Journal of Asian Economics 20 (2009) 489–504

Contents lists available at ScienceDirect

Journal of Asian Economics

The contribution of increased life expectancy to economic development in twentieth century Japan

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ARTICLE INFO

Article history:
Received 30 January 2009
Received in revised form 16 April 2009
Accepted 16 April 2009

JEL classification:
H51
I12
I18
J17

Keywords:
Mortality
Japan
Economic development
Twentieth century

ABSTRACT

This paper estimates the value of improved health in Japan over the twentieth century. By valuing the decline in the death rate and appending this to existing measures of GDP per capita it is possible to calculate health augmented GDP per capita growth and generate original results about the monetary value of improved life expectancy over the twentieth century in Japan. The findings of the paper indicate that this is a pertinent exercise because GDP per capita growth approximately doubles when it is extended to include increases in the life expectancy of the population of Japan. These results also provide a justification for the increase in health care service spending that was evident at the close of the twentieth century.

1. Introduction

Accompanying Japan's successful industrialisation were similarly impressive improvements in health. During the twentieth century life expectancy increased by 36 years, 28.5 of which occurred between 1947 and 2000 (JMHW, 2001). Increases in life expectancy are an important manifestation of improvements in human welfare. However these developments have been unrecognised by conventional 'Hicksian' or production based measures of economic growth, which only consider national output and income.

The motivation for this paper is to value Japan's health in conjunction with existing GDP per capita measures in order to provide a more accurate indication of Japan's economic development. This more comprehensive measure of economic growth will be achieved through adjusting real income to reflect the value of improving health status. The intuition is that the same annual income with a long and healthy life should be ranked as a higher living standard than that income with a short and diseased life. Hence, people are better off when they live longer and this fact should be recognised in measures of their income, living standards, and national product. This feature is especially pronounced given Japan's world leadership in average life expectancy.

Health care expenditure is included in measures of national income, and represents a growing fraction of gross domestic product (GDP). Between 1955 and 1973 Japan's health care spending as a ratio of GDP increased from 2.7% to 3.9%, and by the close of the twentieth century represented over 5% of GDP (Maddison, 2001). Although the cost of health care has been documented there has not been an attempt to value the equivalent output or return on health care over the twentieth

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doi:10.1016/j.asieco.2009.04.006

Table 1
Growth rates of real GDP per capita, Japan, 1900–2000 (% per annum).

Decade	GDP per capita growth rate
1900–1910	1.0
1910–1920	2.6
1920–1930	0.9
1930–1940	4.4
1940–1950	−4.0
1950–1960	7.3
1960–1970	8.9
1970–1980	3.2
1980–1990	3.4
1990–2000	0.7

Sources: author's calculations from Maddison (2001).

century in Japan. Existing techniques that measure the price and quantity of health care are highly defective, and there are no efforts to represent improvements in the length of life. Therefore, measurement of health service output poses a difficult but increasingly relevant challenge that motivates the adoption of a more utility based or 'Fisherian' calculation of economic growth to include an estimate for health care output, in terms of the value of additional life years health care spending or inputs have delivered.

The contributions of the paper are fourfold: the application of a novel methodology will generate original estimates of 'Fisherian' or utility based GDP per capita growth in twentieth century Japan; the results of calculating GDP per capita augmented for health output will specifically highlight the extra contribution that improved mortality has contributed to more detailed measures of growth; these original estimates of health augmented GDP per capita will emphasise the magnitude of Japan's economic development during the twentieth century; the paper also generates optimistic conclusions about the productivity of health care spending which provides a justification for the increase in health care service spending that was evident at the close of the twentieth century under the mandatory long-term care insurance.

The paper is organised as follows. In the next section the key features of Japan's economic and health growth will be summarised. Section 3 presents the methodology that will be used to generate original results about the value of Japan's health augmented GDP per capita growth. Section 4 presents these results and Section 5 concludes.

2. Remarkable growth: economy, health, and government policy in twentieth century Japan

This section summarises twentieth century GDP per capita growth trends, government initiatives towards improving the health of the nation and the health outcomes, as measured by life expectancy.

2.1. Economy

During the twentieth century, particularly the post war period, Japan experienced one of the most successful industrialisation episodes in world history. Initial modern economic growth began with the Meiji Restoration in 1868, after which Japan took-off at a relatively rapid rate of pre-modern economic growth.[1] Another important area of economic development in the pre World War One period was the increase in standards of living and per capita income, by nearly 30% (Smitka, 1988).

The financial crisis of 1920 and the financial panics during the 1920s, combined with the World Depression from 1929 and World War Two burdened Japan with economic problems (Francks, 1992). In contrast, by 1955 Japan had completed her reconstruction and began to enter a phase of rapid economic growth. Numerous reasons have been postulated for such successful growth, from a high investment rate to a unique industrial structure, and a highly educated workforce, among other contributing factors.[2] Additional improvements in the standards of living of the population were yielded by the rise of affluent society and increased levels of consumption and commendably, increased national equality in wages (Gordon, 1993).

During the 1970s Japan's catch-up growth came to and end. The decline in domestic demand-led economic growth was exacerbated by OPEC's fourfold increase in oil prices from late 1973.[3] By 1986 Japan was enjoying demand-led recovery with momentum that continued until the economic 'bubble' burst at the end of the 1980s (Akihiro & Woo, 2001). During the final decade of the twentieth century Japan's economy grew at a mere 1%.[4] Table 1 summarises the per decade growth rates experienced in twentieth century Japan.

The magnitude of Japan's growth achievements over the twentieth century and especially in the post-war era, are reflected in Table 2 which compares Japan's GDP per capita growth with that in the USA and the UK.

1 For a detailed outline of Japan's early twentieth century growth see Okawa and Rosovsky (1973).
2 For a detailed consideration see Horioka (1990), Hunter and Storz (2006), and Flath (2005) for a general overview.
3 For more coverage of this point see Smitka (1988).
4 See Mikitani and Posen (2000) and Amyx (2004) for details about the continuing growth problems caused by the financial crisis and Gao (2001) for an explanation about the effects of mature growth.

Table 2
GDP per capita and GDP per capita compound average per annum growth, Japan, United States, United Kingdom (US dollars).

Year	Japan	United States	United Kingdom
GDP per capita			
1900	2,008	8,634	8,299
1913	2,358	11,188	9,091
1950	3,310	19,864	12,372
1973	19,642	32,599	21,988
2000	35,491	47,477	32,508
Period	**Japan**	**United States**	**United Kingdom**
GDP per capita growth			
1900–2000	2.9	1.7	1.4
1900–1913	1.2	2.0	0.7
1913–1950	0.9	1.6	0.8
1950–1973	7.7	2.1	2.5
1973–2000	2.2	1.4	1.4

Sources: GDP per capita: Maddison (2001); GDP per capita growth: author's calculations from Maddison (2001).

The most remarkable growth phase in Japan in Table 2 was during the period 1950–1973 when GDP per capita increased by an average of 7.7% per annum, versus 2.1 in the USA and 2.5% in the UK. Between 1900 and 2000 compound average rates of per annum growth were 2.9% in Japan versus 1.7% and 1.4% in the USA and UK, respectively. This growth enabled Japan to achieve GDP per capita growth levels that were greater than the UK by the year 2000, from a level that was only one quarter of the UK in 1900.

2.2. Health

Accompanying Japan's economic growth success was a remarkable health transition that occurred during the post-World War Two period. Table 3 summarises the substantial increase in life expectancy in twentieth century Japan.

During the Meiji era the Japanese population experienced health problems such as typhoid fever, bacillary dysentery, cholera, trachoma and venereal disease. Later, when industrialisation generated movement from rural to urban areas, tuberculosis and maternal and child health problems were added to the main health agenda. From about 1935 concerted efforts were made to control tuberculosis and maternal and child health illnesses. By 1956 tuberculosis had been successfully eliminated as one of the five main causes of death. With an ageing population, chronic degenerative diseases such as stroke, cancer and heart disease have increasingly become the main causes of death. However, Japan has faired better than most other developed nations with life expectancy increasing from 63.9 years in 1955 to 80.5 years by the year 2000. In terms of an international rank, this improvement in life expectancy has enabled Japan to improve from 38th place in 1955 to 2nd place in 1980 and 1st place in 1990 and 2000. This is reported in Table 4.

