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Sex Mortality Differentials in the United States: The Role of Cohort Smoking Patterns

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Keywords
Sex differentials, Mortality, Cigarette smoking

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Abstract

This paper demonstrates that, over the period 1948-2003, sex differentials in mortality in the age range 50-54 to 85+ widened and then narrowed on a cohort rather than on a period basis. The cohort with the maximum excess of male mortality was born shortly after the turn of the century. Three independent sources suggest that the turnaround in sex mortality differentials is consistent with sex differences in cigarette smoking by cohort. An age/period/cohort model reveals a highly significant effect of smoking histories on men's and women's mortality. This model suggests that improvements in mortality at older ages are likely to accelerate in the future.

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Life expectancy for females in the United States has exceeded that of males whenever the mortality of the sexes has been compared (e.g., U.S. National Center for Health Statistics, 2004). However, longevity differences in recent years have been narrowing. Female life expectancy at birth exceeded that of males by 7.7-7.8 years from 1972 to 1979 but by 2003 the difference had declined to only 5.3 years (U.S. National Center for Health Statistics, 2004, 2005).

Most of the reduction in sex mortality differentials is attributable to mortality changes above age 50, an age range in which the bulk of deaths are a result of chronic degenerative processes. Some analysts cite the slow improvement in female mortality at older ages as evidence that a century of persistent mortality improvements is coming to an end (Olshansky, et al., 2005). Whether or not this extreme vision is realized, the change in trend of sex mortality differences has created major uncertainties for extrapolative mortality projections that are used to predict the fiscal burdens of an aging population (Wilmoth, 2005).

Narrowing sex differentials in mortality have also been observed in most but not all European countries (e.g., Gjonca, et al., 2005). The most commonly invoked explanation of reduced differentials is the different histories of cigarette smoking for men and women (Gjonca, et al., 2005; Janssen, et al., 2005; Pampel, 2002; Valkonen and van Poppel, 1997). In all countries where data exist, women's uptake of smoking has lagged behind that of men (Pampel, 2002). Cigarette smoking was also implicated in earlier years when sex differentials were widening rather than narrowing (Preston, 1970; Retherford, 1975). Smoking patterns are an obvious place to look for an explanation of sex mortality differences because the health risks are high and long-lasting; large fractions of the population have engaged in the habit; and smoking patterns differ between the sexes (Waldron, 1986).

In this paper, we demonstrate that changes in sex mortality differentials in the United States have been structured on a cohort rather than a period basis and that the cohort imprint is closely related to histories of cigarette smoking. Allowance for the smoking histories of cohorts significantly affects the assessment of mortality trends: national mortality levels would have declined more rapidly in the absence of smoking, and they are likely to decline more rapidly in the future as smoking recedes.

Data

For each sex, we reconstruct age-specific death rates from ages 50-54 to 85+ for every fifth calendar year from 1948 to 2003. Using five-year age groups every fifth calendar year enables us to identify uniquely birth cohorts as they pass through life. Numerators of death rates were drawn from official vital statistics sources; denominators were drawn from U.S. Census sources.[1]

Sex Differences in Rates of Mortality Change

Since our focus is on sex differences in the rate of change of age-specific death rates, we begin by presenting a matrix of those differences. Table 1 shows the difference between male and female proportionate changes in age-specific death rates over a 5-year period. A positive value means that male mortality is increasing relative to female and that the ratio of male to female mortality is rising.

A remarkable pattern is revealed in this Table. Above the diagonal line that is drawn on the Table, 41 of 44 values are positive: male mortality is increasing relative to female. Below the diagonal line, on the other hand, 40 of the 44 values are negative. Thus, the pattern of change in sex mortality differences is tightly organized on a cohort basis, a feature that has previously escaped attention. For the central group of ages 60-84, there is not a single exception out of 55 observations to the diagonalized pattern of sex differences in mortality change.

Relative to females, mortality was growing worse for males through the cohort aged 40-44 in 1948. This cohort was born between 1903 and 1908. Sex differences in mortality began to narrow between this cohort and the cohort born in 1908-13, and they continued to narrow all the way through the cohort born in 1948-53.

Can smoking patterns account for the change in direction of sex differential across these cohorts? Three independent sources of information can help answer this question. The first national sample survey of smoking behavior was conducted by the U.S. Census Bureau for the National Cancer Institute in 1955 (Haenszel et al., 1956). A question was asked about the age at which someone had become a “regular cigarette smoker” and results were tabulated by birth cohort. No allowance was made for differential mortality by smoking status. Table 2 shows the percent who reported that they had become regular cigarette smokers by age 35. Both male and female smoking prevalence continued to increase through cohorts born in the 1920’s, but the sex difference in smoking behavior peaked at 44-45% among the cohorts born in the 1890’s and 1900’s.

A careful and detailed reconstruction of smoking histories was made by Burns et al. (1998a). They employed a total of 15 National Health Interview Surveys conducted between 1965 and 1991 to estimate cohort smoking histories. The reliability of estimates is increased by virtue of the multiple observations available on the same cohort. The authors used evidence on differential mortality by smoking status to translate current reports by the living into past behavior by the living and dead.[2] David Burns supplied us with updated, unpublished estimates using the same methodology. These incorporated data from three additional National Health Interview Surveys through 2001.

