Examining Suicide Rates in Japan and South Korea: An Actuarial Analysis

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Abstract
Japan and South Korea, despite having some of the longest life expectancies in the world, also have the highest suicide rates. This paper uses actuarial multiple decrement techniques to calculate the amount by which life expectancy in each country is impacted by suicide rates in these countries. This shows that suicides shorten life expectancy at birth by 1.05% in Japan and 0.83% in South Korea. The demographics most critically affected by suicide are Japanese males with a 1.50% reduction in life expectancy at birth, and the South Korean over-65 population with a 0.78% reduction in post-65 life expectancy—an alarmingly high percentage when considering overall heightened mortality rates at that age. These results suggest that high suicide rates, especially in Japan and South Korea, have massive implications for quality of life and economic productivity.

Keywords
suicide rates, mortality, life expectancy, multiple decrements, East Asia, Japan, South Korea

Disciplines
Business
Examining Suicide Rates in Japan and South Korea: An Actuarial Analysis

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ABSTRACT

Japan and South Korea, despite having some of the longest life expectancies in the world, also have the highest suicide rates. This paper uses actuarial multiple decrement techniques to calculate the amount by which life expectancy in each country is impacted by suicide rates in these countries. This shows that suicides shorten life expectancy at birth by 1.05% in Japan and 0.83% in South Korea. The demographics most critically affected by suicide are Japanese males with a 1.50% reduction in life expectancy at birth, and the South Korean over-65 population with a 0.78% reduction in post-65 life expectancy—an alarmingly high percentage when considering overall heightened mortality rates at that age. These results suggest that high suicide rates, especially in Japan and South Korea, have massive implications for quality of life and economic productivity.

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INTRODUCTION

Life Expectancies in Japan and South Korea

The Japanese population is well-known around the world for its longevity. Indeed, among the 32 countries that are high-income members of the Organization for Economic Co-operation and Development, Japan ranks the highest in terms of life expectancy at birth, with an overall life expectancy of 83.3 years at birth as of 2013. South Korea, the only other East Asian member of the OECD, also has a notably high life expectancy of 81.5 years. As can be seen in Figure 1, both Japan and South Korea have outpaced the average high-income OECD life expectancy, and significantly exceed the overall life expectancy in East Asia and the Pacific as a whole (World Bank Group 2015a).

Figure 1

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1 As of fiscal year 2016, the World Bank defines a high-income country to be one with gross national income (GNI) of $12,736 or more. Turkey and Mexico, despite being members of the OECD, are not high-income and thus are not included in this comparison.
However, Japan and South Korea, despite having two of the longest life expectancies in the world, also have two of the highest suicide rates. In particular, annual male suicide rates are alarmingly high, reaching 26.9 and 41.7 per 100,000 in Japan and South Korea respectively in 2013. Among high-income OECD countries, South Korea and Japan have the first and third highest suicide rates, respectively. Figure 2 shows the rates of the ten high-income OECD countries with the highest suicide rates as of 2012 (World Health Organization 2015). Clearly, this is a major public health epidemic and is naturally the subject of much discussion and research. The question arises, then, as to how much of an impact suicide rates have on quality of life in South Korea and Japan. This is the guiding question of this paper.

**Figure 2**

![Suicide Rate per 100,000 in 2012](chart)

**Life Expectancy and Quality of Life**

Quality of life is an abstract and multifaceted concept that cannot be measured directly. Similarly, the cost of a public health epidemic, social or economic, is difficult to measure.
However, life expectancy and impact on life expectancy can serve as proxies for each of these respective concepts. As Jean Lemaire says in *The Cost of Firearm Deaths in the United States:*

"The life expectancy at birth is a widely accepted measure of quality of life in a society, summarizing in a single number all the natural and man-made damages that can affect an individual, ranging from poor health care systems and civil war to unhealthy nutrition and sexual behavior." (2005)

Treating life expectancy as a measure of quality of life, one can thus consider impact on life expectancy to be a measure of the cost and magnitude of a public health epidemic. Calculating the degree of impact suicide rates have on life expectancy is then a measure of how much suicide epidemics affect quality of life in a country. This is more practical than attempting to directly calculate the national cost of suicides, as it can be calculated fairly precisely with data on suicide rates and mortality rates across ages, which are well-documented on national vital statistics reports in most developed countries.

