Annex 18A. Materials and Methods

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Overview

This document describes the methods used to calculate the valuation of excess mortality rates due to pandemic influenza. The methods for calculating the value of small changes in mortality rates has been described extensively in other literature.(Hammitt and Robinson, 2011; Viscusi, 2014) The valuation of changes in mortality is expressed in the economics literature as the 'value of a statistical life' (VSL). These assessments of the VSL are derived from questionnaires that canvass how much compensation an individual would demand, in order to accept a small increase in the probability of his death, or from observations of the labor market and reflect how people in fact differentially value and trade very small fatality risks for income.

These changes in mortality risk can be expressed in terms of changes in life expectancy and its associated underlying survival curve. Hence, a recent contribution to this literature by Jamison et al. has calculated the value of a life year (VLY) in terms of changes in mortality rates associated with a one-year increase in life expectancy and the associated changes in the underlying survival curve (Jamison, Summers et al. 2013).

For this study on pandemic influenza, we first calculated the change in age-specific mortality and hence life expectancy resulting from probability *r* of pandemic influenza occurrence. Next, from the literature we obtained the value, expressed in currency units, of a standardized mortality unit (SMU) of 1 death per 10,000 (10^{-4}). This value of a SMU (VSMU) can be conditional on age, in which younger individuals are valued more than older individuals, or unconditional on age, in which all individuals are valued equally regardless of age. Next, the VSMU was multiplied against the excess number of SMUs due to pandemic, calculating the total expected value of excess mortality due to pandemic influenza under a probability *r*.

Methodology and data

To calculate the expected value of excess age-specific mortality rates due to pandemic influenza for a given country, the following methodology was implemented to estimate the following equation:

$$VSMU(x) = s_x \cdot r \cdot v \cdot GDPpc \cdot n_x$$

Where *v* is the value of a standard mortality unit, *GDPpc* is gross domestic product per capita, *n* is the population in age group *x*, *r* is pandemic risk, and s_x is the excess mortality rate by age *x*.

Age-specific estimates of 'severity' *s*: Excess age-specific mortality rates s_x due to pandemic influenza were obtained for each country of interest by literature review and different sources of

estimates were checked against each other. In the literature, 'excess mortality rates' are generally calculated by subtracting mortality rates in counterfactual years without the pandemic from the mortality rates in the pandemic (Luk et al., 2001; Murray et al., 2006). Counterfactual years are typically the 2-3 years preceding the pandemic. These age-specific excess mortality rates were estimated for both a large-scale 'severe' 1918-level pandemic and for a small-scale 'moderately severe' pandemic as seen in 1957 and 1968. Table 18A.1 presents the age-specific mortality rates (ASMRs) for 1918 and 1958 used in the study and the key ASMRs are illustrated in Figure 18A.1.

World population in 1918 was about 1830 million, and deaths from pandemic influenza ranges in historical literature at least 20 million or a 1.1% excess death rate. This figure appears to be an underestimate. The number of deaths occurring in India alone was 14 million and is well documented by multiple researchers (Davis, 1968; Hill, 2011; Murray et al., 2006). Together the numbers would suggest that India implausibly accounted for 73% of world excess flu deaths even though it had 18% of world population.

We calculated excess pandemic deaths in 1918 using Murray et al (2006) regional death rates (which excluded Africa, Central Asia, Middle East, and Southeastern Asian countries) multiplied with world population figures (Roser 2015). We estimated 20 million excess deaths *excluding* these regions. The Murray et al (2006) estimate draws primarily from 27 countries which have vital registration systems, and imputes mortality rates in countries for which it lacked data (i.e. Africa, Central Asia, Middle East, and Southeastern Asian countries). Those countries which lacked any data may well have a higher death rate than the average of those countries which had data. Assuming these regions have an excess mortality rate *at least* the Murray et al (2006) rate of 1.1%, then total excess deaths in 1918 were around 25 million or a world excess mortality rate of 1.3%. Nevertheless, for the purpose of this study, we chose a conservative 1.1% excess mortality rate or 110 SMUs.