Table 3
Life expectancy at birth and age 65 by gender, Japan 1899–2000 (years).

Year	Life expectancy			
	At birth		At age 65	
	Male	Female	Male	Female
1899–1903	43.97	44.85	10.14	11.35
1909–1913	44.25	44.83	10.58	11.94
1921–1925	42.06	43.20	9.31	11.10
1926–1930	44.82	46.54	9.64	11.58
1935–1936	46.92	49.63	9.89	11.88
1947	50.06	53.96	10.16	12.22
1950–1952	59.57	62.97	11.35	13.36
1955	63.60	67.75	11.82	14.13
1960	65.32	70.19	11.62	14.10
1965	67.74	72.92	11.88	14.56
1970	69.31	74.66	12.50	15.34
1975	71.73	76.89	13.72	16.56
1980	73.35	78.76	14.56	17.68
1985	74.78	80.84	15.52	18.94
1990	75.92	81.90	16.22	20.03
1995	76.38	82.85	16.48	20.94
2000	77.64	84.62	17.43	22.44

Sources: Japan Ministry of Health and Welfare (2001).

Table 4
World ranking for life expectancy at birth: rank and years of life expectancy, 1955–2000.

Year	Japan	USA	UK	Norway	Netherlands	Iceland	Sweden
1955	38 (63.9)	11 (68.9)	9 (69.2)	1 (72.2)	2 (72.1)	3 (72.0)	4 (71.8)
1960	39 (66.8)	13 (69.7)	10 (70.4)	1 (73.3)	2= (73.0)	2= (73.0)	4 (72.7)
1970	15 (71.7)	29 (70.4)	10 (71.4)	2 (73.8)	3 (73.6)	4 (73.4)	1 (74.1)
1980	2 (75.5)	16 (73.3)	18 (72.8)	3= (75.3)	3= (75.3)	1 (76.3)	5 (75.2)
1990	1 (78.3)	31 (74.4)	18 (75.0)	10 (76.3)	6 (76.8)	2 (77.8)	4 (77.3)
2000	1 (80.5)	19 (76.2)	17 (77.2)	10 (78.1)	11 (77.9)	2= (79.3)	2= (79.3)

Sources: UNCD (2009).

The most prominent reasons for Japan's performance are: the benefits of a low fat diet that contributes to relatively low levels of heart disease (which is the number one killer in most comparable industrialised nations), and because the long-term effects of post World War Two smoking in males had not presented by the close of the twentieth century. Universal health insurance, which was achieved by the early 1960s, is another important factor. Less obvious reasons such as high levels of educational attainment, which enables more sensitivity towards health issues, combined with rapid and comprehensive development have contributed to good health, as have low rates of poverty in the elderly.

2.3. Government health policy

Health insurance was first available in 1927 for manual workers employed by large corporations, and was later extended to all manual workers in 1935, and white collar workers in 1940 (Ikegami, 1982). Owing to the evolution of the welfare state after World War Two these policies were extended. This trend culminated with the introduction of free universal health care for those aged over 70 years under the 1972 Geriatric Welfare Act. This was reformed (in 1982, 1986, 1992, and 1997) such that costs were not entirely financed by the government, although the aid provided by this health care policy is still regarded as considerable (correspondence with Butler, Pharmaceutical Research and Manufacturers of America, 2001). For the remainder of the population health insurance payments are financed by a combination of workers' premiums, employers' premiums, and the government. Nearly 100% of the population is covered by one of six major health insurance plans (Broida, 1978).

The twentieth century also experienced an increase in industrial health movements. Although it was not until after the Second World War that industrial health was generally recognised, both for the control of disease and the improvement of working conditions, through the Labour Standards Law and the Trade Union Law.

The government is also responsible for twentieth century developments in health education. This includes the training of physicians, establishing an increasing number of medical schools, manpower development plans for supporting health personnel and also creating policies to educate the general public about health and nutrition. Since 1970 there has been an increase in the number of medical schools and enrolment (Ushiba & Suzuki, 1978) and between 1954 and 1984 the number of physicians in Japan almost doubled (Sonoda, 1988).

In 1949 health education was introduced into the lower and secondary school curriculum and in 1952 the government introduced the Nutrition Improvement Law (Toyokawa, 1978). Despite these efforts health education has been slow to develop and some authors claim that it received limited attention during the latter part of the twentieth century (Toyokawa, 1978).

Overriding these contributions is the benefit of government spending and implementing health care insurance schemes for the population. During the second half of the twentieth century health care spending as a proportion of GDP virtually doubled, which can be considered as a direct function of an ageing population and increased demand for medical care, even among those not suffering from debilitating diseases. It seems reasonable to conclude that at least some of the gain in life expectancy is as a result of improvements in health care (that has received significant contributions from the government). The current best estimate is that 50% of health gains can be attributed to the health care service inputs (Poikolainen & Eskola, 1986). It is beyond the scope of the paper to evaluate the collection of factors that contribute to Japan's high life expectancy, although it is important to note that universal health coverage has been achieved at relatively low cost. However, even though the health service in Japan has been successful at increasing life expectancy there are quality issues faced by consumers. For example, the system has been criticised for poor management and limited consumer choice (Ikegami & Campbell, 1995). More fundamental sources of concern are weaknesses in professional standards, inadequate continuing medical education and a lack of quality control (Ikegami & Campbell, 1995).

Therefore, at an initial approximation it would seem that the increase in medical spending is justified given such substantial increases in life expectancy in Japan during the twentieth century (presented in Table 3). In order to provide a more substantiated indication about the return of health care spending, this additional life expectancy needs to be valued and considered in conjunction with GDP per capita. The methodological process that will achieve this is outlined in the following section. It should be noted that this methodology does not consider the performance of the health care service in terms of consumer choice and quality. Typical consumer complaints in Japan cite long waiting times, a lack of explanation, and poor physical facilities (Ikegami & Campbell, 1995). Although these seem not to heavily impinge on life expectancy they do detract from the overall quality and value of health care services.

3. Methodology: willingness to pay (WTP)

A number of development indices and measures incorporate life expectancy. However many of these consider health in an arbitrary manner (e.g. the Human Development Index), do not evaluate income in conjunction with health or do this in a way which undermines the considerable increases in twentieth century Japan (again the HDI income threshold does not indicate the full success story of Japan's economic development). Moreover, numerous measures consider health among many other variables, for example, Dasgupta (1993) considered 6 welfare aspects, one of which is life expectancy at birth.

Other methods for evaluating gains in health utilise physiological measures, for example anthropometric measures and the Body Mass Index (BMI). However, this is more ambiguous than considering life expectancy, particularly in a long-run retrospective study. Moreover, although these measures tend to move with other measures of health status, they are difficult to evaluate and quantify (Nordhaus, 1999).

A more general approach is to measure gains in health outcomes, living or dieing, by considering the change in the death rate over time. Although this lacks precision compared to measuring health per se, it provides a plausible alternative that is not eclipsed by data constraints and ambiguities.

Therefore the most promising approach in the literature considers the value of changes in life expectancy. Although there are still conceptual difficulties associated with trying to incorporate life expectancy into a national income measure these are more surmountable than trying to include heights or BMI into an extended GDP index. When valuing improved mortality, traditional cost benefit analysis has relied upon the human capital approach in which the benefit is the discounted earnings of the affected population, so as to reflect productivity. Even though more data are available on the human capital approach, the WTP method is theoretically superior (Conley, 1976). WTP essentially calculates the value of additional life years as the sum that individuals would be willing to forego in income for an increased probability of survival in the current period (not for a given age of life expectancy).

The WTP approach does not avoid weighting and index number problems but they are less inherent in this methodology than in most of the alternatives, briefly considered above. The largest drawback of WTP is the failure to explicitly account for health improvements. I.e. only mortality is calculated, without an equivalent morbidity component. Although increased longevity is facilitated by improved health, the relationship is not linear. However, the WTP approach is valuable for its superior ability to price mortality and to include life expectancy changes in the utility function coupled with conventional consumption as measured by the national accounts, and therefore compute the value of increased life expectancy in conjunction with increased per capita income.