**Scope and Methodology**

This paper seeks to measure the severity of South Korea and Japan's suicide epidemics by calculating their impacts on life expectancies in both countries using multiple decrement techniques. These calculations show how much longer the already commendably long life expectancies of both countries would be without suicides. This paper also considers impact on life expectancy at various ages (that is, expected remaining lifetime for a person who has already attained age $x$) in addition to life expectancy at birth, which allows for further insight into how suicide affects quality of life for different age groups. It will first discuss methodology, followed by a presentation of results, and then will discuss the results and make comparisons across countries and demographics.
METHODOLOGY AND COMPUTATION

Multiple Decrement Tables

Actuarial multiple decrement theory (also known as competing risk theory in other disciplines) allows for the characterization of competing causes of death and is the basis of this analysis. Multiple decrement theory assumes that there are multiple independent possible causes of death, i.e. decrements, which are competing with each other. The assumption of independence allows for the forces of decrement (also known as hazard rates in other disciplines) to be additive. For instance, in a population with two possible decrements, decrement 1 and decrement 2, the total force of mortality at time $t$ for an individual aged $x$ at time 0 is $\mu_{x+t}^{(r)} = \mu_{x+t}^{(1)} + \mu_{x+t}^{(2)}$. This can be modeled as a continuous inhomogeneous Markov process with $\mu^{(1)}$ and $\mu^{(2)}$ as the instantaneous transition rates (see Figure 3).

*Figure 3: Transition Diagram*

The probability of an individual currently aged $x$ dying by decrement $i$ by the age of $x+t$ is then $tq_x^{(i)} = \int_0^t \mu_{x+s}^{(i)} e^{-\mu_{x+s}^{(r)} s} ds$, and the probability $tq_x^{(r)}$ of dying of any cause by age $x+t$ is just the sum of all $tq_x^{(i)}$ s. The probability of surviving to age $x+t$ is thus $tP_x^{(r)} = 1 - tq_x^{(r)} = 1 - \sum tq_x^{(i)}$. For $t=1$, the left subscript is often omitted. For a life table with radix (i.e. starting population) $l_0$, ...
the surviving population at age $x$, $l_x$ is given recursively by $l_x = l_{x-1} \cdot P_x^{(r)}$. The number of deaths due to cause $i$ between age $x$ and $x+1$ is given by $d_x^{(i)} = l_x \cdot q_x^{(i)}$.

For this analysis, all deaths are split into two decrements: decrement 1, which represents every cause of death except suicide; and decrement 2, which represents suicide. The probability of death by suicide for an individual age $x$, $q_x^{(2)}$, is of course the suicide rate for age $x$, scaled by dividing by 100,000. Using standard life tables from national vital statistics reports, it is simple to calculate $q_x^{(1)}$ by subtracting the annual death probability, $q_x$, which is equivalent to $q_x^{(r)}$. The next step in calculation, then, is to construct a modified life table where suicides do not occur, to see how survival rates, and thus life expectancy, change.

**Independent Probability of Decrement**

At first glance, it may appear simple to calculate the modified annual death probabilities as $q_x = q_x^{(1)}$, the probability of death with probability of suicide subtracted out. However, this ignores the interaction between causes of death in forming the observed patterns of mortality. Because decrements compete, they crowd each other out; an individual who dies from one cause in January cannot again die from another cause in February—to die from one cause of death, one must first survive all other causes of death. As a result, a decrease in one decrement rate actually leads to an increase in other decrement rates. Because of this, $q_x^{(1)}$ and $q_x^{(2)}$ are known as the dependent probabilities of decrement. To calculate the modified life table, it is necessary to calculate the independent probability of decrement for decrement 1—that is, the decrement rates in a population where, all else equal, no other decrements besides decrement 1 exist.