We have converted these data into an estimate of the number of years spent as a current smoker before the age of 40. This value is derived simply by summing across ages between 0 and 39 the proportion of a cohort who were estimated to be a current cigarette smoker. Table 2 shows that this series has the same general conformation as that drawn from the 1955 survey. The peak difference between the prevalence of smoking among women and men occurs in the 1895-99 and 1900-04 cohorts (see also Figure 1). This latter cohort overlaps with the 1903-08 cohort in which sex mortality differentials peak.

Lung cancer death rates are often used as a proxy for cigarette smoking prevalence because such a high fraction of deaths from lung cancer are attributable to smoking (Pampel, 2002; Peto, et al., 1994). We have reconstructed lung cancer death rates for the same ages and periods shown in Table 1.[3] Table 3 presents the difference between male and female lung cancer death rates for these groups.[4] In five out of eight age groups, the sex difference in lung cancer death rates peaks in the cohort born 1903-08, the same cohort identified earlier as having the highest sex mortality differential for all causes combined.

Thus, three independent tests support the plausibility of cigarette smoking patterns as the source of the widening and then contraction of sex mortality differentials. Sex differences in lung cancer mortality change direction approximately five years after smoking patterns change, a pattern that may be attributable to increased smoking intensity by smokers over time.

It is reasonable to ask whether lung cancer is solely responsible for the diagonalized pattern of change in sex mortality differentials shown in Table 1. That would be surprising in view of the fact that lung cancer accounts for only about 28% of the excess deaths from smoking (Department of Health and Human Services, 1989). To investigate this possibility, we have subtracted lung cancer death rates from all-cause mortality and repeated the tabulation shown in Table 1. The result (not shown) is little altered: 39 of 44 observations above the diagonal remain positive, and 39 of 44 below the line remain negative. When lung cancer deaths are removed from Table 1, the difference between the mean values of observations above and below the diagonal declines only from .0752 to .0630. Clearly, other causes of death must also be implicated in this structure.

Age/Period/Cohort Analysis of Mortality Trends

Cohort influences on mortality have been recognized since the pioneering work of Kermack, McKendrick, and McKinlay (1934). Most of the successful studies, like theirs, used graphical methods to demonstrate that age patterns of mortality by cohort were very different from those arranged by period and to argue that the cohort patterns reflected genuine and persistent influences embedded in cohorts.

Less successful have been statistical efforts to disentangle age, period, and cohort effects in an accounting framework using dummy variables. Because each variable is a linear combination of the other two variables, some restriction must be imposed in order that the effects of ages, periods, and cohorts be identified. These restrictions are often arbitrary and results can be highly sensitive to the restriction employed because of the correlation among variables (e.g., Mason and Smith, 1985).

In our case, it is not necessary to study cohort effects by employing a set of dummy variables to represent cohort membership because we have a hypothesis about cohort influences: that a cohort's smoking history affects its level of mortality. We will represent that history by using the variable introduced earlier, the mean number of years that members of a cohort smoked cigarettes before age 40. The value of this variable differs between men and women in the same cohort, reflecting their different smoking histories.

We model age and period effects through a series of dummy variables.

Our model includes both men and women but we allow for well-known sex differences in the level and age pattern of mortality through a set of age/sex interaction dummies. We also allowed for sex differences in the effect of smoking by constructing a sex/smoking interactive variable.

We model the mortality process using negative binomial regression. We initially used Poisson regression but the hypothesis that the data were Poisson-distributed was decisively rejected: the amount of dispersion in outcomes was significantly underestimated by the Poisson model. Our model is

$$D_{ijks} = \exp\{\ln N_{ijks} + B_i X_i + B_j X_j + B_c C_{ks} + B_s X_s + B_{is} X_{is} + V_{ijks}\}$$

where

D_{ijks} = Number of deaths in age group i , period j , cohort k, sex s,

N_{ijks} = Number of person-years of exposure at age i , period j, cohort k, sex s,

X_i = Dummy variable signifying membership in age group i ,

X_j = Dummy variable signifying observation pertained to period j,

X_s = Dummy variable signifying observation applied to sex s,

C_{ks} = Average number of years spent as current smoker prior to age 40 by members of cohort k, sex s,

X_{is} = Interactive dummy variable indicating observation pertained both to age i and sex s,

V_{ijks} = Error term whose exponential is gamma distributed,

B_i, B_j, B_c, B_s, B_{is}, B_{ks} = Coefficients indicating estimated effect of variable on mortality.

Coefficients of this model are estimated using STATA and are presented in the Appendix. Figure 2 shows the predicted age pattern of mortality for men and women, setting the smoking variable at zero and the period at 2003. The age-specific death rates are, to a close approximation, linear in their logs, consistent with the well-known Gompertz curve of mortality. The slope of the female age-pattern of mortality is steeper than that of males.