Usher (1980) has highlighted the importance of improved mortality to society and the likelihood of an individual sacrificing any other modern standard of living to maintain current mortality rates, as individuals consider long life an important aspect of welfare. Certain authors have highlighted the contribution of improved health to economic development to be so substantial that there is not likely to be any magnitude of income that could compensate a year 2000 individual for living under year 1900 health conditions (Bradford DeLong, 2000). The indifference curve diagram in Fig. 1 further illustrates the concept of WTP.

Consider a person observed initially at point 1900 and subsequently at point 2000: between 1900 and 2000 life expectancy has increased from E1 to E2 and income has increased from C1 to C2*, not C2, as traditional measures would indicate. Point C2* is the height of the intersection of the indifference curve attained in 2000 with a vertical line at the value of life expectancy in 1900, whereby the individual maintains 2000 income with 1900 life expectancy. The difference between

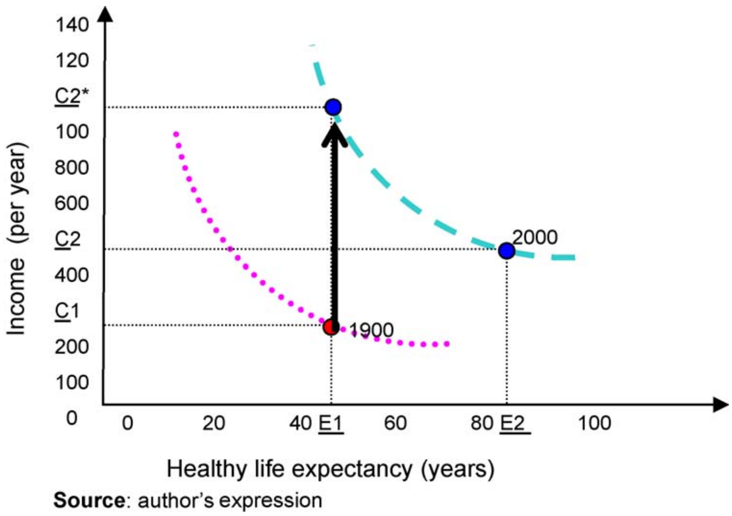


Fig. 1. Indifference curve diagram to illustrate the rationale of willingness to pay (WTP) methodology.

C2 and C2* indicates the income value of increased life expectancy between 1900 and 2000 and the amount of income that an individual would be willing to pay for the improved health conditions of 2000, compared to 1900.

The consideration of real income inclusive of an imputation for changes in mortality forms the foundation of the methodology used in the paper. The practice of adjusting national income measures to account for increases in life expectancy was originally proposed by Usher (1980), who recognised the need to consider the value of maximising age specific mortality rates and societies' willingness to pay for such gains in economic welfare. The primary objective of this methodology is to find a natural approach to coupling GDP per capita and mortality rates into a single comprehensive index, referred to here as health augmented GDP per capita, because the growth of GDP per capita alone significantly understates the extent to which current generations are better off than earlier generations. In this approach gains from improved mortality are treated as an imputation for a change in the environment and as such are not double counted. Hence, the situation where a higher GDP per capita had been achieved by a work force that is healthier and lives longer is not currently accounted for by GDP per capita measures. The key point that is accounted for by the methodology is that the same annual GDP per capita with a long life should be recognised as a higher living standard that that income with a short life (Crafts, 2005). For example, an economy in which the population has a GDP per capita of $20,000 with lives that are short and in poor health would be ranked the same as people having income of $20,000 with a long and healthy life by traditional measures (Nordhaus, 1999). This shortcoming will be addressed by calculating health augmented GDP per capita.

Neo-classical growth models would predict that a healthier workforce enables the labour aspect of the production function to be more effective and as such would lead to an increase in productivity and all things being equal, economic output, which would be captured as increased GDP per capita. Additionally, Kinugasa and Mason (2007) identify that the rise in adult life expectancy has a large and statistically significant effect on aggregate savings, which would also increase GDP per capita. Mason and Kinugasa (2008) identify that for countries encouraging capital accumulation as a means of meeting retirement needs, ageing serves as a fundamental force for creating wealthier and more prosperous society, which would increase GDP per capita levels. However, what is being measured in the paper is the utility value of additional life expectancy and as such there is no existing proxy for this in measures of GDP per capita. This means that the results presented below are not double counting any of the value already contained in twentieth century Japan GDP per capita levels. What can be argued is that GDP is not designed to measure utility type components of the economy. This is not the focus of the paper, which utilised GDP per capita to provide a clear indication about the magnitude of the value of improved life expectancy in Japan over the twentieth century. Moreover, in this approach, gains from improved mortality and morbidity are treated as an imputation for a change in the environment, because increased life expectancy has been largely a result of the accumulation of knowledge on how to cure and prevent diseases that affect all individuals (rich and poor, educated and uneducated), which represents further reasons that these improvements are not included in income measures and therefore not double counted by the imputations made here.

Despite the importance of imputing historical national income growth for improved life expectancy, and the implications for economic development that these changes in health have generated, there have been a very limited number of attempts to retrospectively value gains in mortality. The only studies that have employed WTP methodology to estimate long run historical health gains are Nordhaus (1999), Murphy and Topel (2005), and Hickson (2009) for the USA during the twentieth century, and Crafts (2005) for the UK and Hickson (2009) for England and Wales over the twentieth century.

The WTP mortality approach used in this paper applies what was proposed by Usher (1980) and refined by Nordhaus (1999), to provide a method of measuring the gain in real income from improved life expectancy in the context of the life cycle consumption model in twentieth century Japan. An individual is assumed to value consumption and health according to a lifetime utility function:

$$V[c_t;\theta,\rho,\mu_t] = \int_{\theta}^{\infty} u(c_t)\,\mathrm{e}^{-\rho(t-\theta)} S[\mu_t]\,\mathrm{d}t \tag{1}$$

where $V[c_t; \theta, \rho, \mu_t]$ is the value at time t of the consumption stream, now and in the future, faced by an individual of age θ; c_t is the stream of instantaneous utility; ρ is the pure rate of individual time preference; $S[\mu_t]$ is the set of survival probabilities; and μ_t is the set of mortality rates. The key assumption here is that utility is a function of the expected value of consumption weighted by the probability of survival. It is also assumed that the survival function is exponential, and therefore Eq. (1) becomes

$$V[c_t;\theta,\rho,\mu_t] = \int_{\theta}^{\infty} u(c_t)\,\mathrm{e}^{-(\rho+\mu)(t-\theta)}\,\mathrm{d}t \tag{2}$$

This equation can be further simplified by assuming that the real interest rate faced by the individual is equal to the mortality-adjusted rate of time preference $(\rho + \mu)$. Given these assumptions, an individual will choose a consumption annuity that yields constant consumption during the individual's lifetime, $c_t = c^*$. Integrating Eq. (2) yields a simpler outcome:

$$V[c_t;\theta,\rho,\mu_t] = \frac{u(c*)}{(\rho+\mu)} \tag{3}$$

Eq. (3) shows that the total utility value of consumption, discounted by a discount rate that equals the sum of the force of impatience and the force of mortality.

An individual will often face a trade-off between health and wealth. At age θ, changes in consumption and health yield:

$$\left.\begin{aligned} dV/d\mu &= u(c*)/(\rho+\mu)^2 \\ dV/dc* &= u'(c*)/(\rho+\mu) \end{aligned}\right\} \tag{4}$$

Hence, the trade-off between consumption and mortality:

$$\frac{dc*}{d\mu} = \frac{-u(c*)}{[u'(c*)(\rho+\mu)]} \tag{5}$$

It is then possible to further simplify through making two normalisations. First, utility is defined so that one unit of utility is one extra unit of the consumption good, by setting $u'(c^*) = 1$. Second, the pure rate of time preference is set equal to zero, such that when the utility of consumption is $u(c) = 0$, the individual is indifferent between life and death. This implies that there is zero utility after death. Given these assumptions, Eq. (5) can be reduced to

$$\frac{dc*}{d\mu} = Tu(c*) \tag{6}$$

where T is life expectancy ($T = 1/\mu$). The interpretation here is that a uniform change in mortality rates at every age will produce a welfare change equal to the number of years of life (T) times the goods value of life, $u(c^*)$.