For the 'moderately severe' pandemic scenario, we used the 1957 age-specific excess mortality rates observed in the U.S., scaled to a global aggregate excess mortality rate of 0.05% or 5 SMUs. This figure is also consistent with pandemics recorded in the historical record of moderate scale (Table 18A.1 and Figure 18A.2).

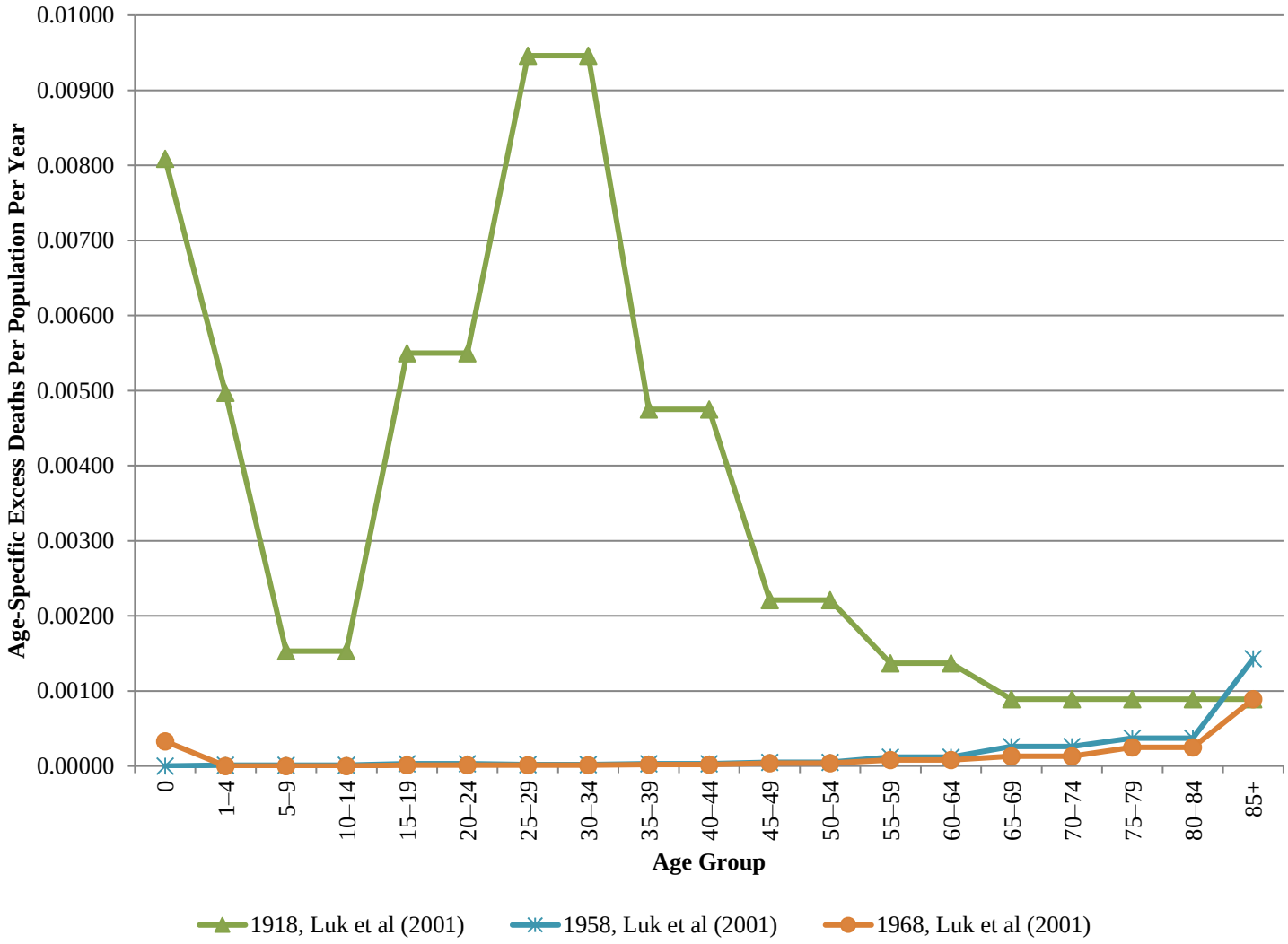
Estimates of 'risk' *r*: Literature on historic pandemic influenza was reviewed to estimate a crude probability that a pandemic influenza (both 'severe' and 'moderately severe') that would occur on the order of 0.67% for a severe pandemic and 2% for a moderately severe pandemic (Table 18A.2).

