Regulation on Gene Diagnosis and Non-Existence of Equilibrium in the Life/Medical Insurance Market†

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Abstract

This study is based on the assumption that in future, genetic testing will create a situation where people can tell whether they are predisposed to certain diseases including cancer, but utilization of such genetic testing is banned for the purposes of medical examination of insurants. What, then, would be the response of people to genetic testing from an economics perspective? The Human Genome Project has made it possible to decode DNA base sequences, creating a significant impact not only in the biological and medical fields but also on our society as a whole. This paper is an analysis of equilibrium in the life/medical insurance market on the assumption that limits are imposed on the utilization of genetic testing for medical examination of insurants, and shows the possibility that no equilibrium exists in the market, thus drawing a counterintuitive conclusion. Furthermore, this paper also shows that utilization of genetic testing for insurance purposes would, in fact, economically benefit insurants.

JEL classification: D82, I10, L50.

Keywords: Genetic Testing, Regulation on Gene Diagnosis, Non-Existence of Equilibrium, Adverse Selection, Insurance Markets.

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1 Introduction

Almost ten years have passed since the launch of the Human Genome Project, with its goal of decoding all human DNA base pairs. The Project has accelerated progress in biology, especially by elucidating the evolutionary processes of living creatures, contributing to the solution of crime by DNA determination and the development of medical care, not to mention its significant contribution to molecular biology and genetic engineering. This has had a major impact on our society, particularly in the field of medical care. It is now been demonstrated that defective genes may be involved in the incidence and development of a range of diseases, and accordingly gene therapy would appear to have much to offer.

On the other hand, the Project has generated a considerable controversy, since genetic information is now able to define individuals to a high degree of accuracy and genetic testing can provide information on, for example, to what kind of diseases an individual may be predisposed. In recent years, new facts have come to light that certain genes are involved in predisposition to cancer. As a result of these developments, a number of physicians and lawyers have demanded a ban, for the first time in Japan, on the use of genetic testing for predisposition to cancer in medical examinations undergone by insurants.[1]

The basic demand by doctors is that a ban be imposed on the results of a search, by means of genetic testing, for a predisposition to cancer being used in medical examinations of insurants. The purpose is to prevent discrimination against those possessing oncogenes, with the emphasis placed on the preservation of the human rights of insurants when applying for insurance as well as on the strict confidentiality of private information. However, no ban on the disclosure of genetic information to relatives is included in this request, since knowledge of oncogenes can be of help in discovering cancer at an earlier stage, leading to early treatment, but on condition that such information shall be treated confidentially.

This request has been incorporated into the Ethical Guidelines. However, is a ban on genetic testing of every kind of hereditary disease justifiable from an economic standpoint?

[1] "An insurant" includes an applicant for insurance in my paper. So, hereinafter "an insurant" refers to an applicant for insurance.

In this paper, I will study from an economic perspective the case where insurers are banned from making a request for genetic testing. In the section 2, a basic model is introduced based on the assumption that gene diagnostic information is obtainable by an insurer. The section 3 deals with an equilibrium analysis as a symmetrical structure for obtaining criteria for comparison. In the section 4, I examine limits to genetic testing to evaluate theoretically the possibility that no equilibrium would exist in the life/medical insurance market, and discuss the reasons for its absence. In this instance, besides an analysis of determining whether equilibrium may exist or not depending on the conventional type of ratio, consideration is given to whether equilibrium may exist or not, depending on the ratio of insurants who undergo genetic testing. Under these conditions, an increase in the number of insurants who do not undergo genetic testing means that the information structure between an insurant and insurers becomes closer to being a symmetric structure (i.e., neither party is informed of the type of an insurant) and it can be surmised by intuition that an increase in the proportion of insurants not undergoing genetic testing would tend to lead to equilibrium. However, the analysis reveals that this perception does not reflect reality, and that the ratio of those not undergo genetic testing plays an important role in the existence of equilibrium. In the section 5, I show my conclusions and reevaluate regulation on genetic testing from an economic perspective.

2 Model

In this model, we assume a insurance market to be in a situation where gene function is known. Suppose Disease I is one type of disease but the death ratio depends on whether genetic information g is defective or not. Also, suppose genetic information on Disease I of an individual j is g_j $(j = 1, \ldots, m)$ and an individual type is determined by whether the gene is defective or not.

Suppose that, unlike the asymmetric structure of conventional models where an insurant is informed of her/his risk whereas insurers are not able to know the risk faced by the insurant, this model is provided with an information structure where an insurant is not informed of her/his own risk in advance but can be informed of her/his risk through genetic testing. In

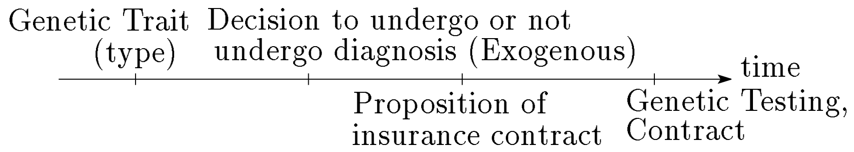

Figure 1

other words, it is assumed that an insurant can be informed of her/his risk only by undergoing genetic testing. Namely, it can be given as $g_j \in \{0, 1, 2\}$ where the results show no defective gene if $g_j = 0$, and the gene is defective if $g_j = 1$. Furthermore, suppose $g_j = 2$ in the event that an insurant does not undergo genetic testing. In this instance, suppose that $1 - \gamma$ is the ratio of insurants undergoing genetic testing where γ is the ratio of insurants not undergoing the test, then whether or not insurants elect to undergo genetic testing is determined exogenously.[2]

Procedures for concluding a contract include determination of a type of an insurant with regard to Disease I and proposition of a contract covering the disease by an insurer. Whether or not an insurant undergoes genetic testing is determined exogenously, and s/he who has previously undergone diagnosis must submit the result to an insurer. The insurant not undergoing genetic testing must submit evidence in the form of a medical certificate showing s/he has not undergone genetic testing. The insurer will then propose the details of a contract in accordance with the results of the genetic test, and the insurant will make the final decision on whether to conclude the contract or not (Figure 1).

Suppose the insurance with which an insurant j is covered is life/medical insurance subject to hereditary diseases. Also suppose insurants face two states (State 1 and 2): State 1 is designated as living/disease-free state wherein the income is c_1^0, while State 2 is designated as dead/morbid state wherein the income is $c_2^0 (= 0)$. Suppose the initial endowment is equal to all

[2]Naturally, whether insurants elect to undergo genetic testing or not should be determined endogenously in the model. However, consideration should be given to the simultaneous determination issue in which insurants elect to undergo genetic testing and at the same time to enter into a contract with an insurer when they elect to undergo testing endogenously. As the result, the utility function becomes extremely complicated and obscures the issues to be investigated in this paper. Hence, in this paper, for the purpose of simplicity, selection of the diagnosis is assumed to be determined exogenously. Needless to say, endogenous selection of the diagnosis is an important issue and I will deal with this issue in section 5.