This arguably simplistic deduction about the real economic and demographic environment provides an initial indication about a more accurate account of Japan's economic growth and indicates increased economic welfare and development, rather than the purely fiscal measure of economic growth that is currently provided by GDP per capita measures. The data required to make this adjustment to the conventional estimates of national income are population by age, death rates by age and the value of death averted. The mortality approach used here to obtain utility or 'Fisherian' national income, referred to as health augmented GDP per capita, values improvements in life expectancy by considering the change in the population weighted average of age specific mortality rates multiplied by the estimated value of death averted, which is approximately equal to the increase in life expectancy times the value of an additional year of life. The goods value of life $u(c^*)$ is empirically estimated through using the results of revealed preference value of a statistical life (VSL) studies.

In order to estimate societies' willingness to pay for reduced mortality it is necessary to establish the amount that a group of people are willing to pay for a reduction in the current period probability of death. VSL studies estimate the value of fatal risk reduction in the expectation of saving one life (of an unidentified person) in the current period. For example, if people are on average willing to pay Y100 for a safety improvement that will reduce their individual risk of death during the coming year by 1 in 100,000, this risk reduction would mean that, on average, in a group of 100,000 people there would be 1 fewer premature deaths and that between them these 100,000 people would be willing to pay Y100 $\times$ 100,000 = Y10 million for the prevention of one statistical fatality, and as such the VSL is equivalent to Y10 million.

In an attempt to determine the goods value of life there is a growing body of empirical evidence concerning premiums individuals are willing to pay to reduce the risk of death by small amounts (Blomquist, 1981). There are three approaches that have been adopted to identify the VSL. First, is based on the implications of individuals' observed behaviour in production, e.g. risk compensating wage studies. Second, is based on the implications of individuals' observed behaviour in consumption, e.g. information concerning the time-inconsistency-safety trade offs involved in seat belt use, motorway speed decisions, the purchase and maintenance of smoke detectors for the home, etc. In contrast to these revealed preference approaches the third method elicits responses to questionnaires that involve asking a sample of individuals about their willingness to pay for various hypothetical changes in risk of fatality.

The majority of revealed preference studies have focused on risk compensating wage differentials or hedonic price studies. It is thought that this provides the most reliable estimate of individuals' willingness to pay for a reduced probability of death because labour market studies reflect actual behaviour, labour force decisions are repeated, and the variety of labour markets within and across countries and over time provides a rich choice of sample (Nordhaus, 1999).

Estimates of the amount individuals are willing to pay to reduce the risk of mortality range widely, from less than \$100,000 to several million dollars (Dillingham, 1983), and as such empirical work in this field has yet to produce a reliable consensus about the VSL. As a result sceptics have claimed that the variation in VSL estimates raises such doubts about their reliability that they are virtually useless as a source of information about the magnitude of marginal rates of substitution of income for the risk of death. For example, for a time this view was adopted by the UK Department of Transport (Jones-Lee, 1989). A preferable approach (on philosophical, scientific and practical grounds) is to identify the reasons for the large variation in VSL estimates and try to define what constitutes a reliable study (Jones-Lee, 1989). Assessment of the reliability of different estimates is clearly a subjective matter, but it is possible to identify some fairly obvious sources of inaccuracy.

The paper will use Kniesner and Leeth's (1991) estimate of the VSL that has been generated using compensating wage differentials for a sample of 21 two-digit manufacturing industries (employing over 30 workers) in Japan in 1986. Given increases in GDP per capita over the twentieth century and the income elasticity of health the paper will use a dynamic VSL in order to more accurately capture such changes. This is achieved through using a VSL multiple with GDP per capita for the mid point of the period under consideration. For example, when considering the entire twentieth century the VSL will be calculated as the VSL multiple*GDP per capita in 1950. Adopting this approach also overcomes problems of selecting a correct discount rate. Miller (2000) provides estimates for the VSL multiple derived from Kniesner and Leeth's (1991) study, which range from 121 to 192, with a mid-point of 157. Hence, when considering the twentieth century the lower bound VSL for Japan = 121 $\times$ 3310 = 400,510 or $0.401 million, where 121 represents the low VSL multiple and 3310 the level of GDP per capita at the mid-point (1950).

The most prominent problems of Kniesner and Leeth's (1991) study are related to the design of their model. They use aggregated industry data rather than considering occupations and corresponding wages. The effects of aggregation are relevant as the estimated compensating wage differentials become more valuable (as wage rate studies that fail to use risk data by occupation tend to overestimate the VSL). For example, the coefficient of the overall injury rate is significantly negative in all regressions, which is interpreted as indicating model misspecification (Kniesner & Leeth, 1991).

Also problematic for estimating an accurate VSL for Japan are unique labour market characteristics that Kniesner and Leeth (1991) fail to overcome. First, low worker inter-firm mobility, for example, post-war monthly worker separation rates are 2–3 times greater in American manufacturing than in Japanese. Second, the situation in Japan, where the largest manufacturing firm pays the highest wages and has the lowest injury rate caused problems for estimating the VSL as they cannot hold firm size constant in their model and therefore fail to overcome this anomaly. Despite these problems the Kniesner and Leeth (1991) estimate will be used given the void of any superior alternative.

On a more positive note, Kniesner and Leeth (1991) attempted to make their study more accurate through selecting years that are neither troughs nor peaks of business cycles. This is because production levels affect injury rates and the equilibrium trade-off between wages and the injury rate. Furthermore, Japan has a national workers compensation wage rate, with uniform benefits across prefectures. This reduces potential inaccuracies as there is no need to account for different compensating wage preferences across the regions of Japan. These two advantages help increase the credibility of the VSL estimate.

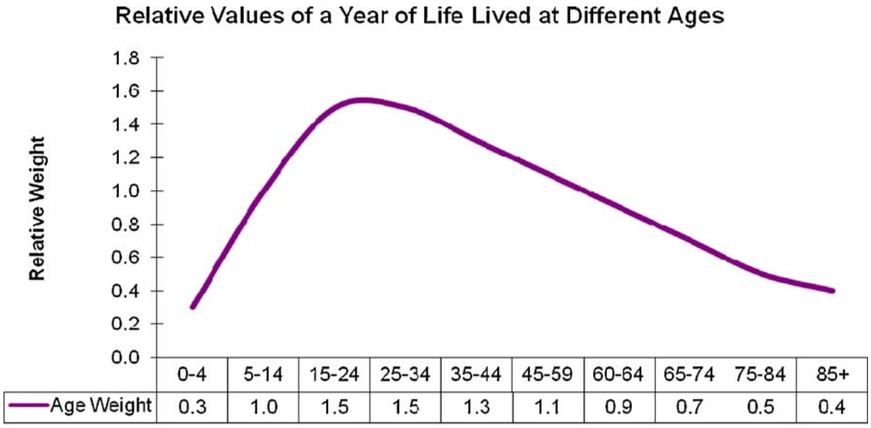
The Kniesner and Leeth (1991) study is especially useful because there are no official VSL estimates for Japan. After extensive research and correspondence with different departments of the Japan government (Ministry of Health, Labour and Welfare; Ministry of Land, Infrastructure and Transport; Cabinet Office; Statistics Bureau; Environment Office) no official form of VSL was found for Japan. Correspondence with Kishimoto (Environment Office, Research Centre for Chemical Risk Management, 2001) informed the author that cost benefit analysis is rarely applied to risk reducing policies and consequently Japan's government does not provide an official estimate of the VSL. In other economies, such as the United States and the United Kingdom, different government agencies (often transport and environment) use willingness to pay value of statistical life estimates to determine the cost versus benefit of different safety measures and regulations. For example, in the United States the Environmental Protection Agency (EPA) suggest that a reasonable estimate of the VSL has a mean of $4.8 million with a confidence interval of plus or minus $3.2 million (US EPA, 1997). Given similar levels of income between Japan and the United States (which is an important driver of the VSL value) there is little reason to assume that if Japan did have an official VSL it would vary markedly. As such it seems viable to accept the Kniesner and Leeth (1991) VSL used here of $0.4 million as a lower bound estimate.

