-c^S)}{mD}\right]\frac{\sqrt{q}}{D}+2\left[\frac{1}{2}\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)^2-\frac{(P^S-c^S)}{mD}\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)\right]\right\}\end{array}\right]dm$$

$$+\frac{1}{D}\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)\left[\begin{array}{c}-\left[\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)+2\frac{(P^N-c^N)}{mD}\right]\\\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)-\frac{(P^S-c^S)}{mD}\end{array}\right]dD.$$

Since Eq.(14) demonstrates that $2\left(P^N-P^S-m\sqrt{q}\right)-(P^S-c^S)>0$, we have

$$|J^S|=\frac{1}{(mD)^2}\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)\left[3\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)-\frac{(P^S-c^S)}{mD}+\frac{(P^N-c^N)}{mD}\right]>0.$$

If the values of g, c^N and c^S are sufficiently high(low)The results are as follows.

$$(mD)|J^S|\frac{dP^{N*}}{d\mu}=\left(\mu+\frac{g}{2}\right)\left[2\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)-\frac{(P^S-c^S)}{mD}\right]-\left(\mu-\frac{g}{2}\right)\left[\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)+\frac{(P^N-c^N)}{mD}\right]>(<)0,$$

$$(mD)|J^S|\frac{dP^{S*}}{d\mu}=\left(\mu+\frac{g}{2}\right)\left[\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)-\frac{(P^S-c^S)}{mD}\right]-\left(\mu-\frac{g}{2}\right)\left[2\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)+\frac{(P^N-c^N)}{mD}\right]>(<)0.$$

The results with respect to g are as follows and the signs are determinate.

$$(mD)|J^S|\frac{dP^{N*}}{dg}=\frac{1}{2}\left(\mu+\frac{g}{2}\right)\left[2\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)-\frac{(P^S-c^S)}{mD}\right]+\frac{1}{2}\left(\mu-\frac{g}{2}\right)\left[\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)+\frac{(P^N-c^N)}{mD}\right]>0,$$

$$(mD)|J^S|\frac{dP^{S*}}{dg}=\frac{1}{2}\left(\mu-\frac{g}{2}\right)\left[2\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)+\frac{(P^N-c^N)}{mD}\right]+\frac{1}{2}\left(\mu+\frac{g}{2}\right)\left[\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)-\frac{(P^S-c^S)}{mD}\right]>0.$$

The results with respect to m and D are as follows.

$$m^2D|J^S|\frac{dP^{N*}}{dm}=\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)\left\{\frac{\sqrt{q}}{D}\left[\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)+\frac{(P^N-c^N)}{mD}\right]\right.$$
$$\left.+\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)\left[\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)+3\frac{(P^N-c^N)}{mD}+\frac{(P^S-c^S)}{mD}\right]\right\}>0,$$

$$m^2D|J^S|\frac{dP^{S*}}{dm}=-\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)\left\{\frac{\sqrt{q}}{D}\left[\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)-\frac{(P^S-c^S)}{mD}\right]\right.$$
$$\left.+\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)\left[\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)-3\frac{(P^S-c^S)}{mD}-\frac{(P^N-c^N)}{mD}\right]\right\},$$

$$m(D)^2|J^S|\frac{dP^{N*}}{dD}=\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)\left\{\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)^2+\frac{(P^N-c^N)}{mD}\left[3\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)-\frac{(P^S-c^S)}{mD}\right]\right\}>0,$$

$$m(D)^2|J^S|\frac{dP^{S*}}{dD}=-\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)\left[\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)-\frac{(P^S-c^S)}{mD}\right]\left[\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)-\frac{(P^N-c^N)}{mD}\right].$$

The condition that determines the sign of $\frac{dP^{S*}}{dm}$ and that of $\frac{dP^{S*}}{dD}$ are as follows.

$$\frac{dP^{S*}}{dm}<0\Leftrightarrow m\sqrt{q}\frac{\left(P^N-P^S-m\sqrt{q}\right)-(P^S-c^S)}{P^N-P^S-m\sqrt{q}}+\left(\boldsymbol{P^N}-\boldsymbol{P^S}-m\sqrt{q}\right)>3(P^S-c^S)+(P^N-c^N),$$

$$\frac{dP^{S*}}{dD}<0\Leftrightarrow\left(\boldsymbol{P^N}-\boldsymbol{P^S}-m\sqrt{q}\right)>(P^N-c^N).$$

The results with respect to q are as follows and the signs are determinate.

$$2m\sqrt{q}(D)^2|J^S|\frac{dP^{N*}}{dq}=\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)\left[\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)+\frac{(P^N-c^N)}{mD}\right]>0,$$

$$2m\sqrt{q}(D)^2|J^S|\frac{dP^{S*}}{dq}=-\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)\left[\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)-\frac{(P^S-c^S)}{mD}\right]<0.$$