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Suppose an insurant is covered by insurance against State 2 (death/disease). Namely, the initial income state is exchanged to $c = (c_1, c_2)$ by a certain ratio of p. In other words, suppose that an insurant pays a premium $c_1^0 - c_1$ on concluding an insurance contract and the claim paid of $c_2 - c_2^0$ is settled when the insurant dies. Suppose the exchange rate of $\dfrac{c_1^0 - c_1}{c_2 - c_2^0} \equiv p$ is the insurance premium.

Now, the following groups are defined with regard to insurants.

Definition 2.1 *Suppose*

$$H = \{j | g_j = 0\}$$

where j belongs to Group H in the case of $j \in H$. Similarly, suppose

$$L = \{j | g_j = 1\}$$

where j belongs to Group L in the case of $j \in L$. Furthermore, suppose

$$Q = \{j | g_j = 2\}$$

where j belongs to Group Q in the case of $j \in Q$.

Namely, where insurants who undergo genetic testing and are found to have a defective gene are classified into Group L, those who undergo testing and are found not to be genetically defective are classified into Group H, and those who do not undergo any diagnosis are classified into group Q. Suppose the probability that insurants j will be killed by the Disease I is π_j ($j = 1, \ldots, m$). Let π_j be assumed as follows.

Assumption 2.1 *Let $\pi_j = \pi_\eta,\ \eta = L, Q, H$ be assumed for a given j.*

Namely, suppose that the probability of an insurant who undergoes genetic testing facing State 2 is π_H for Group H and π_L for Group L, and for an insurant who does not undergo testing, the probability of Group Q facing State 2 is π_Q, thus providing $\pi_L > \pi_Q > \pi_H$. Suppose π_η is equal among insurants in the respective groups.[3] Further suppose that the ratio of insurants with genetic disease who are predisposed to Disease I in a whole market is δ, and let π_Q be[4]

$$\pi_Q \equiv \delta\pi_L + (1-\delta)\pi_H. \tag{1}$$

Suppose that both an insurant and insurers are informed of the exact value of γ, δ.

Let the utility function of an insurant be

$$EU(c_1, c_2, \pi_\eta) = \pi_\eta u(c_2) + (1-\pi_\eta)u(c_1), \; \eta = L, Q, H \tag{2}$$

and let an insurant be risk-averse.

The following expression of (3) can be satisfied for the utility function from $\pi_L > \pi_Q > \pi_H$.

$(sorting - condition)$
In a given $c = (c_1, c_2)$,

$$\frac{\partial}{\partial \pi_L}\left(\frac{\partial EU/\partial c_2}{\partial EU/\partial c_1}\right) > \frac{\partial}{\partial \pi_Q}\left(\frac{\partial EU/\partial c_2}{\partial EU/\partial c_1}\right) > \frac{\partial}{\partial \pi_H}\left(\frac{\partial EU/\partial c_2}{\partial EU/\partial c_1}\right). \tag{3}$$

However,

$$\frac{\partial}{\partial \pi_\eta}\left(\frac{\partial EU/\partial c_2}{\partial EU/\partial c_1}\right) \equiv \frac{\partial}{\partial \pi_\eta}\left(\frac{\partial EU(c_1, c_2, \pi_\eta)/\partial c_2}{\partial EU(c_1, c_2, \pi_\eta)/\partial c_1}\right), \; \eta = L, Q, H.$$

Namely, on the basis of a certain utility, the marginal rate of substitution at a given c is expressed as

$$-\left.\frac{dc_1}{dc_2}\right|_{\bar{U}} = \frac{\partial EU/\partial c_2}{\partial EU/\partial c_1} = \frac{\pi_\eta}{1-\pi_\eta}\frac{u'(c_2)}{u'(c_1)}, \; \eta = L, Q, H, \tag{4}$$

[3] It would be more realistic to take into account the fact that in principle the probability of an insurant facing State 2 resulting from Disease I may vary depending on the environmental states of an insurant. However, in this paper it is assumed that the probability of those facing State 2 resulting from Disease I will be equal among insurants in their respective groups.

[4] From a more practical point of view, it would be possible that the probability that Group Q will die due to Disease I is not in compliance with the probability weighted with δ since an insurant will elect to undergo genetic testing based on the subjective probability. However, in this paper, for reasons of simplicity, the probability that Group Q will die due to Disease I is assumed to be equal to the probability weighted with δ.

and the respective rates obtained for Group L, Group Q and Group H increase in the increasing order of Group L, Group Q and then Group H.

Suppose insurers are risk-neutral and exposed to perfect competition. In other words, suppose insurers are allowed to advance into the market freely and to conclude a contract with an insurant (for example, with Group H or with Group QL only). Furthermore, supposes that the insurers can tell the insurant to which group, L, H or Q, s/he belongs based on a certificate issued from a medical institution in charge of genetic testing. Suppose that the expected profit obtained by the insurer from a contract with an insurant belonging to Group η is

$$\Pi(c_1, c_2, \pi_\eta) = \pi_\eta(c_2^0 - c_2) + (1 - \pi_\eta)(c_1^0 - c_1), \ \eta = L, Q, H. \tag{5}$$

Under the above conditions, equilibrium is defined as follows.

Definition 2.2 *Suppose that with regard to a contract of $\{\lambda, \mu, \nu\}$, Group L is covered by λ, Group Q is covered by μ, and Group H is covered by ν. In order for a contract of $\{c_L^*, c_Q^*, c_H^*\}$ to be equilibrated with Disease I, for a given $\eta = L, Q, H$,*

1. $\Pi(c_{1\eta}^*, c_{2\eta}^*, \pi_\eta) = 0$.
2. *There exists no contract of $\{c_L, c_Q, c_H\}$ that meets the following conditions,*
   $\Pi(c_{1\eta}, c_{2\eta}, \pi_\eta) \geq \Pi(c_{1\eta}^*, c_{2\eta}^*, \pi_\eta)$
   and
   $EU(c_{1\eta}, c_{2\eta}, \pi_\eta) \geq EU(c_{1\eta}^*, c_{2\eta}^*, \pi_\eta)$
   and
   $max[\Pi(c_\eta, \pi_\eta) - \Pi(c_\eta^*, \pi_\eta), EU(c_\eta, \pi_\eta) - EU(c_\eta^*, \pi_\eta)] > 0.$
3. *For a given group $\eta = L, Q, H$,*
   $EU(c_{1\eta}^*, c_{2\eta}^*, \pi_\eta) \geq EU(c_1^0, c_2^0, \pi_\eta)$
   and
   for a given group $\zeta = L, Q, H$,
   $EU(c_{1\eta}^*, c_{2\eta}^*, \pi_\eta) \geq EU(c_{1\zeta}^*, c_{2\zeta}^*, \pi_\eta)$.