In order to calculate the independent probabilities, it is necessary to make assumptions about the distribution of deaths within each interval, as life tables only provide discretized data.
by age interval. A common assumption is the uniform distribution of deaths (UDD) assumption, which linearly interpolates death probability across each interval—that is:

\[ t q_x = \frac{t}{n} \cdot n q_x \quad for \quad 0 \leq t \leq n \]

Assuming that the dependent probabilities of decrement follow UDD within each interval, the independent probability of survival under decrement \( i \), denoted as \( n p_x^{r(i)} \), is:

\[ n p_x^{r(i)} = n p_x^{(r)} n q_x^{(i)} / n q_x^{(r)} \]

which is an exponential interpolation between 1 and \( n p_x^{(r)} \) based on the proportion of total deaths in the interval that are due to decrement \( i \). See Appendix A for a derivation of this formula.

Using this formula, it is simple to calculate the independent probabilities of decrement. This allows the creation of a modified life table without suicides.

**Computing Life Expectancy**

The expectation of time until death, \( T \), of an individual aged \( x \) is defined as \( E[T_x] = \int_x^\infty t \cdot \mu_{x+t} \cdot t p_x \, dt \). This cannot be directly calculated with discretized data, but life tables provide the parameter \( n L_x \), the number of person-years lived between age \( x \) and age \( x+n \). This allows the calculation of future life expectancy at age \( x \) as \( E[T_x] = \frac{n L_x}{l_x} \), the number of person-years lived beyond age \( x \) divided by the number of people alive at age \( x \). This works for dependent probability tables, but not for the modified life tables, as the parameter \( n L_x' \) is different due to the modified survival probabilities.

To estimate the modified number of person-years lived in each \( n \)-year interval, Arias, Heron, and Tejada-Vera (2013) use the following approximation:

\[ n L_x' = (n - n f_x) \cdot l_x' + n f_x \cdot l_{x+n}' \]

where

\[ n f_x = \frac{n l_{x+n} - n l_x}{l_x - l_{x+n}} \]

and for a life table truncated at age \( \Omega \), the person-years lived beyond \( \Omega \) is estimated as:
\[ \omega L^1 = \frac{E[T_\Omega] \cdot l_\Omega}{1 - \omega q_\Omega^{(i)}} \]

where decrement \( i \) is the decrement being removed. Essentially, this method calculates the average number of years lived between \( x \) and \( x+n \) for individuals dying in that interval in the multiple decrement table, then uses this timing to estimate \( nL_x' \) by adding the number of whole years lived by survivors of the intervals to the average fractional years lived by those dying in the interval. The assumption driving this method is that the timing of deaths within each interval is distributed similarly before and after the cause of death elimination. With the modified person-year terms calculated, modified life expectancy is calculated as \( E[T_x'] = \frac{\omega L_x'}{l_x'} \), and the life expectancy impact of decrement \( i \) on an individual aged \( x \) is simply obtained as \( E[T_x'] - E[T_x] \).
RESULTS OF CAUSE OF DEATH ELIMINATION

Life Expectancy at Birth Impact

The above methods were applied to both Japan and South Korea based on mortality data from Statistics Korea (2014) and the Statistics Bureau of Japan (2010 and 2014) to calculate the modified life tables and life expectancies with suicides eliminated.\(^2\) Figure 4 shows the life expectancy impact at birth, both in days and as a percentage of total life expectancy, broken down by country and by sex. The average Japanese newborn loses 318.7 days of life due to suicides, and the average South Korean newborn loses 247.7 days. Particularly notable is the impact that suicide has on the life expectancy of the Japanese male population: over a year, or an alarming 1.5% of total life expectancy.

**Figure 4: Impact of Suicides on Life Expectancy at Birth**

<table>
<thead>
<tr>
<th>Country and Sex</th>
<th>Impact, in days (in percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Japan, Overall</td>
<td>318.7 (1.05%)</td>
</tr>
<tr>
<td>Japan, Female</td>
<td>247.7 (0.68%)</td>
</tr>
<tr>
<td>Japan, Male</td>
<td>435.7 (1.50%)</td>
</tr>
<tr>
<td>South Korea, Overall</td>
<td>247.7 (0.83%)</td>
</tr>
<tr>
<td>South Korea, Female</td>
<td>169.4 (0.55%)</td>
</tr>
<tr>
<td>South Korea, Male</td>
<td>305.2 (1.06%)</td>
</tr>
</tbody>
</table>