The coefficient of the cohort/sex smoking variable is .0259, with a standard error of .0024. It is significant at a .000 level. The coefficient implies that a cohort's death rates will rise by 2.62% for every 1-year increase in average smoking duration by a cohort. The sex/smoking interaction term has a significant (also at .000) coefficient of -.0110, indicating that a particular level of smoking prevalence in a cohort has a smaller proportionate effect on women's mortality than on men's. The ratio of the two relative risks is .0149/.0259 = 0.58. This ratio is roughly consistent with sex disparities in the risk from smoking recorded in large epidemiologic studies. The largest such study, the American Cancer Society Cancer Prevention Study conducted between 1959 and 1972, found a ratio of the mortality of current smokers to never-smokers at ages 40-84 of 1.91 for white males and 1.46 for white females, implying that the excess risk for females was 0.51 of that for males (Burns et al., 1996b: 232, 292). A later large study estimated the ratio to be 2.3 for males and 1.9 for females between 1982 and 1988, suggesting that the relative risks from smoking had risen for both sexes and faster for women (Thun, et al., 1998). The mean of the excess risks from these two studies, which span the 1970s midpoint of our own study, is 0.68 for women and 1.10 for men. The sex ratio of mean excess risk is thus 0.62, very close to our estimate.

The regression results, combined with the smoking data shown in Table 2, enable us to address the question of how much variability smoking has introduced into sex mortality differentials. Figure 3 shows for men and women the percentage increase in mortality by cohort that is estimated to have been attributable to smoking. The impact is clearly higher among men than women, both because more men have smoked and because smoking has elevated mortality more for men than for women. The estimated 59% increase from smoking for the cohort born 1910-14 may seem implausibly high. But it should be remembered that smoking has increased men's mortality risks by a factor of approximately two and that the proportion of this cohort who were current smokers at any one time reached 77% (Burns et al, 1998a).

Among women, the impact of smoking has been smaller. Nevertheless, the rise in smoking prevalence between the cohorts of 1885-89 and the peak cohort of 1940-44 is estimated to have increased women's mortality by 15.5%.

Consistent with earlier data and discussion, the sex differential in the estimated impact of smoking peaks in the cohorts born around the turn of the century. The suggestion that smoking is responsible for the change in pattern of sex mortality differentials is strongly supported by the statistical analysis that controls age and period effects. Clearly, this model depicts a huge role for cigarette smoking in interpreting the national mortality record. It should be noted that measurement error in the smoking variable, which is surely present in view of the assumptions required to reconstruct distant behavior in cohorts many of whose members had died, biases the smoking coefficient downward. Thus, it is likely that the smoking effect is even greater than that revealed in our estimates.

Figure 4 presents the estimated period effects on mortality relative to levels of 1948. Controlling smoking histories, mortality levels are reduced by 56% during this period. Although the advance was relatively steady, a period of slow improvement in the 50's and 60's was followed by a catch-up decade of exceptionally rapid gains in the 1970's.

What would the trend look like if we had omitted the smoking variable from our regression? Figure 4 shows that the period improvements would appear substantially smaller. Rather than declining by 56%, as we have estimated in the full model, the estimated period decline in mortality would have been only 46%. A failure to account for changes in cumulative smoking patterns, which have raised mortality over most of the period in question, would lead to an overly pessimistic view of the period-specific progress that has been made in extending longevity.

Impending Smoking-Related Changes in Future Mortality

Just as mortality improvements in the past half century have been inhibited by increases in smoking, so should mortality declines in the future be accelerated by reductions in smoking. Even without any additional changes in smoking behavior, current age-specific smoking behavior implies that members of future cohorts reaching age 50 will have accumulated fewer years of smoking than cohorts who are currently in this age range. To illustrate this effect, we have created a synthetic cohort whose smoking prevalence is the same at each age as the prevalence recorded at that age in 2000. Cumulating these values to age 40 for males and females and substituting them for the actual cohort-specific values in 2003 indicates how much improvement in mortality can be expected simply if current behavior continues.

Table 4 shows the result of this exercise in the form of probabilities of survival from age 50 to age 85. Note first that our age/period/cohort model comes very close to replicating the actual survival probability in the official U.S. life table for 2003. Substituting the smoking values in the synthetic cohort for those values actually observed in 2003 suggests that male mortality will benefit enormously from the improved smoking histories of cohorts as they reach age 50. The survival probability is estimated to increase from .304 to .384, or by 26%. The expected improvement for females is much lower at only 2%. The main reason for this disparity is that current female smoking patterns do not differ radically from those of the past, whereas male smoking patterns have shown much larger reductions. As a result, it seems quite likely that sex mortality differentials will continue to narrow.

What if smoking were eliminated altogether? Table 4 shows that another large improvement in mortality could be expected, one in which both sexes would share. Thus, there is considerable potential for major mortality reductions from a recession in smoking. Large reductions for males seem not only possible but very likely. It may seem ironic, but the huge impact of smoking on national mortality levels holds out a bright future for American longevity.