C. The Nature of Reaction Functions

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$$\frac{dp^N}{d\bar{L}}=\frac{\left[\left(\mu+\frac{g}{2}\right)-\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)-\frac{(p^N-c^N)}{mD}\right]mD}{2\left[\bar{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]-y\frac{(p^N-c^N)}{mD}}$$

$$=\frac{\frac{y}{\bar{L}}\left[\frac{1}{2}\left(\mu+\frac{g}{2}\right)^2-\frac{1}{2}\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)^2-\frac{(p^N-c^N)}{mD}\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]mD}{2\left[\bar{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]-y\frac{(p^N-c^N)}{mD}},\qquad(\because Eq.(9))$$

$$\frac{dp^S}{d\bar{L}}=\frac{\left[\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)-\left(\mu-\frac{g}{2}\right)-\frac{(p^S-c^S)}{mD}\right]mD}{2\left[\bar{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]+y\frac{(p^S-c^S)}{mD}}$$

$$=\frac{\frac{y}{\bar{L}}\left[-\frac{1}{2}\left(\mu-\frac{g}{2}\right)^2+\frac{1}{2}\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)^2-\frac{(p^S-c^S)}{mD}\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]mD}{2\left[\bar{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]+y\frac{(p^S-c^S)}{mD}},\qquad(\because Eq.(10))$$

$$\frac{dp^N}{dy}=-\frac{\left[\frac{1}{2}\left(\mu+\frac{g}{2}\right)^2-\frac{1}{2}\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)^2-\frac{(p^N-c^N)}{mD}\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]mD}{2\left[\bar{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]-y\frac{(p^N-c^N)}{mD}},$$

$$\frac{dp^S}{dy}=-\frac{\left[-\frac{1}{2}\left(\mu-\frac{g}{2}\right)^2+\frac{1}{2}\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)^2-\frac{(p^S-c^S)}{mD}\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]mD}{2\left[\overline{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]+y\frac{(p^S-c^S)}{mD}},$$

$$\frac{dp^N}{d\mu}=\frac{\left[\overline{L}-y\left(\mu+\frac{g}{2}\right)\right]mD}{2\left[\overline{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]-y\frac{(p^N-c^N)}{mD}}>0,\frac{dp^S}{d\mu}=-\frac{\left[\overline{L}-y\left(\mu-\frac{g}{2}\right)\right]mD}{2\left[\overline{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]+y\frac{(p^S-c^S)}{mD}}<0,$$

$$\frac{dp^N}{dg}=\frac{\frac{1}{2}\left[\overline{L}-y\left(\mu+\frac{g}{2}\right)\right]mD}{2\left[\overline{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]-y\frac{(p^N-c^N)}{mD}}>0,\frac{dp^S}{dg}=\frac{\frac{1}{2}\left[\overline{L}-y\left(\mu-\frac{g}{2}\right)\right]mD}{2\left[\overline{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]+y\frac{(p^S-c^S)}{mD}}>0,$$

$$\frac{dp^N}{dm}=\frac{\left\{\frac{(p^N-p^S)}{mD}\left[\overline{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)-y\frac{(p^N-c^N)}{mD}\right]+\frac{(p^N-c^N)}{mD}\left[\overline{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]\right\}D}{2\left[\overline{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]-y\frac{(p^N-c^N)}{mD}}>0,$$

$$\frac{dp^S}{dm}=\frac{\left\{-\frac{(p^N-p^S)}{mD}\left[\overline{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)+y\frac{(p^S-c^S)}{mD}\right]+\frac{(p^S-c^S)}{mD}\left[\overline{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]\right\}D}{2\left[\overline{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]+y\frac{(p^S-c^S)}{mD}},$$

$$\frac{dp^N}{dD}=\frac{\left\{\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\left[\overline{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)-y\frac{(p^N-c^N)}{mD}\right]+\frac{(p^N-c^N)}{mD}\left[\overline{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]\right\}m}{2\left[\overline{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]-y\frac{(p^N-c^N)}{mD}}$$

$$>0,$$

$$\frac{dp^S}{dD}=\frac{-\left\{\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\left[\overline{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)+y\frac{(p^S-c^S)}{mD}\right]-\frac{(p^S-c^S)}{mD}\left[\overline{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]\right\}m}{2\left[\overline{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]+y\frac{(p^S-c^S)}{mD}},$$

$$\frac{dp^N}{dq}=\frac{\frac{1}{2\sqrt{q}}\left[\overline{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)-y\frac{(p^N-c^N)}{mD}\right]m}{2\left[\overline{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]-y\frac{(p^N-c^N)}{mD}}>0,$$

$$\frac{dp^S}{dq}=-\frac{\frac{1}{2\sqrt{q}}\left[\overline{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)+y\frac{(p^S-c^S)}{mD}\right]m}{2\left[\overline{L}-y\left(\frac{p^N-p^S-m\sqrt{q}}{mD}\right)\right]+y\frac{(p^S-c^S)}{mD}}<0,$$