Additional considerations about the elasticity of the VSL can also need to be evaluated. Costa and Kahn (2003) have highlighted that as an economy develops, income, the quantity of safety and the health and well-being of the population also increase along with the demand for safety and the subsequent compensating wage differential. For example, they estimate that between 1940 and 1980 the VSL increased by 300–400%, rising from roughly 1 million (1990 $) in 1940 to 5 million (1990 $) in 1980 in the USA, which indicates a VSL income elasticity of between 1.5 and 1.7. Conversely, some studies have shown that there is an inelastic relationship between income and the VSL. Viscusi and Aldy (2003) also consider wage risk studies and conclude that the income elasticity for the VSL is less than 1 and they estimates income elasticity as being between 0.5 and 0.7.

The implication of these different levels of income elasticity is the variance of the VSL relative to GDP per capita over the twentieth century. Costa and Kahn's (2003) results imply that as an economy develops, increases in longevity or the VSL become more valuable (as the VSL rises 60% more than GDP per capita or income, because the VSL income elasticity they propose is 1.6%, on average). This is in direct contrast with Viscusi and Aldy's (2003) result, which implies that earlier increases in longevity were more valuable (as the VSL rises approximately 60% less than GDP per capita or income, because they propose that the VSL is inelastic by 0.6%). The implication of these theories is the relative magnitude of the VSL: if the VSL is income inelastic (Viscusi & Aldy, 2003), the value of the VSL is relatively large in earlier time periods, and the opposite is true for an income elastic VSL (Costa & Kahn, 2003), where the VSL becomes increasingly valuable as the twentieth century unfolds.

When Miller's low VSL estimate for twentieth century Japan is $0.401 million, Costa and Kahn (2003) elasticity of 1.6 can be used to adjust the VSL to a level of $0.277 million for twentieth century Japan. The Viscusi and Aldy (2003) VSL with inelasticity of 0.6 is calculated to be worth $0.737 million.

Although there are competing directional biases in the VSL result and contention associated with identifying a universally agreeable value, the lower bound VSL multiple (presented above as 121) with Costa and Khan's (2003) income elasticity of 1.6 and a mid range estimate that uses Miller's mid VSL multiple and unitary elasticity will be used throughout to provide a range of results, from a lower bund estimate to a more plausible mid range, in order to include a form of sensitivity analysis which will generate more acceptable overall results about the value of Japan's 'Fisherian' or health augmented GDP per capita growth. However, it should be noted that the overall conclusions about the value of improvements in mortality hold whichever VSL is selected.



Source: Murray & Lopez (1996).

Fig. 2. Age-weight function: relative value of a year of life lived at different ages.

A further form of sensitivity analysis that will be used to try and incorporate additional accuracy is age-weighting. There is some evidence that the VSL is not consistent across all ages and that relying on the calculation of health effects that are un-weighted for different ages is not wholly satisfactory (Barnum, 1987). Therefore a more desirable approach for estimating societies' willingness to pay would include a consideration about the potential for different ages to adopt different values.

Age-weighting can be conducted from an equity standpoint, where age-weights reflect the feeling that everyone is entitled to some normal span of life and anyone failing to achieve this has been cheated, while anyone getting more than this is living on borrowed time (Williams, 1997). In this type of 'fair innings' argument, younger patients receive a higher age-weight as they have completed a smaller portion of their normal or entitled life span.

Certain authors have highlighted the desirability of age-weighting to reflect economic contribution to society. Cooper and Rice (1976) adopt a human capital approach to include income differentials of different workers, where higher income groups who contribute more to total economic product are given a greater weight. Other authors have studied the extra contribution of more educated workers and emphasise the importance of including differentiation between high school and college graduates (Rosen, 1976).

The alternative and more commonly utilised method of age-weighting considers the relationship between age and efficiency, by reflecting the individual's social role, where people are supported by others during infancy and old age, but support others during adulthood. This continuous age-weighting function is provided by Murray and Lopez (1996) and supports the notion that greater value needs to be attached to years of productive adult life. This is illustrated in Fig. 2.

Murray and Lopez's (1996) age-weighting function will be applied to account for the different roles and contributions of different age groups in order to provide more accurate results about the value of gains in increased life expectancy in twentieth century Japan. It should also be noted that even if the precise age weights are debatable the exercise provides a form of sensitivity analysis to create lower bound results. This is because much of the improvement in life expectancy has been a result of a fall in the number of deaths at the youngest and oldest ages, which are given a lower weighing. Moreover, there are unique features to Japan which exacerbate the lower bound nature of this age-weighting function. Japanese practices of lifetime employment and considerable on-the-job retraining create a scenario where substantially higher wage rates are experienced towards the end of an employee's career (Mincer & Higuchi, 1988). Further underestimates are likely to be manifest in Japan's highly literate and educated work force.

The drawbacks of using this age-weighting function are twofold. First, is the static nature of the function, whereby the changing economic contribution of different age and gender groups over the twentieth century is not reflected. Second, is the generic nature of the age-weighting which is not specific to Japan's economy. However, the basic objective of adding another layer of sensitivity analysis is accomplished and the results should be deemed acceptable as a first order estimate. Moreover, it is not possible to include any form of official age-weight estimates for Japan because the government does not calculate a VSL or age-weighted VSL. Hence, at this stage there is no superior alternative and therefore Murray and Lopez's (1996) age-weights will be included, at the least as a form of sensitivity analysis and at the most to provide a more detailed indication of the value of improved life expectancy in twentieth century Japan.

4. Results: WTP in twentieth century Japan

Accounting for the improved health status of the population of Japan is likely to make a substantial difference to current measures of economic welfare during the twentieth century. When considering the growth of living standards in twentieth century Japan it seems worthwhile to consider the consumption or GDP per capita equivalent of increased life expectancy for two primary reasons. First, one of the most remarkable achievements of twentieth century Japan was the increase in

Table 5
Values of the decline in the death rate in Japan, 1900–2000 (million $).

Period/estimate	Decline in death rate (per million population)	Value of death averted (million $)		Value of reduced mortality (per million population)	
		Un-weighted	Age-weighted	Un-weighted	Age-weighted
1900–2000 lower bound	22,551	0.277	0.083–0.416	6,247	4462
1920–2000 mid range	2,255	0.520	*0.156–0.780*	11,727	8376

Sources: decline in death rate: author's calculations from MIAC (2009) and Ministry of Internal Affairs and Communications (2008a,b); value of death averted: author's calculations from combining decline in the death rate with value of a statistical life (VSL) data from Miller (2000) and income elasticity from Costa and Kahn (2003), and age-weighting from Murray and Lopez, 1996), where applicable. Lower bound = Miller's (2000) low VSL and Costa and Kahn (2003) positive income elasticity, which gives the lowest adjustment, and mid range = Miller's (2000) mid VSL and unitary elasticity. Value of reduced mortality: author's calculation from previous columns.

longevity, such that by the year 2000 life expectancy at birth was nearly 78 years for males and 85 years for females, representing the highest in the world (Imai, 2002). Second, there is convincing evidence that reduced risks of mortality are highly valued as consumers are willing to pay significant amounts to reduce the risk of mortality (Usher, 1980). The willingness to pay methodology that has been outlined above will be applied to the data for Japan in this section.

Table 5 reports the improvements in life expectancy in terms of declines in the death rate, in an age-weighted and un-weighted format for the period 1900–2000. The value of death averted is representative of the VSL. The final column of Table 5 presents the value of lower mortality or improved life expectancy, referred to as the mortality gain.