Endnotes

1. The numbers of deaths by age and sex are obtained from *Vital Statistics of the United States* for calendar year 1948, 1953, 1958, 1963, 1968, 1973 and 1978. Death rates from 1983 to 1998 are obtained on-line from the website of National Center for Health Statistics, Center for Disease Control and Prevention. Unpublished death data for 2003 were supplied by the National Center for Health Statistics. The population at risk by age and sex between 1948 and 1978 is obtained from U.S. Census Bureau, Current Population Reports, Series P-25, No. 311, No. 314, No. 519, No. 870, and Series P-20, No. 441. Population estimates in 2003 are taken from the website of U.S. Census Bureau.

2. Estimates were not available in this source for black cohorts born before 1900. We accounted for blacks in the three earliest national cohorts by fitting a linear trend line to the relationship between national smoking prevalence and white smoking prevalence for cohorts born 1900-04 to 1950-54. This line was extrapolated backwards in time and actual white cohort values were used to predict national prevalence. The disparity between white values and national values was always very small.

3. The numbers of deaths from malignant neoplasm of trachea, bronchus and lung are drawn from the same sources as deaths from all causes combined (see footnote 1). For 1948, we combine two categories from the published data, "cancer of trachea" and "cancer of bronchus and lung"; for data between 1952 and 1963, we combine code 162 (malignant neoplasm of respiratory system of trachea, and of bronchus and lung specified as primary) and code 163 (malignant neoplasm of lung and bronchus, unspecified as primary or secondary). Between 1968 and 1978, data are coded according to the Eight Revision, International Classification of Diseases, where malignant neoplasm of trachea, bronchus, and lung is code 162. Between 1983

and 1998, the Ninth Revision is used, wherein malignant neoplasm of trachea, bronchus, and lung is also coded 162. 2003 data employ the Tenth Revision in which malignant neoplasm of trachea, bronchus, and lung is coded as C33-C34.

4. The sex difference in death rates is preferred to the ratio for this comparison because the difference should be linearly related to the difference in smoking prevalence between the sexes, assuming a linear relation between smoking and mortality for each sex.

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Table 1. Sex Differences in Rates of Mortality Change by Age and Period: United States, 1948-2003*

Period	Age Interval							
	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85+
1953-1948	0.0221	0.0629	0.0891	0.0765	0.0625	0.0404	0.0630	-0.0402
1958-1953	0.0716	0.0410	0.0487	0.0712	0.0718	0.0452	0.0036	0.0221
1963-1958	0.0243	0.0579	0.0269	0.0816	0.0844	0.0627	0.0216	0.0259
1968-1963	0.0029	0.0179	0.0781	0.0035	0.0894	0.0672	0.0265	-0.0539
1973-1968	-0.0192	-0.0299	-0.0043	0.0646	0.0052	0.0453	0.0981	0.1326
1978-1973	-0.0048	-0.0325	-0.0475	-0.0118	0.0291	0.0324	0.0475	0.0371
1983-1978	-0.0361	-0.0201	-0.0540	-0.0628	-0.0224	0.0402	0.0220	0.0126
1988-1983	-0.0245	-0.0534	-0.0350	-0.0526	-0.0415	-0.0339	0.0006	-0.0241
1993-1988	-0.0029	-0.0312	-0.0438	-0.0378	-0.0612	-0.0419	-0.0030	0.0096
1998-1993	-0.0383	-0.0418	-0.0504	-0.0615	-0.0478	-0.0509	-0.0562	-0.0484
2003-1998	0.0294	-0.0104	-0.0347	-0.0431	-0.0476	-0.0505	-0.0515	-0.0694

$$* \frac{M_i(t+5) - M_i(t)}{M_i(t)} - \frac{F_i(t+5) - F_i(t)}{F_i(t)},$$

where M_i = death rate for males in age interval i , year t.

F_i = death rate for females in age interval i , year t.

Source: U.S. National Center for Health Statistics, U.S. Department of Vital Statistics, and U.S. Bureau of the Census.

Table 2. Two Estimates of the Prevalence of Smoking within Birth Cohorts

Cohort Born	1955 Survey: Cumulative % Who Had Became Regular Cigarette Smoker by age 35[A]			National Health Interview Survey Data Since 1964: Estimated Number of Years Spent as Current Smoker Before Age 40 Per Member of Cohort [B]		
	Males	Females	Difference	Males	Females	Difference
1885-89	28.1*	1.7*	26.4*	11.6	0.8	10.7
1890-94 } 1895-99	51.6	6.1	45.1	12.9	1.4	11.5
				15.8	2.4	13.5
1900-04 } 1905-09	62.7	18.5	44.2	16.6	3.2	13.4
				17.5	5.3	12.3
1910-14 } 1915-19	67.3	33.8	33.5	17.9	7.5	10.4
				17.8	8.9	9.0
1920-24 } 1925-29	68.4	42.0	28.4	17.7	9.3	8.3
				17.3	10.1	7.2
1930-34				16.4	10.3	6.1
1935-39				15.1	10.5	4.7
1940-44				14.4	10.5	4.0
1945-49				12.5	9.2	3.3
1950-54				10.7	8.5	2.3

Notes: *Born before 1890.