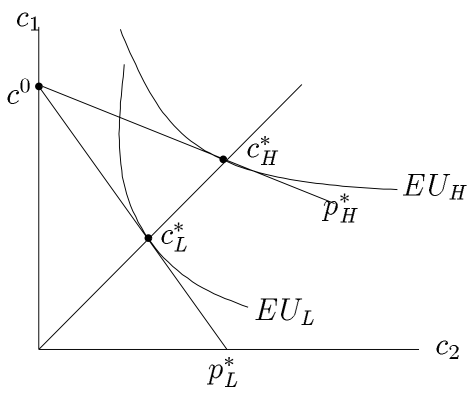

Figure 2-1

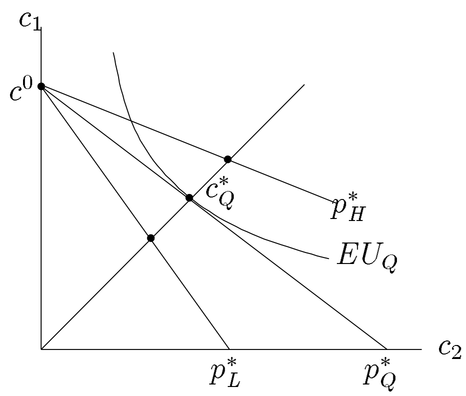

Figure 2-2

Namely, in this equilibrium, the expected profit by insurers is zero and there exists no new contract assuring the insurers of profit greater than the equilibrium at the same time as providing an insurant with greater utility.[5] Furthermore, suppose that the equilibrium meets individual rationality (IR) and incentive compatibility (IC).

3 Equilibrium Analysis (Benchmarking):The Symmetric Information Structure

In the first place I will discuss equilibrium in a symmetric information structure where perfect information is available, namely, an insurant will submit true and accurate results of genetic testing and an insurer is able to compulsorily separate groups of insurants on the basis of the diagnostic results. In this instance, if equilibrium is obtained with $\{c_L^*, c_Q^*, c_H^*\}$, c_η^* meets the following expression.

$$\frac{\pi_\eta}{1-\pi_\eta}\frac{u'(c_{2\eta}^*)}{u'(c_{1\eta}^*)} = p_\eta^*, \quad \left(p_\eta^* \equiv \frac{\pi_\eta}{1-\pi_\eta}, \ \eta = L, Q, H\right). \tag{6}$$

When an insurant undergoes genetic testing for Disease I, s/he can be informed of her/his type and insurers are also able to be informed of her/his classification of the group by means of a medical certificate. Then, the insurers can impose c_H^* on Group H and c_L^* on Group L, thus equilibrating their contracts (Figure 2-1).

[5]In this Condition 2, neither expected utility nor expected profit shall meet $\{c_\eta^*\}$ and the equality sign with regard to contract $\{c_\eta\}$, for which condition is $max[\cdot] > 0$.

On the other hand, where an insurant does not undergo genetic testing, neither insurers nor insurant are informed of her/his type. In other words, an insurant is in Group Q, and insurers are able to propose a contract c_Q^* on the basis of a medical certificate declaring that s/he has not undergone genetic testing, thus equilibrating the contract (Figure 2-2).

In this instance, an insurant who is found to be in Group L through diagnosis is not able to make a false statement that s/he has not received a diagnosis (Group Q) or belongs to H. This is because if an insurant who is found to be in Group L through genetic testing were to claim not to have received a diagnosis, s/he would be required to submit a medical certificate as evidence to this effect. Medical institutions in charge of genetic testing are able to locate the details and history of an individual diagnosis. Namely, because an insurant who did not undergo genetic testing can be traced retrospectively to find out her/his true history, s/he found by diagnosis to be Group L is not able to make a false statement.

In this instance, the information structure is symmetric and full coverage insurance offered to the respective groups is equilibrated.

4 Regulation on Gene Diagnosis and Non-Existence of Equilibrium

The previous section dealt with an analysis of equilibrium in a situation where results of genetic testing are available before conclusion of an insurance contract. In this instance, insurers are able to offer full coverage insurance based on true and accurate statements made by the respective groups concerning diagnostic results.

In the following instance, suppose a situation where insurers are unable to use the results of genetic testing of an insurant while the insurant is able to use the results of the diagnosis and can be informed of her/his type if s/he receives a diagnosis, but otherwise remains unaware of her/his type. At this time, insurers need to take into account the possibility that an incentive is being given to an insurant to make a false statement because the insurers are not able to use the diagnostic results. In other words, insurers must take into account the possibility that an insurant who did not undergo genetic testing

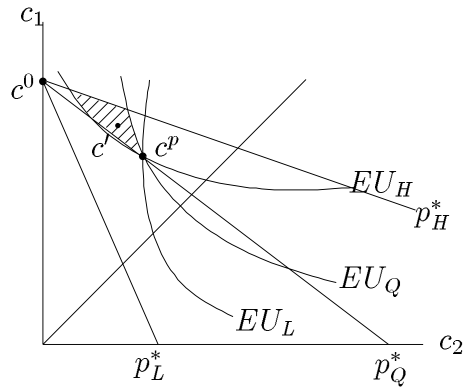

Figure 3

for Disease I or s/he who is found to be in Group L by means of diagnosis may make a false statement that they did not undergo testing (Group Q) or that they belong to Group H. Under these circumstances, suppose that p_H^0 is the premium by which conditions belonging to Group H are met by equality sign. When a plurality of these groups are insured by a contract c, a contract $\{c, c, c\}$ is defined as a pooling contract. A pooling contract comprising two given groups is specifically referred to as $\eta\zeta$ pooling contract $(\eta, \zeta = L, Q, H,\ \eta \neq \zeta)$.

Lemma 4.1 *Suppose that insurers are banned from requiring an insurant to undergo genetic testing before the conclusion of an insurance contract. In this instance, the pooling contract is not equilibrated with a given p_Q^*.*

Proof Suppose that insurers propose a pooling contract $\{c^p, c^p, c^p\}$ with respect to a given premium of $p_Q^* \in (p_H^*, p_H^0]$. At this time, a contract $\{c^p, c^p, c'\}$ always exists, which can meet the following

$$\begin{aligned} &EU(c_1', c_2', \pi_H) > EU(c_1^p, c_2^p, \pi_H), \\ &EU(c_1', c_2', \pi_\eta) < EU(c_1^p, c_2^p, \pi_\eta),\ \ \eta = L, Q \end{aligned} \tag{7}$$

with regard to $\{c^p, c^p, c^p\}$ (Figure 3).

Hence, the insurer can make a positive profit by concluding a contract with only Group H and therefore $\{c^p, c^p, c'\}$ does not comply with the definition of equilibrium.

On the other hand, in the case of $p_Q^* > p_H^0$, no incentive is given to insurants in Group H so as to conclude an insurance contract. Furthermore,

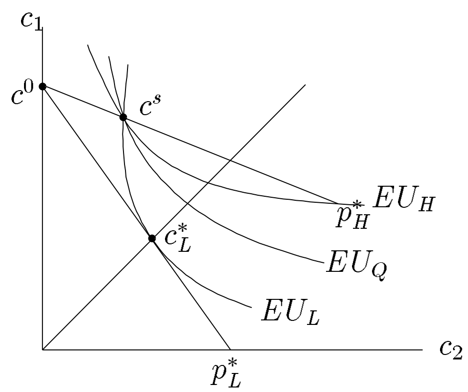

Figure 4

$p_Q^* \geq p_H^*$ is always established from $0 \leq \delta \leq 1$. When $p_Q^* = p_H^*$, $\delta = 0$ is established, and all insurants belong to Group H. It is evident that no pooling contract exists at this time. **Q.E.D.**

In general, the non-existence of a pooling contract is well known as apparent from various models including that of Rothschild and Stiglitz (1976). The subsidiary Lemma 4.1 shows that equilibrium is not attained in a pooling contract even if Group Q members exist who do not undergo genetic testing.