The excess age-specific mortality rates and probability of a pandemic were then applied to the life table of the country or region of interest in order to calculate changes in life expectancy from the pandemic. Life tables for 2015-2020 were obtained from the United Nations Population Division for the World and presented in Table 18A.3 (United Nations Population Division, 2015). Standard demographic methods – specifically a single decrement life table – were used to decompose a difference in life expectancy (Preston and others 2000). Table 18A.4 present calculations for a severe pandemic of 0.67% probability of occurrence in the World and correspond to the results in Tables 2 and 3 in the main text.

Parameters of value of a life year *v*: The country of interest's gross national income (GNI) and GNI per capita from the World Development Indicators, and the number of people by age group from the World Population Prospects were used to calculate the VSMU for the country, both conditional on age group and unconditional on age (constant) (United Nations Population Division, 2015; "World Development Indicators | Data," 2015). These values by age group are presented in the last five columns of Table 18A.4. Projected population for 2015 and GNI per capita for 2013 are used in this paper.

Sensitivity checks of main results were conducted using different income elasticities affecting *v* and letting value of losses depend by age (second to last column in Table 18A.4). We let value as a function of age *x* directly proportional to the years of life lost at that age, relative to the reference age of 35 for which we have empirical estimates of VSMU, i.e. VSMU(x) = VSMU(35)* e(x)/e(35). The main results of the paper use VSMU expressed as a 1.4% of annual per capita GNI, with a sensitivity analysis conducted with VSMU ranging between 1.0% and 1.8% based on the literature by Hammitt and Robinson, 2011.