A. Source: Haenszel, et al. 1956:56.
B. Source: Burns, et al. 1998a; updated estimates supplied by David M. Burns, June 29, 2005.

Table 3. Differences in Lung Cancer Death Rates Between Men and Women (Deaths per 100,000 Population)

Year	Age Interval							
	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85+
1948	33.7	56.0	67.4	64.3	53.9	43.8	34.5	26.8
1953	48.3	80.6	106.4	109.8	94.3	78.7	62.1	39.3
1958	56.0	92.5	142.0	163.9	145.5	116.1	88.7	54.5
1963	58.7	105.7	161.7	219.4	215.9	182.1	137.3	95.7
1968	**64.1**	**117.6**	191.7	248.1	306.2	261.5	187.4	124.1
1973	63.2	116.4	**192.4**	**270.1**	331.5	344.2	282.6	194.0
1978	63.1	110.5	188.9	263.9	**361.0**	396.3	382.7	247.5
1983	51.2	101.0	161.9	247.3	338.6	**404.8**	411.0	315.0
1988	44.4	90.5	156.6	225.7	307.9	381.5	**421.1**	353.7
1993	31.9	72.2	132.9	204.6	257.7	320.2	385.9	**361.8**
1998	21.2	50.6	91.4	154.6	229.5	273.0	311.9	334.0
2003	18.4	38.0	65.6	114.4	173.4	233.8	262.5	252.0

Sources: U.S. National Center for Health Statistics, U.S. Department of Vital Statistics, U.S. Bureau of the Census.

Table 4. Estimated Changes in Probabilities of Surviving from Age 50 to Age 85 if Smoking were Reduced or Eliminated

	Probability of Surviving from age 50 to 85	
	Males	Females
U.S. Life table of 2003*	.302	.464
Age/Period/Cohort Model		
2003 Predictions with actual smoking histories	.304	.468
2003 Predictions with 2000 current smoking behavior	.384	.479
2003 Predictions with no smoking	.464	.519

*Source: National Center for Health Statistics, 2005

Figure 1. Average Number of Years Spent as Cigarette Smoker Prior to Age 40 among Men and Women in Different Birth Cohorts