Regulation on genetic testing renders asymmetric information structure from an originally symmetric structure, as explained in the previous section. However, the following can be proved from my model in this paper.

Lemma 4.2 *Suppose insurers are banned from requiring an insurant to undergo genetic testing before the conclusion of an insurance contract. In this instance, if the separating contract of* $[c_L^*, c^s]$ *based on the Rothschild and Stiglitz (1976) is equilibrium,* $\gamma = 0$ *is obtained.*

Proof In the case of $[c_L^*, c^s]$, c_L^* will meet the following from the expression of (6),

$$\frac{\pi_L}{1-\pi_L}\frac{u'(c_{2L}^*)}{u'(c_{1L}^*)} = p_L^*, \ \left(p_L^* \equiv \frac{\pi_L}{1-\pi_L}\right). \tag{8}$$

Suppose that c^s is a contract with a premium of $p_H^* \equiv \dfrac{\pi_H}{1-\pi_H}$, meeting the following, with regard to the expected utility of Group L (Figure4),

$$EU(c_1^s, c_2^s, \pi_L) = EU(c_{1L}^*, c_{2L}^*, \pi_L). \tag{9}$$

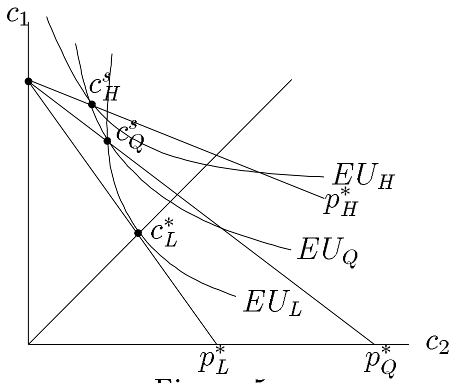

Figure 5

Suppose that when $[c_L^*, c^s]$ is equilibrated, $0 < \gamma \leq 1$ is obtained. In this instance, when insurants undergo genetic testing, insurants in Group L will select c_L^* and those of Group H will select c^s. Similarly, because insurants in Group Q who do not undergo genetic testing will select c^s with regard to $[c_L^*, c^s]$, an insurance contract is given as $\{c_L^*, c^s, c^s\}$. However, the resultant expected profit for an insurer is

$$\Pi(c_1^s, c_2^s, \pi_H) + \Pi(c_1^s, c_2^s, \pi_Q) < 0, \tag{10}$$

which does not comprise equilibrium. **Q.E.D.**

In a situation where insurers is banned from using genetic testing and when $\gamma = 0$, a separating contract based on the Rothschild-Stiglitz model is equilibrated; otherwise, $[c_L^*, c^s]$ is no longer equilibrated. This is primarily because of the existence of Group Q who have not undergone genetic testing. In the Rothschild-Stiglitz model, an insurant is fully informed of her/his type and the insurant belongs either to Group L or Group H, with Group Q nonexistent. Therefore, the insurance contract is in the form of $[\lambda, \nu]$, and in Group L a λ contract is concluded while in Group H a ν contract is concluded. Namely, the separating contract as shown in the model of Rothschild-Stiglitz can be equilibrated when the ratio of undergoing genetic testing is 1; namely, $\gamma = 0$ in my model.

4.1 Existence of Equilibrium

A contract that can be equilibrated under these circumstances is a separating contract of $\{c_L^*, c_Q^s, c_H^s\}$ (Figure 5). Suppose that c_Q^s is a contract in which a premium $p_Q^* \equiv \dfrac{\pi_Q}{1-\pi_Q}$, meeting

$$EU(c_{1Q}^s, c_{2Q}^s, \pi_L) = EU(c_{1L}^*, c_{2L}^*, \pi_L) \tag{11}$$

with respect to the expected utility of Group H. Furthermore, suppose that c_H^s is a contract in which a premium $p_H^* \equiv \dfrac{\pi_H}{1-\pi_H}$, meeting

$$EU(c_{1H}^s, c_{2H}^s, \pi_Q) = EU(c_{1Q}^s, c_{2Q}^s, \pi_Q) \tag{12}$$

with respect to the expected utility of Group Q.

Suppose when insurers propose a contract of $\{c_L^*, c_Q^s, c_H^s\}$, the expected utility of Group L can meet

$$EU(c_{1L}^*, c_{2L}^*, \pi_L) = EU(c_{1Q}^s, c_{2Q}^s, \pi_L) > EU(c_{1H}^s, c_{2H}^s, \pi_L) \tag{13}$$

and Group L will select c_L^*. Similarly, suppose that the expected utility of Group Q can meet

$$EU(c_{1Q}^s, c_{2Q}^s, \pi_Q) = EU(c_{1H}^s, c_{2H}^s, \pi_Q) > EU(c_{1L}^*, c_{2L}^*, \pi_Q) \tag{14}$$

and Group Q will select c_Q^s. In addition, suppose that the expected utility of Group H can meet

$$EU(c_{1H}^s, c_{2H}^s, \pi_H) > EU(c_{1Q}^s, c_{2Q}^s, \pi_H) > EU(c_{1L}^*, c_{2L}^*, \pi_H) \tag{15}$$

and Group H will select c_H^s. The profit for an insurer can be expressed as

$$\Pi(c_{1L}^*, c_{2L}^*, \pi_L) + \Pi(c_{1Q}^s, c_{2Q}^s, \pi_Q) + \Pi(c_{1H}^s, c_{2H}^s, \pi_H) = 0 \tag{16}$$

and no contract exists which can yield a greater profit with regard to $\{c_L^*, c_Q^s, c_H^s\}$.

4.2 Non-existence of Equilibrium

When insurers propose a separating contract of $\{c_L^*, c_Q^s, c_H^s\}$, Group L makes a self-selection of c_L^*, Group Q selects c_Q^s, and Group H selects c_H^s. However, this contract will not necessarily meet the condition of equilibrium. In this paper, I study a case where the separating contract cannot be equilibrated.