Figure 18A.1. Excess Age-Specific Mortality Rates due to Pandemic Influenza



Source: Luk and others 2001

Figure 18A.2. Epidemic Severity *s*

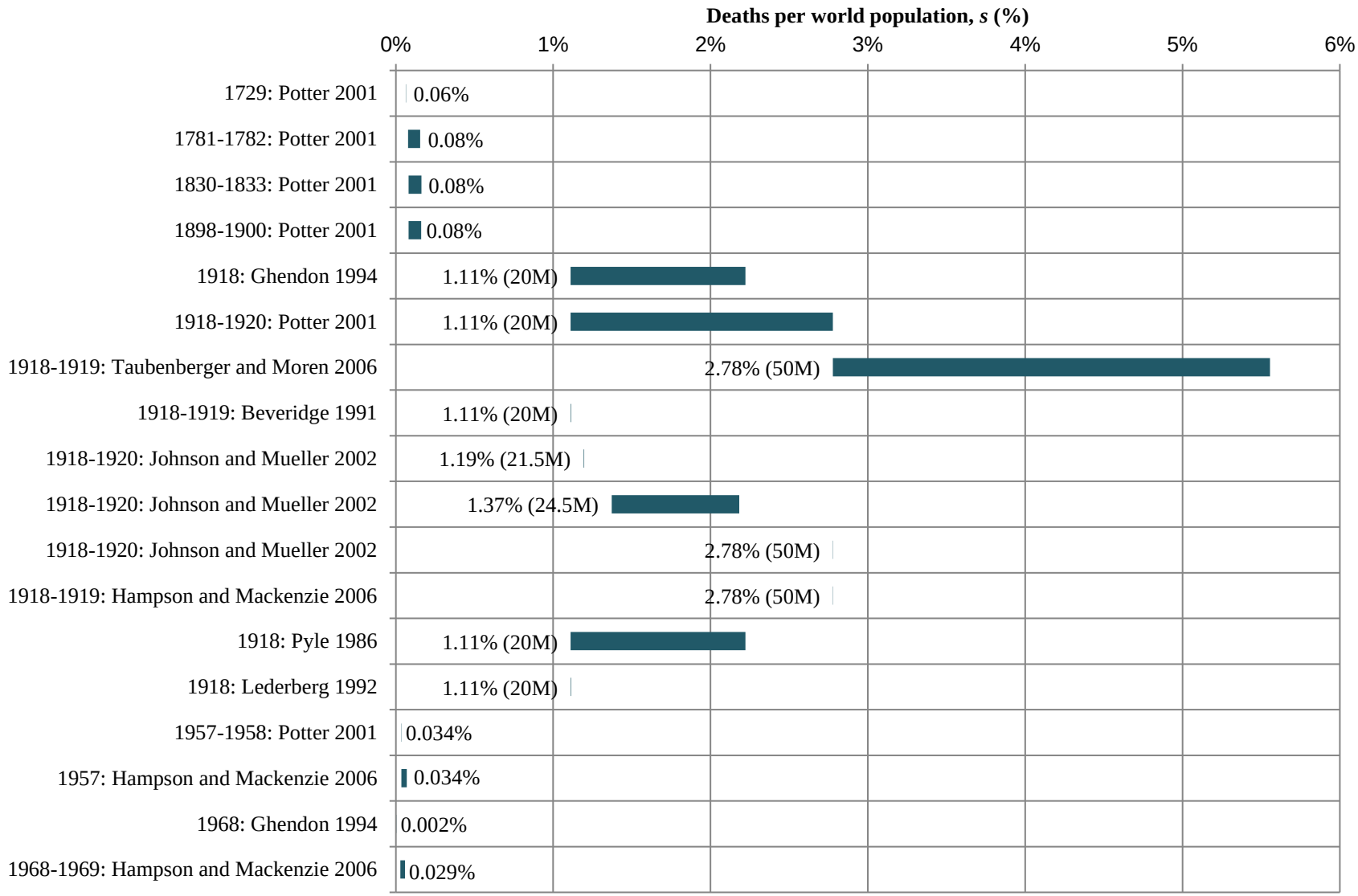


Table 18A.1. Excess Age-Specific Mortality Rates Due to Pandemic Influenza

Region	World	World	USA		
Year	1918	1957	1918	1957	1968
SCENARIO	(1a)	(1b)	(2)	(3)	(4)
Age group:					
0	0.021034	0	0.00809	0.00000	0.00033
1–4	0.012922	0.0000787	0.00497	0.00001	0.00000
5–9	0.003978	0.0000787	0.00153	0.00001	0.00000
10–14	0.003978	0.0000787	0.00153	0.00001	0.00000
15–19	0.0143	0.0002361	0.00550	0.00003	0.00001
20–24	0.0143	0.0002361	0.00550	0.00003	0.00001
25–29	0.024596	0.0001574	0.00946	0.00002	0.00001
30–34	0.024596	0.0001574	0.00946	0.00002	0.00001
35–39	0.01235	0.0002361	0.00475	0.00003	0.00002
40–44	0.01235	0.0002361	0.00475	0.00003	0.00002
45–49	0.005746	0.0003935	0.00221	0.00005	0.00004
50–54	0.005746	0.0003935	0.00221	0.00005	0.00004
55–59	0.003562	0.0009444	0.00137	0.00012	0.00008
60–64	0.003562	0.0009444	0.00137	0.00012	0.00008
65–69	0.002314	0.0020462	0.00089	0.00026	0.00013
70–74	0.002314	0.0020462	0.00089	0.00026	0.00013
75–79	0.002314	0.0029119	0.00089	0.00037	0.00025
80–84	0.002314	0.0029119	0.00089	0.00037	0.00025
85+	0.002314	0.0112541	0.00089	0.00143	0.00089

Source: Luk and others 2001

Notes: Column (2) wa obtained from table 1 of Luk and others (2001) and was disaggregated for 10-year age groups except age groups 0 and 1-4. Negative excess deaths were assigned the rate for age group 65-69 (0.00089). Column (1a) was obtained by using excess age-specific mortality rates (ASMRs) due to pandemic influenza for the United States from Luk and others (2001) column (2) scaled by a factor of 2.6, which yielded a world excess death rate of 1.1%, and column (1b) used column (3) scaled by a factor of 7.87 to obtain an world excess death rate of 0.05%. Columns (3) and (4) are also obtained from table 1 of Luk et al (2001). Additional sensitivity checks were conducted using the Murray et al (2006) ASMRs, scaled up to obtain the excess death rate for a given region and were consistent with Luk and others (2001) figures.