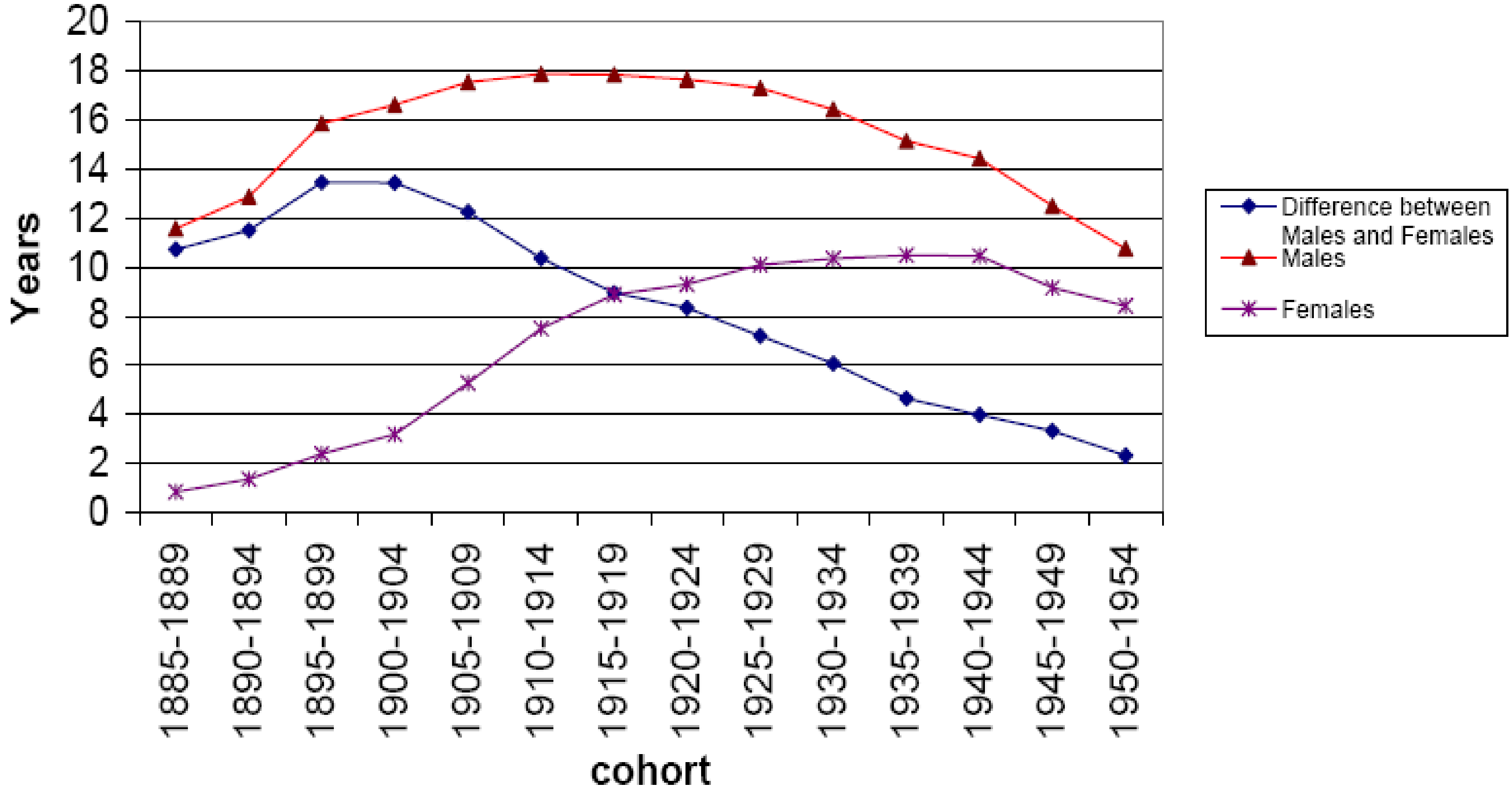


Figure 2. Model Predictions of Age Patterns of Mortality