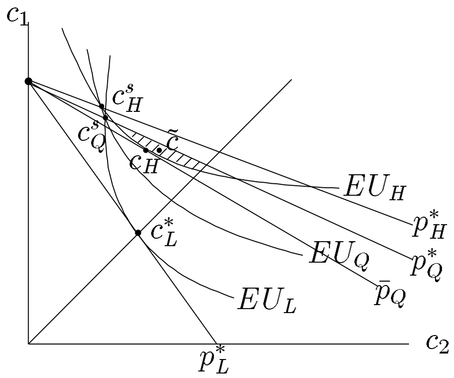

Figure 6

4.2.1 Type Share Analysis

As described previously, the ratio of insurants with genetic disease in the overall market was designated as δ. Supposes that $c_H = (c_{1H}, c_{2H})$ is a contract which can meet

$$EU(c_{1H}^s, c_{2H}^s, \pi_H) = EU(c_{1H}, c_{2H}, \pi_H) \tag{17}$$

$$\frac{\pi_H}{1-\pi_H}\frac{u'(c_{2H})}{u'(c_{1H})} = p,\ p \in [p_H^*, p_L^*] \tag{18}$$

with regard to $\{c_L^*, c_Q^s, c_H^s\}$ and the premium for c_H is $\bar{p}_Q$. In other words, suppose that the tangent line coming from the point of c^0 and extending to the indifference curve of Group H passing through c_H^s is $\bar{p}_Q$. Also, suppose that δ corresponding to $\bar{p}_Q$ is $\bar{\delta}$. Whether $\{c_L^*, c_Q^s, c_H^s\}$ can be equilibrated or not is dependent on the degree of relation of p_Q^* with $\bar{p}_Q$.

When $\bar{p}_Q > p_Q^*$, ($\bar{\delta} > \delta$) is established.

$\bar{p}_Q > p_Q^*$, there exists in the shaded portion of Figure 6 a pooling contract of $\{\tilde{c}, \tilde{c}, \tilde{c}\}$ which meets

$$\begin{aligned} &EU(\tilde{c}_1, \tilde{c}_2, \pi_L) > EU(c_{1L}^*, c_{2L}^*, \pi_L), \\ &EU(\tilde{c}_1, \tilde{c}_2, \pi_\eta) > EU(c_{1\eta}^s, c_{2\eta}^s, \pi_\eta), \quad \eta = Q, H \end{aligned} \tag{19}$$

and

$$\sum_{\eta \in L,H,Q} \Pi(\tilde{c}_1, \tilde{c}_2, \pi_\eta) > \Pi(c_{1L}^*, c_{2L}^*, \pi_L) + \Pi(c_{1Q}^s, c_{2Q}^s, \pi_Q) + \Pi(c_{1H}^s, c_{2H}^s, \pi_H)$$

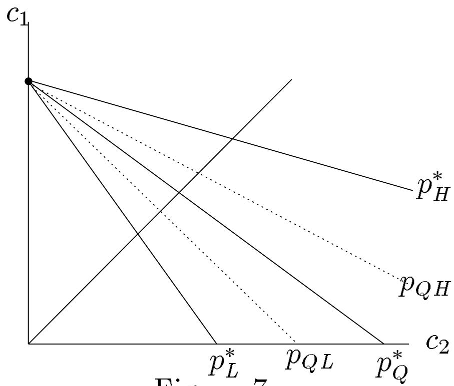

Figure 7

for an insurant and insurers. However, as shown in the subsidiary Lemma 4.1, no pooling contract exists, and consequently no equilibrium exists in the market.

When $\bar{p}_Q \leq p_Q^*$, $(\bar{\delta} \leq \delta)$ is established.

However, when $\bar{p}_Q \leq p_Q^*$, no contract exists which can give Pareto improvement to all insurants and insurers. In other words, $\{c_L^*, c_Q^s, c_H^s\}$ is equilibrated, as shown in Figure 5 of section 4.1.

The ratio of insurants with genetic disease is low in this situation; analysis of which is well known from various models including the Rothschild-Stiglitz model. In my model, Group Q is defined on the basis of δ and no equilibrium of $(\bar{\delta} > \delta)$ exists when δ is low.

However, where insurants belonging to Group Q exist, it is necessary to discuss the existence of equilibrium in view of γ which is the proportion of Group Q.

4.2.2 Group Share Analysis

The above discussion deals with the analysis on the basis of δ which is the ratio of insurants with genetic disease in the overall market. The rate of undergoing diagnosis is expressed as $1 - \gamma$, namely, the ratio of Group Q in the market is γ, based on which analysis should be made. From the relationship of γ with δ, the ratios of the respective groups in the market can be expressed as

$$L : Q : H = \delta(1-\gamma) : \gamma : (1-\delta)(1-\gamma). \tag{20}$$

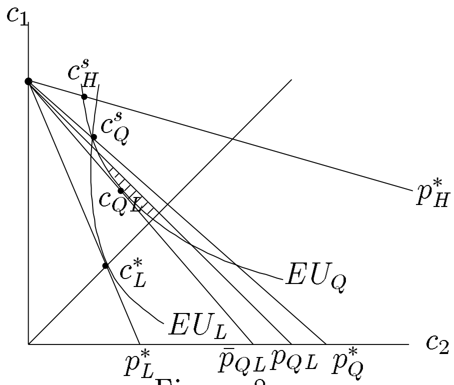

Figure 8

At this time, the premium obtained by weighting the premiums of Group L and Group Q according to their ratios is expressed as

$$p_{QL} \equiv \frac{\delta(1-\gamma)}{\delta(1-\gamma)+\gamma} p_L^* + \frac{\gamma}{\delta(1-\gamma)+\gamma} p_Q^*. \tag{21}$$

and the premium obtained by weighting the premiums of Group Q and Group H according to their ratios is expressed as below (Figure 7);

$$p_{QH} \equiv \frac{\gamma}{\gamma+(1-\delta)(1-\gamma)} p_Q^* + \frac{(1-\delta)(1-\gamma)}{\gamma+(1-\delta)(1-\gamma)} p_H^* \tag{22}$$

The thus obtained premiums, p_{QL} and p_{QH}, tend to shift toward p_Q^* when γ rises according to γ, the ratio of Group Q who do not undergo genetic testing, whereas p_{QL} tends to shift toward p_L^* and p_{QH}, toward p_H^* when γ falls (Refer to the Mathematical Appendix).

At this time, suppose that $c_{QL} = (c_{1QL}, c_{2QL})$ is a contract which meets

$$EU(c_{1Q}^s, c_{2Q}^s, \pi_Q) = EU(c_{1QL}, c_{2QL}, \pi_Q), \tag{23}$$

$$\frac{\pi_Q}{1-\pi_Q}\frac{u'(c_{2QL})}{u'(c_{1QL})} = p,\ p \in [p_Q^*, p_L^*], \tag{24}$$

with regard to a separating contract of $\{c_L^*, c_Q^s, c_H^s\}$, and a premium for c_{QL} gives $\bar{p}_{QL}$ (Figure 8). In other words, suppose that the tangent line coming from point c^0 and extending toward the indifference curve of Group Q passing through c_Q^s gives $\bar{p}_{QL}$. Also, suppose that γ corresponding to $\bar{p}_{QL}$ gives $\bar{\gamma}$, and $\bar{\gamma}$ assumes a certain value in relation to given δ. Whether or not equilibrium can exist in the market is dependent on the relation of p_{QL} with $\bar{p}_{QL}$, or the magnitude of relation between γ and $\bar{\gamma}$.

When $\bar{p}_{QL} > p_{QL}$, $(\bar{\gamma} < \gamma)$ is obtained.