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$$\frac{dP^N}{d\mu}=\frac{\left(\mu+\frac{g}{2}\right)mD}{2\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)+\frac{(P^N-c^N)}{mD}}>0,\qquad \frac{dP^S}{d\mu}=-\frac{\left(\mu-\frac{g}{2}\right)mD}{2\left(\frac{P^N-P^S-m\sqrt{q}}{mD}\right)-\frac{(P^S-c^S)}{mD}}<0,$$

$$\frac{dP^N}{dg} = \frac{\frac{1}{2}\left(\mu + \frac{g}{2}\right) mD}{2\left(\frac{P^N - P^S - m\sqrt{q}}{mD}\right) + \frac{(P^N - c^N)}{mD}} > 0, \qquad \frac{dP^S}{dg} = \frac{\frac{1}{2}\left(\mu - \frac{g}{2}\right) mD}{2\left(\frac{P^N - P^S - m\sqrt{q}}{mD}\right) - \frac{(P^S - c^S)}{mD}} > 0,$$

$$\frac{dP^N}{dm} = \frac{\left\{\left[\left(\frac{P^N - P^S - m\sqrt{q}}{mD}\right) + \frac{(P^N - c^N)}{mD}\right]\frac{\sqrt{q}}{D} + 2\left[\frac{1}{2}\left(\frac{P^N - P^S - m\sqrt{q}}{mD}\right)^2 + \frac{(P^N - c^N)}{mD}\left(\frac{P^N - P^S - m\sqrt{q}}{mD}\right)\right]\right\} D}{\left[2\left(\frac{P^N - P^S - m\sqrt{q}}{mD}\right) + \frac{(P^N - c^N)}{mD}\right]} > 0,$$

$$\frac{dP^S}{dm} = -\frac{\left\{\left[\left(\frac{P^N - P^S - m\sqrt{q}}{mD}\right) - \frac{(P^S - c^S)}{mD}\right]\frac{\sqrt{q}}{D} + 2\left[\frac{1}{2}\left(\frac{P^N - P^S - m\sqrt{q}}{mD}\right)^2 - \frac{(P^S - c^S)}{mD}\left(\frac{P^N - P^S - m\sqrt{q}}{mD}\right)\right]\right\} D}{\left[2\left(\frac{P^N - P^S - m\sqrt{q}}{mD}\right) - \frac{(P^S - c^S)}{mD}\right]} < 0,$$

$$\frac{dP^N}{dD} = \frac{\left(\frac{P^N - P^S - m\sqrt{q}}{mD}\right)\left[\left(\frac{P^N - P^S - m\sqrt{q}}{mD}\right) + \frac{2(P^N - c^N)}{mD}\right] m}{2\left(\frac{P^N - P^S - m\sqrt{q}}{mD}\right) + \frac{(P^N - c^N)}{mD}} > 0,$$

$$\frac{dP^S}{dD} = -\frac{\left(\frac{P^N - P^S - m\sqrt{q}}{mD}\right)\left[\left(\frac{P^N - P^S - m\sqrt{q}}{mD}\right) - \frac{(P^S - c^S)}{mD}\right] m}{2\left(\frac{P^N - P^S - m\sqrt{q}}{mD}\right) - \frac{(P^S - c^S)}{mD}} < 0,$$

$$\frac{dP^N}{dq} = \frac{\frac{1}{2\sqrt{q}}\left[\left(\frac{P^N - P^S - m\sqrt{q}}{mD}\right) + \frac{(P^N - c^N)}{mD}\right] m}{2\left(\frac{p^N - p^S - m\sqrt{q}}{mD}\right) + \frac{(p^N - c^N)}{mD}} > 0, \qquad \frac{dP^S}{dq} = -\frac{\frac{1}{2\sqrt{q}}\left[\left(\frac{P^N - P^S - m\sqrt{q}}{mD}\right) - \frac{(P^S - c^S)}{mD}\right] m}{2\left(\frac{P^N - P^S - m\sqrt{q}}{mD}\right) - \frac{(P^S - c^S)}{mD}} < 0.$$

1) See “Ministry of Agriculture, Forestry and Fisheries”, http://www.maff.go.jp/e/index.html.
2) See “The State of World Population 2011”.
3) Showing 2008 data, based on population subgroups stratified by family income, race and so on, from the National Health Interview Survey(NHIS), Cawley and Ruhm (2011) displayed the empirical evidence of existence of disparities in health behaviors across subgroups.

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Web Resource

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National Health Interview Survey, http://www.cdc.gov/nchs/nhis.htm