by Sex, 2003

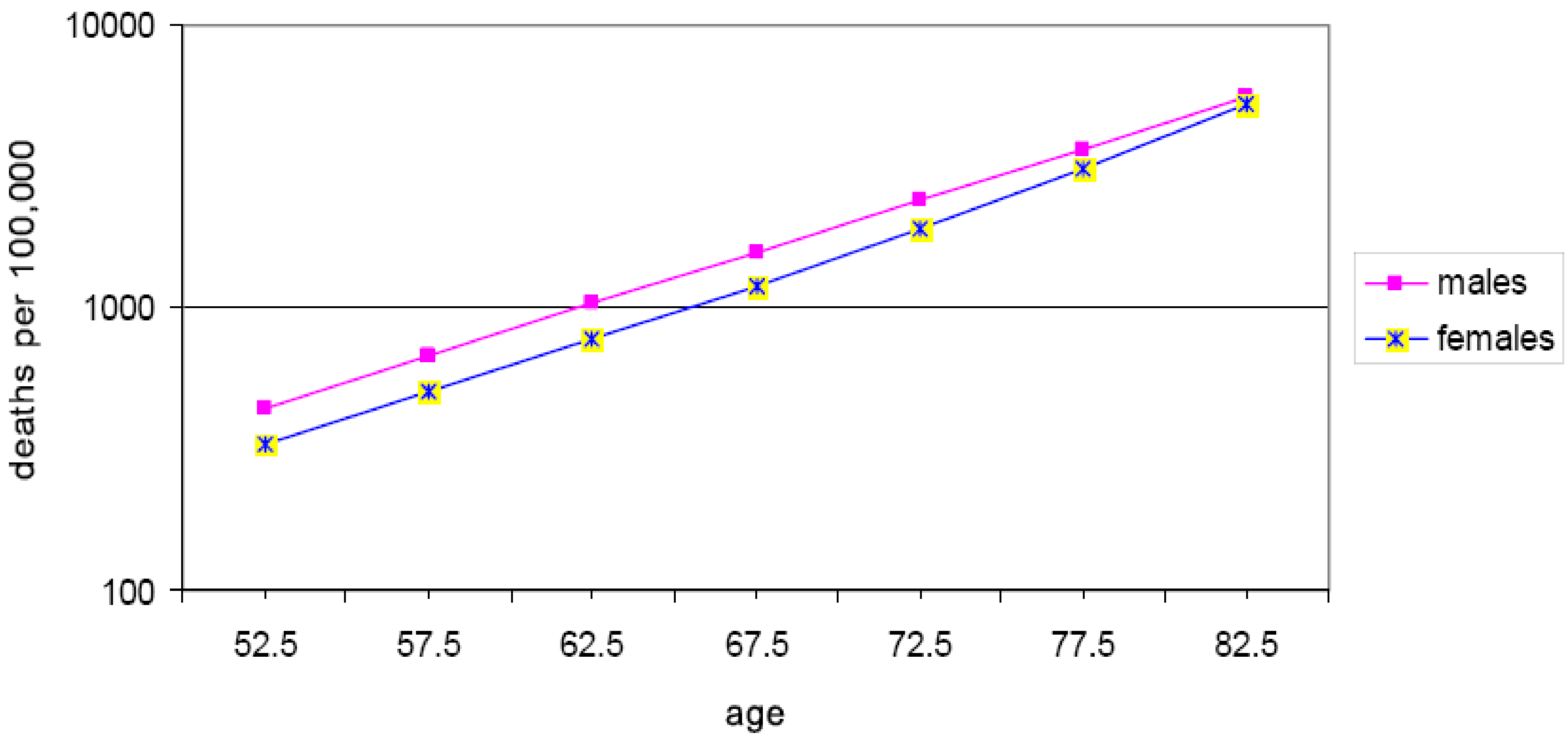
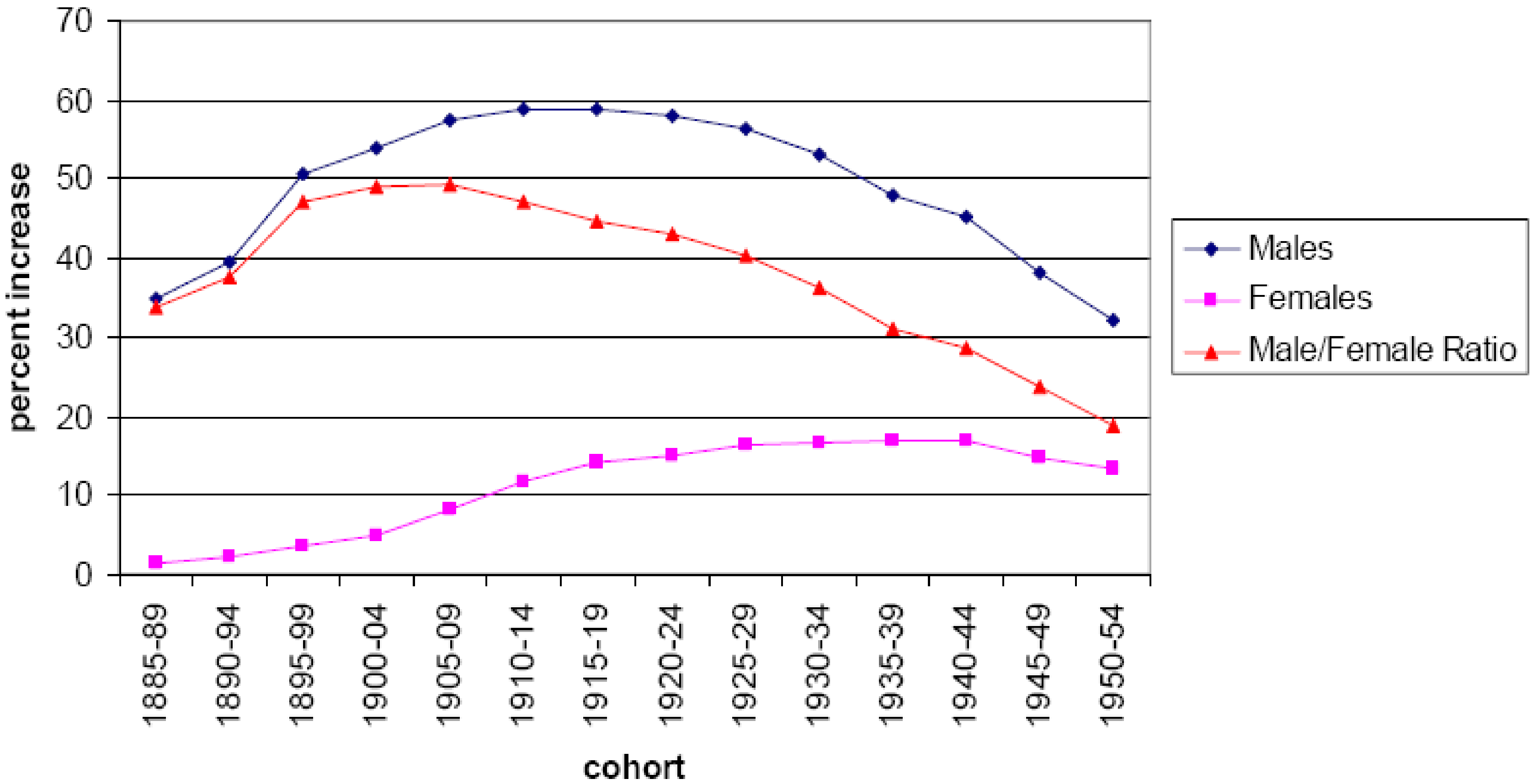


