ORIGINAL CONTRIBUTION

Social Cost of Smoking for the 21st Century

Kimihiro Goto^{1,2} and Shaw Watanabe¹

Lung cancer became the leading cause of cancer deaths among males in Japan in 1993. Smoking is a major attributable risk of lung cancer. Many other diseases, such as cardiovascular and chronic obstructive respiratory disease are also related to the smoking habit. The Japanese government and the public will have to pay more social cost of smoking in the future. We estimated the social cost of smoking from 1990 to 2030 through computerized simulation introducing effective variables to assess the costs, such as medical treatment, loss of life, fire, etc. The stochastic process called Ito process and financial engineering techniques are employed for making the model. The result showed that the social cost of smoking is expected to grow and reach 2.01 and 3.32 times in the year of 2010 and 2030, respectively. Fifty percent reduction of tobacco consumption could not reduce the social cost, which still climbs up to mark 1.58 in 2020. Should Japan succeed in reducing tobacco consumption by 20% per annum starting from 1996, the social cost would peak out at 1.30 in 2001 and come down to 0.93 in 2030. We estimate that 11 trillion yen (US\$ 110 billion) per annum of social cost can be saved in and around 2030 in this case. A proper development of medical economics and public health policy should be an important factor to bring forth a sound and healthy society in the next century. *J Epidemiol*, 1995; 5: 113-116.

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In the U.S.A. cigarette smoking has been recognized as the most important public health issue since the 1970s. The cigarette consumption was decreased by 20% from 1980 to 1990, reflecting the fact that 20% of all the deaths are attributed to smoking¹⁾. Number of deaths from lung cancer attributed to smoking, however, increased from 85,000 to 120,000 (+41%) during the same period. The same tendency is observed in Japan. In spite of the saturation of tobacco consumption in recent years²⁾, number of lung cancer deaths has been increasing³⁾. In addition to the heavily painful feeling to the cancer patients and their family, their economic disadvantages are enormous. Tobacco is not an immediate poison, but its medical and social effect will appear creeping up after 20 years or more⁴⁻⁶⁾. Through these observations, the old hypothesis that tobacco's social cost is in proportion to its annual consumption was inadequate, so a new system model to forecast the social cost was elaborated.

MATERIALS AND METHODS

In order to properly assess the influence of tobacco on social cost, we have introduced a new concept of an "effective variable", which represents tobacco's accumulated effect or inertia toward its social cost. This variable stands for an aggregate morbidity already residing in people's bodies in a nation. For example, tobacco, already consumed years ago, may still have influence over morbidity inside of the smoker's lungs. The effective variable S is a quantitative expression of the morbidity caused by smoking, and is defined as follows:

$$S(t) = \int_0^t \lambda(t) dt - \int_0^t \mu(t) dt + S(0)$$

S : smoking morbidity variable

λ : "creation variable" at time t .

μ : "withdrawal variable" at time t .

$\lambda(t)$ expresses an additional morbidity newly created at

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¹Cancer Information and Epidemiology Division, National Cancer Center Research Institute, Tokyo, Japan.

²Tokyo Institute of Technology, Tokyo, Japan.

Address for correspondence: Shaw Watanabe, Cancer Information and Epidemiology Division, National Cancer Center Research Institute, 5-1-1 Tsukiji Chuo-ku Tokyo, 104 Japan.

time t , i.e. a degree of tobacco production plus net import into a nation. $\mu(t)$ is a degree of a disappearing morbidity at time t through disposal of unused tobacco and affected corpses. Burning of smoker's corpses diminishes accumulated smoking morbidity.

Regarding the content of the expenditure, the social cost is composed of two types of costs as follows:

$$SC(t) = SC1(S) + SC2(\lambda, \mu)$$

$SC(t)$: social cost total

$SC1$: social cost dependent on accumulated smoking morbidity. $SC1$ is defined as medical expense plus life insurance payout.

$SC2$: social cost subject to annual tobacco consumption.

For this analyses, we confined the cost to be actually disbursed, but excluded such opportunity cost as lost income to be earned in the future. $SC2$ contains fire expense and fire insurance payout, which are obviously functions of tobacco consumption in a year itself. We have designed the system so that the social cost variables follow a stochastic process known as Ito process because of its strength that it can handle general formulae^{7,8)}.

For the calculation of number of deaths, the principle published by Hirayama and Maeda⁹⁾ was employed, incorporating the recent information published by Bartecchi et al.¹⁾ as well as Barnum⁵⁾.

RESULTS AND COMMENTS

Number of deaths attributed to smoking has been sharply increasing to 115,000 sharing 14% of all the Japanese mortality in 1990 (Table 1, Figures. 1 and 2). Number of deaths of cancer attributed to smoking reached 65,000 in 1990 (Figure. 2).

The result of the simulation is shown in Figure. 3. The social cost of smoking is expected to grow from 1 in 1990

Figure 1. No. of premature deaths attributed to smoking. Total No. of deaths attributed to smoking increased to 115,000 in 1990. Tobacco consumption is more or less saturated nowadays.

Figure 2. Breakdown of the deaths from smoking by causes. Out of 115,000, 65,000 died of cancers. The rest died of cardiovascular and chronic obstructive respiratory diseases.