When $\bar{p}_{QL} > p_{QL}$ (Figure 8), there exists in the shaded portion of Figure 8 a QL pooling contract of $\tilde{c}_{QL}$ which gives

$$EU(\tilde{c}_{1QL}, \tilde{c}_{2QL}, \pi_\eta) > EU(c^*_{1L}, c^*_{2L}, \pi_\eta), \ \eta = L, Q. \tag{25}$$

On the other hand, the expected utility of Group H can be expressed as

$$EU(\tilde{c}_{1QL}, \tilde{c}_{2QL}, \pi_H) < EU(c^s_{1H}, c^s_{2H}, \pi_H), \tag{26}$$

and consequently Groups L and Q will select $\tilde{c}_{QL}$ and Group H will select c^s_H. An insurer obtains profit given as

$$\sum_{\eta \in L,Q} \Pi(\tilde{c}_{1QL}, \tilde{c}_{2QL}, \pi_\eta) + \Pi(c^s_{1H}, c^s_{2H}, \pi_H) \geq 0 \tag{27}$$

and can propose a contract of $\{\tilde{c}_{QL}, \tilde{c}_{QL}, c^s_H\}$. However, a contract of $\{\tilde{c}_{QL}, \tilde{c}_{QL}, c^s_H\}$ is not equilibrated either, because there exists a new contract with Group Q which yields a greater profit than a contract of $\tilde{c}_{QL}$, and so the QL pooling contract fails to meet the conditions for equilibrium.

As a result, only c^s_H remains as a candidate for an equilibrium contract, but if all insurants are covered with a contract of c^s_H, the profit for an insurer will be negative. It is clear from the subsidiary Lemma 4.1 that $\{c^s_H, c^s_H, c^s_H\}$ is not equilibrated.

When $\bar{p}_{QL} \leq p_{QL}$, $(\bar{\gamma} \geq \gamma)$ is obtained.

In this case, suppose that $c_{QH} = (c_{1QH}, c_{2QH})$ is a contract which can meet

$$EU(c^s_{1H}, c^s_{2H}, \pi_H) = EU(c_{1QH}, c_{2QH}, \pi_H), \tag{28}$$

$$\frac{\pi_H}{1-\pi_H}\frac{u'(c_{2QH})}{u'(c_{1QH})} = p, \ p \in [p^*_H, p^*_Q], \tag{29}$$

and a premium for c_{QH} gives $\bar{p}_{QH}$ (Figure 9). In other words, suppose that the tangent line coming from point c^0 and extending indifference curve of Group H passing through c^s_H gives $\bar{p}_{QH}$. Also, suppose that the point of intersection at which the indifference curve of Group L passing through c^*_L meets with the indifference curve of Group H passing through c^s_H gives c_{LH},

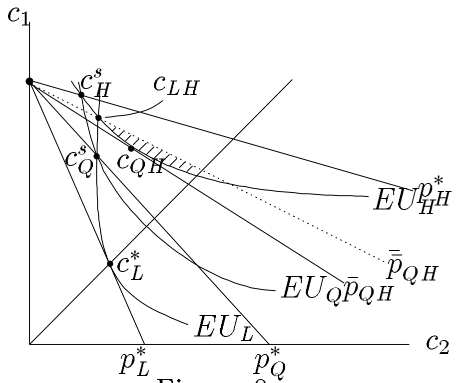

Figure 9

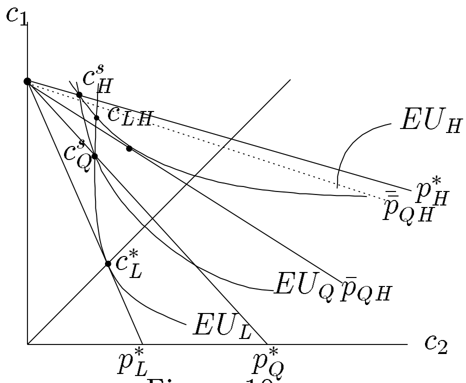

Figure 10

and the premium p_{QH} passing through c_{LH} gives $\bar{\bar{p}}_{QH}$, and p_{QL} corresponding to $\bar{\bar{p}}_{QH}$ gives $\bar{\bar{p}}_{QL}$. Furthermore, γ corresponding to $\bar{\bar{p}}_{QL}$ gives $\bar{\bar{\gamma}}$.

When $\bar{p}_{QL} \leq p_{QL}$, no contract exists which can give Pareto improvement to Groups L, Q and provide an insurer with a greater profit. However, the possibility of a QH pooling contract should be discussed, which may yield a greater profit by providing Groups Q, H with insurance coverage. If $\bar{p}_{QL} \leq p_{QL}$ gives $\bar{p}_{QH} > p_{QH} \geq \bar{\bar{p}}_{QH}$, there exists a QH pooling contract which gives

$$EU(\tilde{c}_{1QH}, \tilde{c}_{2QH}, \pi_\eta) > EU(c^s_{1Q}, c^s_{2Q}, \pi_\eta), \;\; \eta = Q, H, \tag{30}$$

with regard to Groups Q, H, and Groups Q, H will select $\tilde{c}_{QH}$. However, at this time,

$$EU(\tilde{c}_{1QH}, \tilde{c}_{2QH}, \pi_L) > EU(c^*_{1L}, c^*_{2L}, \pi_L) \tag{31}$$

is given to Group L also, and Group L will select $\tilde{c}_{QH}$. Consequently, an insurer will show a negative profit and would thus never propose this type of contract. Therefore, the separating contract of $\{c^*_L, c^s_Q, c^s_H\}$ is equilibrated.

However, when $\bar{\bar{p}}_{QH} > p_{QH}$, there exists a contract in which a QH pooling contract of $\tilde{c}_{QH}$ is proposed to Groups Q and H, while Group L remains covered with a contract of c^*_L, thus providing an insurer with a greater profit (Figure 10). In other words, when $\bar{\bar{p}}_{QH} > p_{QH}$, insurers can propose a contract $\{c^*_L, \tilde{c}_{QH}, \tilde{c}_{QH}\}$ which yields a greater profit by allowing Groups Q and H to select $\tilde{c}_{QH}$ and Group L to select c^*_L. However, insurers can also propose a new contract specific to Group H only, which can yield a greater profit in comparison with a QH pooling contract of $\tilde{c}_{QH}$, since a contract of $\{c^*_L, \tilde{c}_{QH}, \tilde{c}_{QH}\}$ cannot meet the conditions required for equilibrium.

Consequently insurers responds by proposing c_L^* by which, however, only Group L is insured. Equilibrium is obtained for $\{c_L^*, c^0, c^0\}$, created by adverse selection in the market.

As explained above, in my model it is necessary to refer to the existence of equilibrium on the basis of group share analysis, with attention given to γ, namely the role of Group Q in the market, in addition to conventional type share analysis. When γ is high or the ratio of Group Q rises, there exists a QL pooling contract which affords Groups L and Q Pareto improvement and profits insurers, and consequently no equilibrium exists. On the other hand, when γ is low or the ratio of Group Q decreases, there exists a contract which can gives Groups Q and H Pareto improvement, but insurers can achieve profits only if the ratio of Group Q is extremely low ($\bar{\bar{\gamma}} > \gamma$), and the equilibrium obtained then shows adverse selection. When the ratio of Group Q is relatively low ($\bar{\gamma} \geq \gamma \geq \bar{\bar{\gamma}}$), there exists a QH pooling contract which affords Pareto improvement to Groups Q and H as well as to insurers. However, Group L is also insured in this instance, by which insurers are unable to gain a profit. Therefore, a separating contract of $\{c_L^*, c_Q^s, c_H^s\}$ is equilibrated.