The decline in the death rate between 1900 and 2000, has been calculated by considering the age distribution of the population in 1900 and 2000, whereby the decline in the death rate has been calculated for the 1900 population structure and the year 2000 population structure and these two results are then averaged to provide a single estimate for the decline in the death rate (see Appendix A for the more detailed calculations). For example, between 1900 and 2000, the fall in the death rate ranged from 17,741 when fixed to 1900 population structure and 27,361 when fixed to 2000 population structure, with a mid point of 22,551 (per million population). Once the decline in the death rate was established this was valued through multiplying these additional life years as a result of a decline in the death rate with the hypothetical value to society of theses additional life years, referred to here as the VSL or the value of death averted. This has been calculated for a lower bound and mid range. The former utilises Miller's (2000) low VSL and Costa and Khan's (2003) positive income elasticity, which generates a lower VSL value. A more likely VSL is calculated using Miller's (2000) mid VSL and assuming unitary elasticity. The lower bound estimate is included as a form of sensitivity analysis. When the lower bound VSL ($0.277 million) and the mid range VSL ($0.520 million) were applied to Murray and Lopez's (1996) age-weighting function, the VSL values varied by age group from $0.083 to $0.416 million for the lower bound VSL and $0.156–$0.780 million for the mid range VSL. This is because older and younger ages are deemed to be less productive and therefore less lucrative. The detailed calculations are outlined in Appendix, and the final result about the un-weighted and age-weighted lower bound and mid range value of reduced mortality are presented in Table 5. The value of the decline in the death rate, or the mortality gain, can be calculated more simplistically when it is un-weighted, by combining the reduction of deaths with the value of death averted. Table 5 presents these results as $6247 million (lower bound) and $11,727 million (mid range), and the age-weighted equivalents ranged from $4462 million to $8376 million.

In order to add further significance to the findings about the magnitude of the improvement in life expectancy in Japan over the twentieth century the results in Table 5 will be considered in relation to GDP per capita. This is desirable for two reasons. First, considering the numbers generated in Table 5 relative to GDP per capita will instil the results of the paper with more tangible significance. Second, one of the motivations of the paper is to consider a more comprehensive national output, referred to as utility or 'Fisherian' national income referred to as health augmented GDP per capita, which will be achieved through considering health gains in terms of additional GDP per capita growth or health service output. Table 6 presents these results whereby the final column, 'Augmented growth', comprises the sum of GDP per capita growth and the value of the decline in the death rate (presented in Table 5). Recall that the value of improved mortality is elicited by identifying the consumers' trade-off of consumption for reduced mortality. This is outlined algebraically above and diagrammatically in Fig. 1.

Table 6
Growth of real GDP per capita adjusted for the value of reduced mortality (% per annum).

Period/estimate	GDP per capita growth	Mortality imputation		Augmented growth	
		Un-weighted	Age-weighted	Un-weighted	Age-weighted
1900–2000 lower bound	2.9	1.9	1.3	4.8	4.2
1920–2000 mid range	2.9	3.5	2.5	6.4	5.4

Sources: GDP per capita growth: author's calculation from Maddison (2001); mortality imputation: author's calculation from valuing reduced mortality, presented in Table 5; augmented growth: author's calculation from previous columns. Lower bound = Miller's (2000) low VSL and Costa and Khan's (2003) positive income elasticity. Mid range = Miller's (2000) mid VSL and unitary elasticity.

Table 6 suggests that taking account of improved mortality creates a more optimistic indication of Japan's economic development during the twentieth century. The improvements in mortality are significant relative to GDP per capita. At the lower bound estimate, gains add between 1.3% and 1.9%, and at a mid range estimate, gains add between 2.5% and 3.5% to compound average rates of annual GDP per capita growth, which was 2.9%, such that health augmented GDP per capita growth is estimated to be between 4.2% and 6.4% (depending on lower bound or mid range and age-weighted or un-weighted). Even the smallest result in Table 6 provides a substantial boost to conventional GDP per capita measures. Hence, between 1900 and 2000 compound average annual rates of GDP per capita growth were 2.9% and the lower bound (low VSL and positive income elasticity and age-weighted) growth rates for the value of the decline in the death rate was 1.3%, such that when growth is adjusted, health augmented GDP per capita grew at an annual average of 4.2%. These results are particularly impressive when considered in the context of Japan's rapid industrialisation growth during the twentieth century. GDP per capita increased from $2008 in 1900 to $35,491 in 2000, and as such marks one of the most impressive growth episodes of the twentieth century.

The results in Table 6 are also impressive by international standards. This is highlighted by comparing health augmented GDP per capita growth achieved in Japan with the equivalent estimates for the US and England and Wales. Hickson (2009) has made this calculation for a comparable period (1900–2000). The un-weighted mid range health augmented GDP per capita estimate for the USA is annual growth of 3.8% and for England and Wales, 3.1%, versus the un-weighted mid range health augmented GDP per capita growth which has been calculated to be 6.4% per annum for Japan. The performance of Japan is even more impressive when the level of GDP per capita growth is considered, because it was higher in Japan. Table 2 compares the compound average annual rates of GDP per capita growth for the period 1900–2000, which was 2.9% in Japan and as such considerably grater than the level of 1.7% in the US and 1.4% in the UK. Hence, in addition to being impressive relative to Japan's GDP per capita growth, the results about health augmented GDP per capita growth calculated here (in Table 6) are even more remarkable by international standards.

As well as providing a more comprehensive evaluation of Japan's growth during the twentieth century these results also underline the need to consider health augmented GDP per capita growth as well as existing less detailed national income measures. Although there is contention associated with the precise value that the decline in mortality should adopt, even the lower bound estimates provided here highlight the significant contribution of improved longevity to economic development in twentieth century Japan. This conclusion seems plausible given the substantial increase in life expectancy in twentieth century Japan coupled with the value that consumers attach to health and longevity, which is illustrated by the magnitude of estimates about the VSL.

Bradford DeLong (2000) emphasises the astronomical income that would be necessary to compensate an individual enjoying year 2000 health circumstances to return to the health conditions that were evident during the initial years of the twentieth century, and the chance that no amount of income could compensate for improved health. Nordhaus (1999) further illuminates this claim with his 'Sears-catalogue question', where individuals are polled for their choices between 1998 health conditions (polio vaccine, new pharmaceuticals, joint replacement, improved sanitation, improved automobile safety, etc.) and 1998 non-health standards of living (jet plane, television, computers), whereby individuals are asked to chose between either having 1948 health conditions and 1998 non-health conditions or 1998 health conditions and 1948 non-health conditions. If you choose the latter then you agree with the basic implications of this paper and the majority of individuals polled, that health is more valuable than any alternative consumption. Such findings further emphasise the endorsement for more 'Fisherian' measures of economic growth which has been indicated above.

The results in Tables 5 and 6 are also pertinent for policy makers because they provide a more detailed indication about the output of the health care service in Japan. Currently GDP per capita measures include the cost of the health service, or input, with no indication about the return or the value of the health care service outputs. When GDP per capita is considered in an extended 'Fisherian' format, such as health augmented GDP per capita, then it is possible to identify the return on health care spending and analyse the relationship between health care service inputs and outputs. For example, health care spending increased from less than 2% to nearly 7% of GDP per capita over the twentieth century in Japan. Consider this in conjunction with the health care output identified here as the value of reduced mortality in Table 5, which is about 45% as valuable as GDP per capita growth (lower bound contribution of 1.3–2.9% per annum GDP per capita growth). Hence, a 2–7% investment in health inputs has generated a 45% return, given the value of health outputs identified in Tables 5 and 6, which indicates a rate of health care service return in the region of 600% (investment of 7% yields 45%, therefore return on investment = 45/7 = 643%). Hence, the twentieth century economic welfare from improved health appears to have contributed about half as much towards economic growth as the rest of consumption expenditures, however the social productivity of health care spending appears to have been many times that of other spending.

Recent studies have strengthened this positive view on health care spending through indicating the significant effects of improved health for economic growth and consequently the importance of Japan's twentieth century mortality improvements for neoclassical endogenous growth theory (for example see Arora, 2001). Certain studies have indicated that health has a statistically significant effect on economic growth to a magnitude of a 1 year improvement in a populations' life expectancy contributing an additional 4 percentage points in output (Bloom, Canning, & Sevilla, 2001).