Table 18A.2. Pandemic Recurrence Risk and Severity

Start Year	Influenza Activity Level	Severity	SMUs (Reference)
1729	Trans-regional Pandemic	S	6 (1)
1732	Global Pandemic	S	..
1737	Trans-regional Pandemic	S	..
1761	Trans-regional Pandemic	S	..
1773	Global Pandemic	M	..
1776	Global Pandemic	M	..
1781	Global Pandemic	S	8 (1)
1788	Widespread epidemic in Europe	M	..
1830	Global Pandemic	M	7 (1)
1833	Global Pandemic	S	..
1836	Global Pandemic	S	..
1847	Trans-regional Pandemic	S	..
1889	Pandemic	S	7 (1)
1918	Pandemic	S*	120-550 (1–4)
1957	Pandemic	M	3 (1)
1968	Pandemic	M	3-6 (5)
1977	Pandemic	M	..

Notes: List of pandemics and severity of pandemics as identified by (Morens and Taubenberger, 2011). Severity is labeled as either S for severe or M for 'mild' as labeled by Morens and Taubenberger (2011) for pandemics before 1888 (labeled as 'moderately severe' in this paper). Severe pandemics resulted in 6 or more SMUs, and M resulted in fewer than 6 SMUs – with one exception of the 1830 pandemic appearing to be labeled by Morens and Taubenberger as M but another paper indicating deaths implying 7 SMUs. Mortality for the 1977 pandemic likely to be a fraction of the 1957 pandemic.(Taubenberger and Morens, 2009) The 1788 'widespread epidemic in Europe' is included because it was separately classified by Morens and Fauci (2007) as a pandemic.(Morens and Fauci, 2007) References: (1) (Potter, 2001); (2) (Beveridge, 1991); (3) (Ghendon, 1994); (4) (Johnson and Mueller, 2002); (5) (Hampson and Mackenzie, 2006).

Table 18A.3. Life Table for World, 2015-2020

Exact Age	Age-Specific Death Rate	Years in Age Group	Separation Factor	Survivors to Age x	*P*(dying from age x, x+n)	*P*(surviving from age x, x+n)	Deaths b/w ages x, x+n	Person-Years lived b/w ages x, x+n (mid-year pop)	Person-Years lived after age x	Life expectancy at age x
x	${}_nM_x$	n	${}_na_x$	l_x	${}_nq_x$	${}_np_x$	${}_nd_x$	${}_nL_x$	T_x	e_x
0	0.0326437	1	0.13941841	100000	0.031751685	0.968248315	3175	97268	7165620	71.7
1–4	0.0032267	4	1.56730139	96825	0.012806231	0.987193769	1240	384283	7068353	73.0
5–9	0.0011138	5	2.2581322	95585	0.005551917	0.994448083	531	476469	6684070	69.9
10–14	0.0008426	5	2.45130513	95054	0.004204016	0.995795984	400	474252	6207601	65.3
15–19	0.0011515	5	2.62073171	94655	0.005741772	0.994258228	543	471980	5733348	60.6
20–24	0.0015207	5	2.57422466	94111	0.007575775	0.992424225	713	468826	5261368	55.9
25–29	0.001715	5	2.55801866	93398	0.008539033	0.991460967	798	465043	4792542	51.3
30–34	0.0020307	5	2.57895019	92601	0.010103647	0.989896353	936	460738	4327499	46.7
35–39	0.0025289	5	2.58240126	91665	0.012567669	0.987432331	1152	455540	3866761	42.2
40–44	0.0030975	5	2.5945111	90513	0.01537318	0.98462682	1391	449218	3411221	37.7
45–49	0.0040425	5	2.63092896	89122	0.020020865	0.979979135	1784	441380	2962004	33.2
50–54	0.0058355	5	2.66088547	87337	0.028784711	0.971215289	2514	430806	2520623	28.9
55–59	0.0089706	5	2.66805577	84823	0.043934024	0.956065976	3727	415426	2089818	24.6
60–64	0.0140633	5	2.65563511	81097	0.068072169	0.931927831	5520	392541	1674392	20.6
65–69	0.0218393	5	2.63756272	75576	0.103839064	0.896160936	7848	359341	1281851	17.0
70–74	0.0343336	5	2.61776172	67728	0.158688881	0.841311119	10748	313038	922509	13.6
75–79	0.0537278	5	2.57307641	56981	0.237650903	0.762349097	13542	252039	609471	10.7
80–84	0.0829693	5	2.50524932	43439	0.343704029	0.656295971	14930	179949	357432	8.2
85+	0.1606292		6.22551872	28509	1	0	28509	177483	177483	6.2