Proposition 4.1 *Suppose that insurers are banned from requiring an insurant to undergo genetic testing before concluding a contract. In this instance,*

1. *When* $\bar{p}_Q > p_Q^*(\bar{\delta} > \delta)$ *or* $\bar{p}_{QL} > p_{QL}(\bar{\gamma} < \gamma)$, *no equilibrium exists.*

2. *When* $\bar{p}_Q \leq p_Q^*(\bar{\delta} \leq \delta)$ *and* $\bar{p}_{QL} \leq p_{QL} \leq \bar{\bar{p}}_{QL}(\bar{\gamma} \geq \gamma \geq \bar{\bar{\gamma}})$, $\{c_L^*, c_Q^s, c_H^s\}$ *is equilibrated.*

3. *When* $\bar{p}_Q \leq p_Q^*(\bar{\delta} \leq \delta)$ *or* $\bar{\bar{p}}_{QL} < p_{QL}(\bar{\bar{\gamma}} > \gamma)$, $\{c_L^*, c^0, c^0\}$ *is equilibrated.*

Here, I reevaluate this model from the perspective of γ which is the ratio of insurants (Group Q) who do not undergo genetic testing (Figure 11). A situation of $\gamma = 0$ is where all insurants undergo genetic testing. This is simply a case of an asymmetric information structure as dealt with by Rothschild and Stiglitz (1976). In other words, insurants are informed of their type but this information is concealed from insurers. The value insurers can

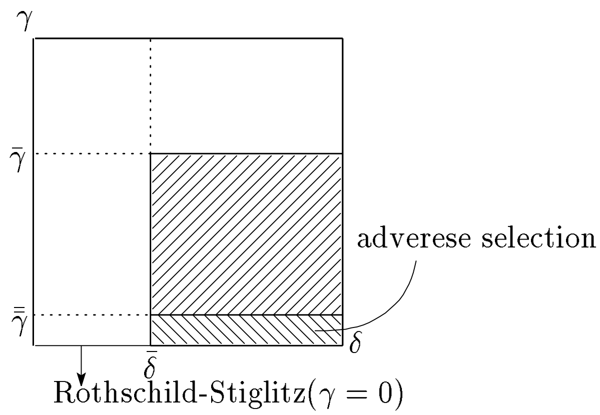

Figure 11

see is γ, namely, the ratio occupied by insurants with diseases in the market. It is well known from the above type share analysis or other analyses including that dealt by Rothschild and Stiglitz (1976) that equilibrium is dependent exclusively on the magnitude of γ.

On the other hand, the situation $\gamma = 1$ is where no insurant undergoes genetic testing, or all insurants belong to Group Q. In this situation, neither insurer nor insurant is informed of their type, so the information structure is symmetric. It is apparent from the basic literature on insurance that equilibrium always exists in this situation and assumes the most standard structure (Spence and Zeckhause (1971), Ehrlich and Becker (1972), Pauly (1974) *et al*).

More particularly, a value of γ approaching 1, or an increase in the ratio of insurants who do not undergo genetic testing shows that the information structure shifts from an asymmetric to a symmetric structure. In this instance, it would appear at first glance that an increase in γ would favor an increased state of equilibrium.

However, the group share analysis in this model has resulted in a counterintuitive conclusion: the higher the ratio of insurants who do not undergo diagnosis, the lower the likelihood of equilibrium. This results from the symmetric information structure in which γ is equal to 1, namely, the mere existence of insurants who undergo genetic testing would lump the small number in Group L and the large number in Group Q together, resulting in undermining of equilibrium because there exists a QL pooling contract capable of profiting insurers.

Therefore, in order for equilibrium to exist, γ must assume a relatively low value ($\bar{\gamma} \geq \gamma$). Furthermore, where the ratio of insurants who receive diagnosis ($\bar{\bar{\gamma}} > \gamma$) is extremely low, equilibrium is obtained when only Group L is insured, causing the market to fall into adverse selection.

In other words, even if equilibrium were to be obtained in the Rothschild-Stiglitz model ($\bar{\delta} \leq \delta$), insurants who do not undergo genetic testing are present in the formula and an increase in the ratio of such insurants will rule out equilibrium.

The above discussion is of particular note in that it has leads to a conclusion entirely different from the intuitive conclusion surmised from the perspective of information structure.

5 Conclusions

In this paper, I have provided an economic analysis of the situation where insurers are banned from requiring an insurant to undergo genetic testing before the conclusion of a contract with an insurer and also regulation is imposed on the proposition of an insurance contract to an insurant on the basis of the results of the diagnosis, on the assumption that gene function is known at that time. A ban on the requirement by insurers that an insurant undergoes genetic testing means that the information structure is rendered asymmetric from an economic perspective. Under these circumstances, if conventional separating contracts based on the Rothschild-Stiglitz model are equilibrated, it is correct to understand that such contracts deal with the situation where $\gamma = 0$. In other words, it may be interpreted that the separating equilibrium found in the Rothschild-Stiglitz model exists in a special situation where the rate of undergoing genetic testing is 1, namely, all insurants undergo genetic testing, as shown in my model (subsidiary Lemma 4.2).

The Rothschild-Stiglitz model and my model are similar as to information structure in that both of which are asymmetric, but their basic structure is different. The Rothschild-Stiglitz model approaches the analysis on the assumption that all insurants are informed of their types, whereas in my model it is assumed that insurants are not informed of their types in advance and can be informed of their types only as a result of a choice to undergo genetic testing. Furthermore, my model allows the existence of Group Q who do not undergo genetic testing.

As a result, an important conclusion can be drawn that equilibrium, if any, would involve a separating equilibrium $\{c_L^*, c_Q^s, c_H^s\}$ or a adverse selection equilibrium $\{c_L^*, c^0, c^0\}$.

Whether or not equilibrium exists is determined primarily by a conventional analysis based on the ratio of insurants with defective genes in the market, namely, δ (type share analysis). As explained in the previous section, this is a well-known analysis, as used, for example, by Rothschild and Stiglitz (1976).

This paper makes a contribution in terms of economics in the following areas. Specifically, the second analysis on whether or not equilibrium may exist is based on the ratio of insurants who do not undergo genetic testing (group share analysis). The analytical result shows that equilibrium is obtained in a situation only where the ratio of insurants who do not undergo testing is relatively low, namely, $\bar{\gamma} \geq \gamma$, and a separating contract is equilibrated when $\bar{\gamma} \geq \gamma \geq \bar{\bar{\gamma}}$. Furthermore, in a situation where the ratio of insurants not undergoing genetic testing is extremely low, namely $\bar{\bar{\gamma}} > \gamma$, equilibrium shows adverse selection. Where the ratio of insurants not undergoing genetic testing is high, namely, $\bar{\gamma} < \gamma$ ($\bar{p}_{QL} > p_{QL}$), no equilibrium exists since a QL pooling contract exists which gives Groups Q and L Pareto improvement and thus profits insurers.