The results generated here provide some justification for the increase in health care spending that became increasingly evident at the close of the twentieth century, for example, mandatory long-term care insurance which was introduced in April 2000. However, the results presented here mask quality issues that ought to be considered. For example, questions about the extent to which problems of consumer choice detract from the perceived (reduced mortality) benefits of Japan's health care service need to be addressed. Moreover, the policy implications of the results provided in this paper are unclear. Much more needs to be discovered about what is driving these health advances in conjunction with the costs and benefits of government health care policy. Hence an important consideration is the extent to which health developments arise from improved basic knowledge (such as microbiological theory of disease and the discovery of anti-infectives) or the investment in improved health capital and infrastructure (from larger investments in health education or improvements in hospitals). Furthermore, the quality of health care beyond the life expectancy outcome needs to be considered in more detail. Despite the micro or internal problems, on a macro or international level the Japanese health care service has been relatively productive, because big gains in life expectancy have been delivered at a cheaper price, especially compared to the United States, but even compared to the UK, which represents a more pertinent comparison. The UK has universal health care coverage and also experiences complaints about the quality for consumers. However, the UK has still not achieved life expectancy levels of Japan's magnitude (see Table 4). Although it has not been the focus of this paper it is important to recognise that these issues need to be considered before the results of this project can be taken any closer towards providing policy recommendations.

Moreover, the contribution of government was only one of the drivers of improvements in health care technology and therefore cannot receive all the credit for the magnitude of the mortality gains presented in Table 5. Current best estimates would attribute 50% of the mortality gain to government health policies (Cutler, Rosen, & Vijan, 2006; Poikolainen & Eskola, 1986), or half of the additional growth from the mortality imputation outlined in Table 6 (which would contribute between 0.65% and 1.75% additional per annum GDP per capita 'Fisherian' growth), which is still impressive. In terms of the return on health care spending this represents about a 300% return on investment or input. An important next step in the literature would undertake analysis about how this varies between different countries and in doing so reveal the most prominent drivers of Japan's international dominance of life expectancy and the role of government health policies.

A final omission from the project is the value of reduced morbidity. This is largely a result of the complexities and ambiguities associated with measuring health, which would warrant an independent investigation. Despite the difficulty in evaluating the numerous dimensions of health, assessment of illness (as well as fatalities) is critical when considering the value of health improvements. However, recent studies indicate that by considering twentieth century improvements in the quality of life associated with illness as well as fatality would increase the value of the results and therefore this enhances the lower bound health augment GDP per capita results in Tables 5 and 6 (Hickson, 2006).

Therefore, despite the weaknesses associated with the health measurement methodology and certain inevitable omissions the results of the paper corroborate an overwhelmingly optimistic story about Japan's economic growth and development and the contribution of improved health.

5. Conclusion

By applying a willingness to pay methodology to twentieth century Japan it has been possible to more comprehensively calculate economic development, by creating an original measure of health augmented GDP per capita. The results of this exercise seem worthwhile as the value of reduced mortality over the twentieth century has been estimated to be in the region of $4462 to $11,727 million. This adds between 1.3% (lower bound) and 3.5% (mid range) to conventional measures of per annum GDP per capita growth. As such health augmented GDP per capita approximately doubles conventional compound average annual rates of growth between 1900 and 2000. These results emphasise the story about Japan's growth as they indicate that development (which is better proxied by gauging mortality as well as income) has also experienced substantial gains over the twentieth century.

Hence, the twentieth century phenomenon of significantly improved mortality in Japan has provided many crucial benefits for economic developments. The precise extent of this contribution is difficult to determine although it is possible to present a lower bound estimate, which nearly certainly underestimates the true value. The paper has also clarified the importance of mortality improvements and the subsequent need to include these in considerations of future policy. Most importantly when analysing Japan's twentieth century growth is the need to adopt a more 'Fisherian' methodology as the contribution from improved health has been substantial.

Finally, the results of this paper about the magnitude of health gains, their contribution to growth indicate that the role of the health care systems ought to be reconsidered more favourably. The results presented here indicate that the return from health care spending is likely to be many times that of alternative public and private spending, which is evidenced by the magnitude of twentieth century health augmented GDP per capita growth.

Appendix A

A.1. Change in death rate by age: absolute value and value contribution to GDP per capita—Japan 1900–2000

The first stage in the methodology is to calculate the death rate in 1900 and 2000. This is achieved by combining the number of deaths data with population data in order to calculate the death rate per 1000 population in 1900 and 2000. This calculation is presented in Table A1.

Table A1
Death rate and population structure, Japan 1900 and 2000.

Age	Population 1900	Population 2000	% Pop 1900	% Pop 2000	Deaths 1900	Deaths 2000	Death rate 1900 per 1000	Death rate 2000 per 1000
0–4	5,624,663	5,904,098	0.1251	0.0465	322,036	5,269	57.25427665	0.892430986
5–14	9,254,695	12,568,401	0.2059	0.0990	41,515	1,482	4.48583144	0.117914761
15–24	8,412,723	15,909,625	0.1872	0.1253	64,993	6,432	7.725560072	0.40428357
25–34	6,503,723	18,566,919	0.1447	0.1463	54,013	10,413	8.304934985	0.560836184
35–44	5,147,037	15,915,084	0.1145	0.1254	53,425	17,525	10.37975789	1.101156613
45–59	6,312,549	28,092,170	0.1404	0.2213	113,857	101,571	18.0366119	3.615633823
60–64	1,283,421	7,735,833	0.0286	0.0609	44,825	60,680	34.92618012	7.844016281
65–74	1,737,005	13,006,515	0.0386	0.1025	117,099	205,586	67.41429819	15.80638626
75–84	593,784	6,765,289	0.0132	0.0533	50,702	278,060	85.38801004	41.10097883
85+	78,862	2,233,348	0.0018	0.0176	48,224	273,912	611.5001179	122.6463587

Sources: Population in 1900: MIAC (2009); population in 2000: Ministry of Internal Affairs and Communications (2008b); % pop in 1900 and 2000: author's calculation from previous columns (age group population/total population); deaths in 1900 and 2000: Ministry of Internal Affairs and Communications (2008a); Death rate per 1000 in 1900 and 2000: author's calculations ([deaths/population] × 1000).

The next stage in the methodology is to calculate the decline in the death rate between 1900 and 2000, based on the population structure in 1900 and in 2000. The result of this process is an estimate about the decrease in the death rate per million between 1900 and 2000, based on 1900 and 2000 population distributions. This is presented in Table A2.

The next stage in the methodology values the decline in the death rate. This is achieved by combining the decline in the death rate (presented in Table A2) with the valuation function, referred to as the VSL. Miller's (2000) lower bound VSL is applied in age-weighted and un-weighted formats. The age-weighting provides a series of weights for different age groups that were proposed by Murray and Lopez (1996), where younger and older ages are less valuable than prime working age groups. The results of this calculation are presented in Tables A3.1 and A3.2. Table A3.1 presents the value for the age-weighted VSL, and Table A3.2 provides the equivalent results for the un-weighted VSL. The VSL used in Tables A3.1 and A3.2 has also been adjusted (downwards) for positive income elasticity, proposed by Costa and Kahn (2003). These calculations are referred to as lower bound. The same

Table A2
1900–2000 change in death rate weighted to: (a) 1900 population structure and (b) 2000 population structure.