Table 1. No. of deaths attributed to smoking.

Disease	Japan* in 1990	c.f. U.S.A. ¹⁾ in 1990
Cardiovascular disease	33,000	179,820
Cancer total	65,000	151,322
Lung cancer	29,000	119,920
Other cancers	36,000	31,402
Respiratory diseases	17,000	84,475
Others		3,073
Total (No. of deaths attributed to smoking)	115,000	418,690
Total (% of all the deaths)	14.0%	19.5%
No. of all the deaths	820,305	2,148,000

* Estimated from Vital Statistics, Ministry of Health and Welfare, Japan, assuming 80% of lung cancer deaths is attributed to smoking and 20% for other diseases.

to 1.47, 2.01, 2.63, and 3.32 in 2000, 2010, 2020 and 2030, respectively, if any further action be not adopted. The future social cost will only be projected with probability at this stage. For example, the one sigma confidence interval in 2000 is between 1.407 and 1.542; i.e. the social cost is projected to fall in this interval with 68% of probability when the normal distribution is assumed. The volatility grows when time passes due to the nature of the Brownian movement.

Expenditures for medical treatment and life insurance expand as time passes by due to the accumulated inertia of smoking, while expenditures for fires stay steady reflecting the saturation of tobacco consumption.

In order to assess the importance of the public health policy, the effect of public action on the problem is considered. A new variable $P(t)$ was introduced, which represents people's action and public health policy toward this issue. Different from other endogenous variables,

Figure 3. Projection of social cost of smoking. It would decrease to 0.93 in 2030 with 20% per annum of consumption reduction.

$P(t)$ is an exogenous variable of the designed system¹⁰, which people shall decide at a future time t . With the introduction of P , the social cost SC is now expressed as a function of public action.

$$SC(t) = SC(S, \lambda, \mu, P)$$

P : "public action variable" to influence the cost.

Starting from 1996, we assume any kind of social consensus be obtained to reduce tobacco consumption to improve the public health status. The result of the social actions is shown in Figure 3. If the tobacco consumption be reduced to a half, there would be a considerable improvement of the social cost from 2.63 to 1.58 in 2020. The social cost, however, would continue to rise gradually to mark 1.67 in 2030, and then peak out. If the consumption reduction be achieved by 20% per annum, the cost would peak out at 1.30 in 2001 with gradual improvement thereafter. In this case, the cost can be improved from 3.32 to 0.93 in 2030. This means that ¥ 11 trillion per annum of social saving could be achieved in Japan, assuming the current social cost of ¥ 4.5 trillion in 1990. If Japan can invest the saved amount properly, ¥ 55 trillion of an additional gross national product (GNP) would be newly created assuming the marginal propensity to consume (mpc) of 80%¹¹. Based on the theory of multiplier by Keynes, incremental GNP = investment $\times$ multiplier = 11 / (1 - mpc) = 55. This accounts for 12% of the current GNP. In this way, Japan can become a healthier and wealthier nation without heavy pain nor burden.

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Addendum on the system design to assess the future cost

1. Ito process is expressed under the following stochastic differential equation:

$$dSC = f(x)dt + \sigma \varepsilon (dt)^{1/2}$$

whereas SC : social cost at time t ,

x : effective variable on the social cost

ε : random sampling from the normal distribution $N(0, 1)$,

$\sigma^2 dt$: variation of the process from time t to $t + dt$.

The above formula is composed of the following terms. The first term corresponds to drifting part of the process, whereby the process drifts by $f(x) dt$ during a very small time from time t to $t + dt$. The second term expressed the geometric Brownian movement, which Brown found in 1877, Einstein formulated in 1905 and Ito developed in 1951. The variables x , λ , and μ also have this Brownian movement term (hereinafter referred to as Z clause), as stochastic variables do when used to forecast uncertain future events. For an actual application of the process, we have determined the following formula and decided various coefficients through statistical analysis.

$$S(t) = A \{ \exp(at) - 1 \} / a - A' \{ \exp(a't) - 1 \} / a' + S(0) + Z \text{ clause}$$

This formula was obtained from the application of the following equations on λ and μ .

$$\lambda(t) = A \exp(at) + Z \text{ clause}$$

$$\mu(t) = A' \exp(a't) + Z \text{ clause}$$

In the developed countries like Japan the above coefficient "a" is very close to zero. In the U.S.A. "a" has already turned to negative because of penetration of public health thought on the tobacco issue.

2. For the simulation, we have adopted the following formula.

$$S(t) = 66.1368(\exp(0.01447t) - 1) - 6.1513(\exp(0.02287t) - 1) + 20$$

The above smoking morbidity variable fitted well to explain no. of deaths (D) attributed to smoking as shown

below.

year	S	D calculated from S^*	D actual**
1989	22.497	110988	110000
1990	23.352	114747	115000
1991	24.217	118555	118000

$$* \quad 4400S + 12000$$

** Estimated from Vital Statistics.

3. We assumed the following cost for the basic year 1990 and cost formulae (¥ trillion):

medical expense	¥ 3.15	$0.18S - 1.05$
life insurance payout	¥ 1.21	$0.0517S$
fire expense	¥ 0.14	0.1423λ
fire insurance payout	¥ 0.04	0.0361λ