From the information structure perspective, an increase in insurants not undergoing genetic testing may allow the structure to shift from asymmetric to symmetric. At this time, it is logical to conclude that an increase in γ, namely, information which becomes more symmetric in the structure would favor equilibrium in the insurance market; however, this is merely an intuitive conclusion, not supported by the facts. As discussed in the previous section, an increase in insurants who have not been genetically tested undermines any equilibrium, thus resulting in an entirely counterintuitive conclusion. This means that the information structure shifts from asymmetric to symmetric cannot be predicted by the merely intuitive expectation that equilibrium would be favored. Hence, the existence of insurants not undergoing genetic testing (Group Q) as defined in this paper will be of extreme importance.

In this model, whether or not an insurant elect to undergo genetic testing was determined exogenously. At this time, when the role of insurants not undergoing genetic testing has been found to be so important, it will be of interest and should be further studied as to whether or not to undergo genetic testing should be determined endogenously in the model, with consideration given to the model in which insurants opt for genetic testing.

The Japanese Society for Familial Tumor organized by physicians, lawyers and others has recently made a request for the first time in Japan to the effect that insurers should be banned from using genetic testing for predisposition to cancer in medical examinations of insurants. This request was reported at the recently held meeting sponsored by the Japanese Cancer Society, resulting in the preparation of Ethical Guidelines with the aim of preventing discrimination against individuals possessing oncogenes, with the emphasis placed on the preservation of human rights of insurants and strict management of confidential information. On the other hand, however, disclosure of genetic information to relatives of insurants having oncogenes has been approved, on the condition that the information must be regarded as confidential.

From an economic perspective, if insurers were to be banned from utilizing genetic testing of all and any hereditary diseases including diagnosis of oncogenes, the insurers would have to design a contract which does not allow insurants to make false statements. Consequently, insurers are able to propose a contract with optimal conditions to Group L, but the remaining groups have no choice but to conclude a contract with less favorable conditions than those given under conditions of equilibrium of a symmetric structure. Furthermore, the less favorable contract may not be equilibrated. It may then be desirable, to provide the optimal outcome for all the groups, that insurers be able to propose a contract to an insurant on the basis of the results of genetic testing on the conditions that the information should be held in strict confidence, instead of banning the utilization of information on genetic testing.

Modern science has progressed rapidly, as exemplified by the growth in recombinant DNA and cloning technologies, and we sometimes find it difficult to keep abreast of new developments. The reality is that the Human Genome Project will, within a few years, achieve the complete decoding of human DNA base sequences. The functions of individual genes, namely, when and how they exert their function, will become known. More studies will be needed to formulate realistic strategies for dealing with genetic information on insurants.

Mathematical Appendix

In this paper, the following two premiums were defined on the basis of $L : Q : H$ ratios. First, the premium of Groups L and Q obtained by weighting the respective ratios was defined as

$$p_{QL} \equiv \frac{\delta(1-\gamma)}{\delta(1-\gamma)+\gamma}p_L^* + \frac{\gamma}{\delta(1-\gamma)+\gamma}p_Q^*,$$

and the premium of Groups Q and H obtained by weighting the respective ratios was defined as

$$p_{QH} \equiv \frac{\gamma}{\gamma+(1-\delta)(1-\gamma)}p_Q^* + \frac{(1-\delta)(1-\gamma)}{\gamma+(1-\delta)(1-\gamma)}p_H^*.$$

The relation of these premiums with the group ratios can be expressed as

$$\frac{\partial p_{QL}}{\partial \gamma} = \frac{\{\gamma+(1-\delta)(1-\gamma)\}(p_Q^*-\delta p_L^*) - \{\gamma(1-\delta)p_L^*+\delta p_Q^*\}}{\{\gamma+(1-\delta)(1-\gamma)\}^2}.$$

Therefore,

$$\begin{aligned} Numerator &= \gamma(1-\delta)p_Q^* + \delta p_Q^* - \gamma\delta(1-\delta)p_L^* - \delta^2 p_L^* \\ &\quad -\delta(1-\delta)(1-\gamma)p_L^* + \gamma(1-\delta)p_Q^* \\ &= \delta(p_Q^* - p_L^*) < 0, \end{aligned}$$

namely, $\frac{\partial p_{QL}}{\partial \gamma} < 0$ was obtained. As the ratio of Group Q increases, the premium p_{QL} decreases. Similarly, the following expression is obtained.

$$\frac{\partial p_{QH}}{\partial \gamma} = \frac{\{1-(1-\gamma)\delta\}\{p_Q^*-(1-\delta)p_H^*\} - \{\delta p_Q^*+(1-\delta)(1-\gamma)p_H^*\}\gamma}{\{\gamma+(1-\delta)(1-\gamma)\}^2}.$$

Therefore,

$$\begin{aligned}
Numerator &= p_Q^* - (1-\delta)p_H^* - (1-\gamma)\delta p_Q^* + (1-\delta)(1-\gamma)\delta p_H^* \\
&\quad -\gamma\delta p_Q^* - (1-\delta)(1-\gamma)\delta p_H^* \\
&= (1-\delta)(p_Q^* - p_H^*) > 0.
\end{aligned}$$

As a result, $\dfrac{\partial p_{QH}}{\partial \gamma} > 0$ is obtained. As the ratio of Group Q increases, the premium p_{QH} rises.

References

[1] Akerlof,G.1970. The market for lemmons : Quality uncertainty and the market mechanism. *Quarterly Journal of Economics* **84** : 488-500.

[2] Doherty, Neil A. and Lisa L. Posey. 1998. On the value of a checkup : Adverse selecton, moral hazard and the value of information. *The Journal of Risk and Insurance* **65** : 189-211.

[3] Ehrlich,I. and Becker,G.S.1972. Market Insurance,Self-Insurance and Self-Protection. *Journal of Political Economy* **80** : 623-648.

[4] Gibbons,R.1992. Game Theory for Applied Economics : Princeton University Press.

[5] Hirshleifer and Riley.1992. The analytics of uncertainty and information. Cambridge *surveys of* Economic Literature : Cambridge University Press.

[6] Murray,T.1991. Ethical issues in human genome reseach. *FASEB Journal* **5** : 55-60

[7] Pauly,M.V.1974. Overinsurance and public provision of insurance:The Roles of Maral Hazard and Adverse Selection. *Quarterly Journal of Economics* **88** : 44-62.

[8] Rothschild,M. and J.E.Stiglitz.1976. Equilibrium in competitive insurance markets : An essay in the economics of imperfect information. *Quarterly Journal of Economics* **90** : 629-649.

[9] Spence,M.1973. Job Market Signaling. *Quarterly Journal of Economics* **87** : 355-374.

[10] Spence,M. and Zeckhauser,R.1971."Insurance, Information and Individual Action," *American Economic Review* **61** : 380-387.

[11] Stiglitz,J.E.1977. Monopoly, Non-linear Pricing and Imperfect Information:The Insurance Market. *Review of Economic Studies.* October 1977.44,138 : 407-430.