Age	% Pop in 1900	DR 1900	Weighted 1900 Pop, 1900 DR	% Pop in 1900	DR 2000	Weighted 1900 Pop, 2000 DR	Decrease per 1000	Decrease per million
(a) 1900–2000 change in death rate weighted to 1900 population structure								
0–4	0.1251	57.25427665	7.164560952	0.1251	0.892430986	0.111675085	7.052885867	7,053
5–14	0.2059	4.48583144	0.923613347	0.2059	0.117914761	0.024278141	0.899335207	899
15–24	0.1872	7.725560072	1.445944894	0.1872	0.40428357	0.075667234	1.37027766	1,370
25–34	0.1447	8.304934985	1.201665127	0.1447	0.560836184	0.081149014	1.120516113	1,121
35–44	0.1145	10.37975789	1.188583478	0.1145	1.101156613	0.126093168	1.06249031	1,062
45–59	0.1404	18.0366119	2.533056603	0.1404	3.615633823	0.507778577	2.025278026	2,025
60–64	0.0286	34.92618012	0.997253241	0.0286	7.844016281	0.223971549	0.773281692	773
65–74	0.0386	67.41429819	2.605183653	0.0386	15.80638626	0.610827973	1.99435568	1,994
75–84	0.0132	85.38801004	1.128002985	0.0132	41.10097883	0.542957106	0.585045879	585
85+	0.0018	611.5001179	1.07287318	0.0018	122.6463587	0.215182279	0.857690901	858
								17,741
Age	% Pop in 2000	DR 1900	Weighted 2000 Pop, 1900 DR	% Pop in 2000	DR 2000	Weighted 2000 Pop, 2000 DR	Decrease per 1000	Decrease per million
(b) 1900–2000 change in death rate weighted to 2000 population structure								
0–4	0.0465	57.25427665	2.663246918	0.0465	0.892430986	0.041512429	2.62173449	2622
5–14	0.0990	4.48583144	0.44419424	0.0990	0.117914761	0.011676109	0.432518131	433
15–24	0.1253	7.725560072	0.968366731	0.1253	0.40428357	0.050675259	0.917691472	918
25–34	0.1463	8.304934985	1.214859413	0.1463	0.560836184	0.08204003	1.132819383	1133
35–44	0.1254	10.37975789	1.301505784	0.1254	1.101156613	0.138072749	1.163433035	1163
45–59	0.2213	18.0366119	3.991996867	0.2213	3.615633823	0.800238924	3.191757943	3192
60–64	0.0609	34.92618012	2.128668917	0.0609	7.844016281	0.47807443	1.650594487	1651
65–74	0.1025	67.41429819	6.908168265	0.1025	15.80638626	1.619733185	5.28843508	5288
75–84	0.0533	85.38801004	4.551276174	0.0533	41.10097883	2.190728014	2.360548159	2361
85+	0.0176	611.5001179	10.75976754	0.0176	122.6463587	2.158047514	8.601720025	8602
								27,361

Sources: % pop in 1900 and 2000: author's calculation in Table A1; death rate 1900 and 2000: author's calculation in Table A1; weighted population and death rate: author's calculation from previous columns (% pop × death rate); decrease: author's calculation from previous columns.

Table A3.1
Age-weighted mortality gain 1900–2000 lower bound (million $).

Age	Age-weight (Murray and Lopez)	VSL (low) + C&K elasticity (million $)	Weighted VSL (million $)	Fall in DR 1900 pop structure	Mortality gain 1900 pop structure	Fall in Dr 2000 pop structure	Mortality gain 2000 pop structure
0–4	0.3	0.277	0.083	7052.885867	586.0948156	2621.73449	217.8661361
5–14	1	0.277	0.277	899.3352066	249.1158522	432.5181307	119.8075222
15–24	1.5	0.277	0.416	1370.27766	569.3503677	917.6914718	381.3008065
25–34	1.5	0.277	0.416	1120.516113	465.5744448	1132.819383	470.6864537
35–44	1.3	0.277	0.360	1062.49031	382.6027605	1163.433035	418.952236
45–59	1.1	0.277	0.305	2025.278026	617.1022145	3191.757943	972.5286454
60–64	0.9	0.277	0.249	773.281692	192.7791258	1650.594487	411.4932056
65–74	0.7	0.277	0.194	1994.35568	386.7055664	5288.43508	1025.427562
75–84	0.5	0.277	0.139	585.0458793	81.02885428	2360.548159	326.9359201
85+	0.4	0.277	0.111	857.690901	95.03215183	8601.720025	953.0705787
				17,741	3625	27,361	5298

Table A3.2
Un-weighted mortality gain 1900–2000 lower bound (million $).

Age	VSL (low) + C&K elasticity (121 × 3310) C&K	Fall in DR [(17,741 + 27,361)/2]	Mortality gain (million $)
All	0.277	22,551	6247

Table A3.3
GDP per capita adjusted for mortality gain lower bound.

Period	Mortality gain	GDP per capita at midpoint	t	Contribution to GDP per capita		Weighting
				Total	Annual	
1900–2000	6247	3310	100	189	1.9	Un-weighted
1900–2000	4462	3310	100	135	1.3	Age-weighted

Period	GDP per capita at start ($t1$)	GDP per capita at end ($t2$)	t	$t2/t1$	Ln	Ln/t	Growth
GDP per capita growth							
1900–2000	2008	35,491	100	17.6748008	2.872139941	0.028721399	2.9

Sources: age-weight: Murray and Lopez (1996); value of a statistical life (VSL): Miller (2000) and Costa and Kahn (2003) elasticity; weighted VSL: calculated from previous columns (age-weight × VSL); fall in death rate: author's calculations in Table A2; mortality gain: author's calculation (weighted VSL × fall in death rate); mortality gain: author's calculation (average of mortality gain 1900 and 2000 population structures in Table A3.1); GDP per capita data: Maddison (2001).

calculation has been made for mid range in Tables A4.1 and A4.2. These tables use Miller (2000) mid range VSL and assume unitary income elasticity of demand for health care (Table A4.3). The results of the age-weighted and un-weighted lower bound and mid range calculations in Tables A3.1, A3.2, A4.1 and A4.2 provide an estimate for the value of the decline in the death rate between 1900 and 2000.

Table A4.1
Age-weighted mortality gain 1900–2000 mid range (million $).

Age	Age-weight (Murray and Lopez)	VSL (mid) + unit elasticity (million $)	Weighted VSL (million $)	Fall in DR 1900 pop structure	Mortality gain 1900 pop structure	Fall in Dr 2000 pop structure	Mortality gain 2000 pop structure
0–4	0.3	0.52	0.156	7052.885867	1100.250195	2621.73449	408.9905804
5–14	1	0.52	0.520	899.3352066	467.6543074	432.5181307	224.909428
15–24	1.5	0.52	0.780	1370.27766	1068.816575	917.6914718	715.799348
25–34	1.5	0.52	0.780	1120.516113	874.0025679	1132.819383	883.5991189
35–44	1.3	0.52	0.676	1062.49031	718.2434493	1163.433035	786.4807318
45–59	1.1	0.52	0.572	2025.278026	1158.459031	3191.757943	1825.685544
60–64	0.9	0.52	0.468	773.281692	361.8958319	1650.594487	772.47822
65–74	0.7	0.52	0.364	1994.35568	725.9454677	5288.43508	1924.990369
75–84	0.5	0.52	0.260	585.0458793	152.1119286	2360.548159	613.7425214
85+	0.4	0.52	0.208	857.690901	178.3997074	8601.720025	1789.157765
				17,741	6806	27,361	9946

Table A4.2
Un-weighted mortality gain 1900-2000 mid range (million $).

Age	VSL (mid) + unitary elasticity (157 × 3310)	Fall in DR [(17,741 + 27,361)/2]	Mortality gain
All	0.52	22,551	11,727

Table A4.3
GDP per capita adjusted for mortality gain mid range.

Period	Mortality gain	GDP per capita at midpoint	t	Contribution to GDP per capita		Weighting
				Total	Annual	
1900–2000	11,727	3310	100	354	3.5	Un-weighted
1900–2000	8376	3310	100	253	2.5	Age-weighted

Period	GDP per capita at start ($t1$)	GDP per capita at Start ($t2$)	t	$t2/t1$	Ln	Ln/t	Growth
GDP per capita growth							
1900–2000	2008	35,491	100	17.6748008	2.872139941	0.028721399	2.9

Sources: age-weight: Murray and Lopez (1996); value of a statistical life (VSL): Miller (2000); weighted VSL: calculated from previous columns (age-weight × VSL); fall in death rate: author's calculations in Table A2; mortality gain: author's calculation (weighted VSL × fall in death rate); mortality gain: author's calculation (average of mortality gain 1900 and 2000 population structures in Table A3.1); GDP per capita data: Maddison (2001).

The final stage of the methodology considers the magnitude of the value of the decline in the death rate relative to GDP per capita growth, referred to as GDP per capita adjusted for mortality gain. This is calculated for the lower bound (Table A3.3) and mid range (Table A4.3) estimates. Below both of these Tables is the calculation of compound average annual rates of GDP per capita growth, which needs to be identified in order to estimate the contribution of the mortality gain.

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