Figure 3. Estimated Impact of Smoking History on Mortality by Cohort



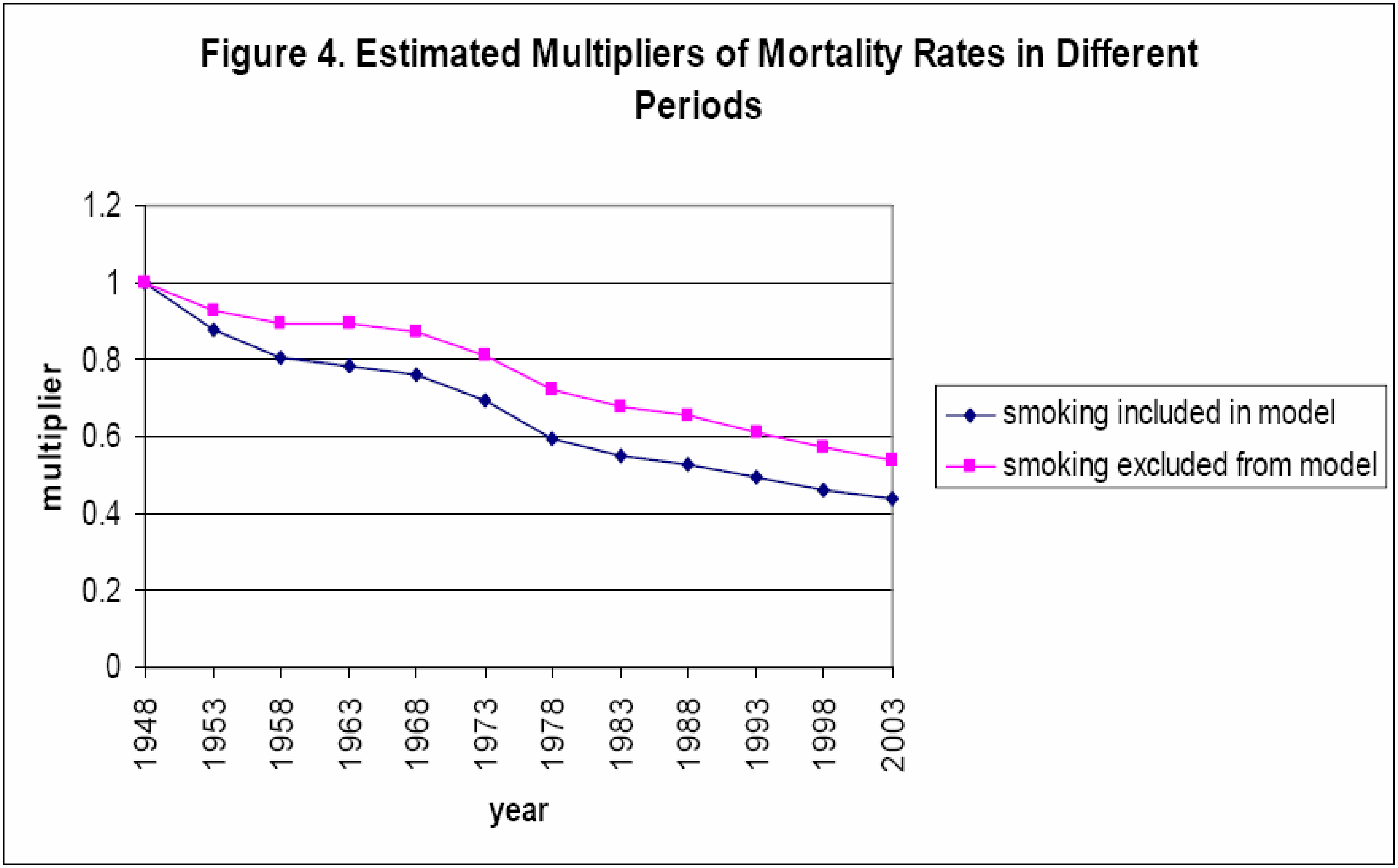


Figure 4. Estimated Multipliers of Mortality Rates in Different Periods
multiplier
1.2
1
0.8
0.6
0.4
0.2
0
1948
1953
1958
1963
1968
1973
1978
1983
1988
1993
1998
2003
year
smoking included in model
smoking excluded from model

Appendix: Estimates of Coefficients of the Age/Period/Cohort Model

Covariates	Coefficients	Standard Error	z	P>z
Age Groups				
50-54(Ref.)				
55-59	0.4292	0.0142	30.28	0.000
60-64	0.8669	0.0146	59.50	0.000
65-69	1.2755	0.0150	85.00	0.000
70-74	1.6912	0.0155	108.98	0.000
75-79	2.1025	0.0161	130.38	0.000
80-84	2.5378	0.0169	150.39	0.000
85+	3.1098	0.0178	174.55	0.000
Periods				
1948(Ref.)				
1953	-0.1285	0.0227	-5.66	0.000
1958	-0.2158	0.0218	-9.91	0.000
1963	-0.2420	0.0213	-11.34	0.000
1968	-0.2732	0.0212	-12.89	0.000
1973	-0.3677	0.0212	-17.36	0.000
1978	-0.5170	0.0213	-24.30	0.000
1983	-0.5966	0.0217	-27.49	0.000
1988	-0.6402	0.0220	-29.04	0.000
1993	-0.7096	0.0223	-31.82	0.000
1998	-0.7725	0.0224	-34.47	0.000
2003	-0.8293	0.0223	-37.20	0.000
Number of years as current smoker prior to age 40	0.0259	0.0024	10.86	0.000
Female	-0.2976	0.0406	-7.33	0.000
Interactions:				
Female*Age 55-59	-0.0044	0.0201	-0.22	0.825
Female*Age 60-64	-0.0005	0.0206	-0.03	0.980
Female*Age 65-69	0.0203	0.0212	0.96	0.338
Female*Age 70-74	0.0734	0.0219	3.35	0.001
Female*Age 75-79	0.1483	0.0228	6.51	0.000
Female*Age 80-84	0.2331	0.0238	9.77	0.000
Female*Age 85+	0.4497	0.0252	17.87	0.000
Female* Number of years as current smoker prior to age 40	-0.0110	0.0027	-4.08	0.000
Constant	-4.5953	0.0399	-115.10	0.000