By contrast, using mortality rate data from the Centers for Disease Control and Prevention (2015), the National Vital Statistics Reports (Arias 2014), and the Taiwan Ministry of the

\(^2\) The Japanese mortality rates are based on 2010 data, in 1-year age intervals. Japanese suicide rates are based on 2013 data, in 5-year age intervals. The South Korean mortality and suicide rates are based on 2013 data, in 5-year age intervals.
Interior (2015), applying the same methodology shows a 116.9-day and 139.9-day life expectancy impact for American and Taiwanese newborns, respectively.

Clearly, the life expectancy impacts for Japan and South Korea are substantially larger than those for the United States, a high-income OECD peer; and Taiwan, a neighboring high-income East Asian society (World Bank Group 2015b). The impact for South Korea is nearly as much as that of the United States and Taiwan combined, and the impact for Japan is significantly more that this. From this comparison, it is apparent that the cost on quality of life of suicide is particularly expensive in Japan and South Korea compared to other peer nations. Especially notable is that, despite having by far the highest suicide rate among high-income OECD nations, South Korea actually has a lower life expectancy impact than Japan. This is largely due to the differences in the age distribution of individuals dying by suicide in Japan and South Korea. Thus, it is particularly relevant to consider the life expectancy impact of suicide across age groups.

**Life Expectancy Impact Across Ages**

Observing mortality rates by age group in Japan and South Korea, it is clear that the two countries have dramatically different suicide rate trends by age. In Japan, suicide rates rise rapidly between ages 15 to 20, then stay roughly constant after age 20 through all older age groups. In South Korea, on the other hand, suicide rates rise slowly but consistently from ages 15 to 65, then begin to rise rapidly after age 65, leading to alarmingly high suicide rates in the over-65 population. This explains why South Korea exhibits a smaller life expectancy impact than Japan: with Japan's steady suicide rate, more suicides are concentrated around younger ages, where deceased individuals have more years of "potential life" lost, which has a larger impact on life expectancy at birth than older individuals who are more likely to die from another cause of
death relatively soon; in South Korea, on the other hand, impact on life expectancy at birth is smaller due to suicides being concentrated around older populations.

Because of this, impact on life expectancy at birth does not tell the whole story. While impact on life expectancy at birth demonstrates the lifelong impact on a newborn individual, it is also relevant to consider the life expectancy impact on other age groups. Thus, the same methodology was applied to calculate the impact of suicides on future life expectancy across age groups—that is, the impact suicide rates have on how much longer the average individual aged $x$ is expected to live. The impact of suicide on future life expectancy, in percentage, is presented in Figure 5. Impact peaks at the 15-20 age group in Japan at 1.39%, then steadily declines for all older age groups. On the other hand, impact in South Korea peaks at the 20-29 age group at 1.06%, but stays fairly flat across all age groups, with a 0.80% impact on over-60 age groups.

**Figure 5**

![Impact on Future Life Expectancy as a Function of Age](image)

The decrease in impact by age in Japan is to be expected, as the roughly constant suicide rates are dwarfed by other causes of death whose forces of decrement increase sharply with age,
such as heart disease. Thus, it is rather alarming that the proportional impact of suicides in South Korea stays roughly constant with age–this means that the increase in suicide rate keeps pace with other sources of mortality, which grow rapidly with old age. This shows that suicide is a massive detriment to quality of life in South Korea's over-65 population, comparable to natural causes of death that also increase sharply with old age. Japan, on the other hand, sees its working age population most dramatically affected by suicide, especially young adults.
DISCUSSION AND CONCLUSION

Many possible explanations have been proposed for Japan and South Korea's high suicide rates, as well as potential suicide prevention measures. Lester, Motohashi, and Yang (1992) found a strong positive association between suicide rates and unemployment, in addition to a significant positive association between female labor force participation and male suicide rates. This calls into question economic factors in Japan, as well as family structure and the sexual division of labor. The association between unemployment and suicide is also supported by Chang et al. (2009), who found that the economic crisis of 1997 to 1998 was associated with sharp increases in suicide rates in both Japan and South Korea. Kwon, Chun, and Cho (2009) note that economic factors may also contribute to South Korea's alarmingly high elderly suicide rate, due to weakening support from family and inadequate welfare and care, which has forced much of the elderly population to remain in the labor force long after retirement age. Lester and Abe (2007) found that the detoxification of domestic gas in Japan reduced suicide rates, without an observable increase in suicide by methods other than gas, suggesting that restriction of access to suicide methods may also play a role in preventing suicide, in addition to economic factors.