Source: United Nations Population Division 2015.

Table 18A.4. World: Change in Life eEpectancy in 2015 under Severe Pandemic Influenza Scenario

Exact Age	Age-Specific Excess Death Rate from Pandemic Influenza	Life Expectancy at Age *x* w/Pandemic Influenza	Life Expectancy at Age *x* w/o Pandemic Influenza	Difference in life expectancy at age *x*	VSMU conditional on age *x*	Constant VSMU	Population, 2015 (thousands)	Value of Change in Mortality using VSMU conditional on age *x*	Value of Change in Mortality using constant VSMU
x	${}_nM_x^*$	e_x^*	e_x	Δ_e	$VSMU_x$	$VSMU$	n_x	$VSMU_x \cdot n_x \cdot \Delta SMU \cdot P$(Pandemic)	$VSMU \cdot n_x \cdot \Delta SMU \cdot P$(Pandemic)
0	0.0283	71.3	71.7	**-0.22**	$127	$150	134,186	-$23,857,888,718	-$28,142,191,034
1–4	0.0124	72.7	73.0	-0.21	$127	$150	536,743	-$58,627,296,380	-$69,155,347,066
5–9	0.0038	69.7	69.9	-0.19	$248	$150	637,449	-$41,847,231,316	-$25,283,672,509
10–14	0.0038	65.0	65.3	-0.18	$231	$150	607,431	-$37,238,161,543	-$24,093,059,312
15–19	0.0138	60.3	60.6	-0.17	$214	$150	590,069	-$120,597,790,259	-$84,133,525,839
20–24	0.0138	55.7	55.9	-0.15	$198	$150	603,509	-$113,871,255,537	-$86,049,722,333
25–29	0.0237	51.1	51.3	-0.12	$182	$150	609,793	-$181,683,593,302	-$149,546,781,761
30–34	0.0237	46.6	46.7	-0.08	$166	$150	551,085	-$149,626,941,539	-$135,149,180,063
35–39	0.0119	42.1	42.2	-0.05	$150	$150	497,756	-$61,293,320,162	-$61,293,320,162
40–44	0.0119	37.6	37.7	-0.03	$134	$150	485,058	-$53,378,769,815	-$59,729,734,981
45–49	0.0055	33.2	33.2	-0.02	$118	$150	454,043	-$20,507,280,698	-$26,013,105,471
50–54	0.0055	28.8	28.9	-0.01	$102	$150	401,753	-$15,758,797,800	-$23,017,327,023
55–59	0.0034	24.6	24.6	-0.01	$87	$150	339,691	-$7,051,997,248	-$12,064,478,609
60–64	0.0034	20.6	20.6	-0.01	$73	$150	292,727	-$5,093,010,155	-$10,396,481,700
65–69	0.0022	17.0	17.0	0.00	$60	$150	215,047	-$1,996,835,981	-$4,961,660,596
70–74	0.0022	13.6	13.6	0.00	$48	$150	153,207	-$1,142,487,742	-$3,534,858,567
75–79	0.0022	10.7	10.7	0.00	$38	$150	114,652	-$671,399,535	-$2,645,307,581
80–84	0.0022	8.2	8.2	0.00	$29	$150	71,450	-$321,874,007	-$1,648,518,241
85+	0.0022	6.2	6.2	0.00	$22	$150	53,823	-$183,466,642	-$1,241,838,355

Note: Uses age-specific mortality rates from column 1a in Table A1, r=0.67%, and v=1.4% of per capita GNI.

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