This paper estimates the life expectancy lost due to suicide rates in South Korea and Japan across various age groups. The findings suggest that life expectancy would be 318.7 days longer in Japan and 247.7 days longer in South Korea if suicide were eliminated as a cause of death in each respective country. This shows the cost to life expectancy of both countries' high suicide rates, and the potential gains to be made were suicides more effectively prevented. Based on the 2013 life expectancies discussed above, if Japan eliminated all suicides from its society, its life expectancy at birth would exceed 84 years, an unprecedented high life expectancy placing Japan well ahead of all other countries in the world. Similarly, if South Korea eliminated all
suicides, its life expectancy at birth would exceed 82 years, giving it the seventh highest life expectancy at birth among high-income OECD countries.

There is also reason to believe that this underestimates the life expectancy impact of suicidality, as only successful suicides have been taken into account, without consideration of survivors of previous suicide attempts. Depending on the method of the attempt and presence of medical intervention, survivors may suffer from disability or permanent health conditions and injuries that put them at a higher risk of mortality, inadvertently reducing life expectancy. Thus, if the long-term effects of unsuccessful suicide attempts were taken into account, the life expectancy impact may be even greater.

Of course, it is not reasonable to expect a complete eradication of suicide in Japan or South Korea–while there are wide variations in suicide rates across countries, as of 2012 not a single country in the world had a suicide rate of zero (World Health Organization 2015). The most that can be expected is a substantial reduction in suicide rates. Nonetheless, this analysis gives an upper limit for what is to be gained by better preventing suicides, and also provides insight into which demographics are most drastically affected: in particular, the Japanese working-age male population and the South Korean over-65 population. This paper shows that the suicide epidemics in Japan and South Korea have profound impacts on quality of life in both countries, and that both countries have much to gain through more effective suicide prevention measures.
APPENDIX A: DERIVATION OF INDEPENDENT PROBABILITY FORMULA

Based on the assumption of uniform distribution of decrements (UDD) for each decrement in the multiple decrement table, the intra-interval probability of decrement \( i \) becomes:

\[
tq^{(i)}_x = \frac{t}{n} \cdot nq^{(i)}_x \quad \text{for} \quad 0 \leq t \leq n
\]

From this, it is trivial to derive the force of decrement (hazard rate) for each decrement as:

\[
\mu^{(i)}_{x+t} = \frac{\frac{d}{dt}q^{(i)}_x}{tP^{(r)}_x} = \frac{\frac{1}{n} \cdot nq^{(i)}_x}{1 - \frac{t}{n} \cdot nq^{(r)}_x} \quad \text{for} \quad 0 \leq t < n
\]

From the definition that \( tP_x = e^{-\int_0^t \mu_{x+s} ds} \), the independent probability of survival is derived by calculating the survival probability in a population where only decrement \( i \) exists:

\[
nP^{(i)}_x = e^{-\int_0^n \mu^{(i)}_{x+s} ds}
\]

\[
= e^{-\int_0^n \frac{1}{n} \cdot \frac{1}{n} q^{(i)}_x ds}
\]

\[
= e^{\frac{nq^{(i)}_x}{n} \ln (1 - \frac{1}{n} q^{(r)}_x) \bigg|_{s=n}^{s=0}}
\]

\[
= e^{\frac{nq^{(i)}_x}{n} \ln (nP^{(r)}_x)}
\]

\[
= nP^{(r)}_x \cdot \frac{nq^{(i)}_x}{nq^{(r)}_x}
\]

This final result is the formula used for all independent probability calculations in this paper.
REFERENCES


