Assessing Progress in Reducing the Burden of Cancer Mortality, 1985-2005

Samir Soneji, Hiram Beltrán-Sánchez, and Harold Sox

Supplementary Methods

As a simple example, suppose two causes of death operate in a population, A and B, and the mortality rates of either cause may change over time. We estimate the average person-years of life lost (PYLL) for cause A at time 1 and time 2 and compute the change in PYLL as their difference. Now suppose mortality from cause A declined over the period; cause A would be responsible for fewer PYLL at time 2 than at time 1. However, we must also consider the change in mortality from cause B. Any mortality decline from cause B will yield an increase in the PYLL for cause A (17). If the decline from cause B was large enough, compared to the decline from cause A, we will observe an increase in PYLL for cause A. Similarly, if the mortality decline from cause A was large enough, compared to the decline from cause B, we will observe a decrease in PYLL for cause A. Thus, we decompose the change in PYLL between two time points and determine the direct contribution of cause A to the change in the burden of cause A at the population level. This example demonstrates that the observed increase in PYLL for some cancer sites, which we show in Section 3, may not entirely result from increases in cancer mortality rates. On the contrary, mortality rates from some cancers may have declined over time but their decline could have been offset by even larger declines in mortality rates from all other causes.

Formally, let $\mu(a,t)$ represent the hazard of mortality at age a and time t. The probability of survival from birth to age a at time t, $p(a,t)$, equals $p(a,t) = e^{-\int_0^a \mu(s,t)\,ds}$. The probability of survival determines life expectancy. Life expectancy at age x at time t, $e(x,t)$, equals $\int_x^\omega p(a,t)\,da$, where ω corresponds to the highest attainable age in the population.

Let $i = 1, \ldots, n$ represent a set of mutually exclusive and exhaustive causes of death, $\mu(a,t) = \sum_{i=1}^{n} \mu_i(a,t)$. Suppose cause i is the only cause of death operating in the population with $\mu_i(a,t)$

representing the hazard of mortality for this scenario. Then, the probability of survival from birth to age a at time t equals

$$p_i(a,t) = e^{-\int_0^a \mu_i(s,t)\,ds}. \tag{1}$$

Now suppose cause i is the only cause of death *not* operating in the population which we denote with index $-i$. The corresponding probability of survival in this case is similar to equation 1 with subindex i replaced with $-i$. Thus, $p_{-i}(a,t) = e^{-\int_0^a \mu_{-i}(s,t)\,ds}$.

Let $\text{PYLL}_i(x,t)$ represent the average person-years of life lost at age x time t due to cause i. Formally, $\text{PYLL}_i(x,t)$ equals $\int_x^\omega p_{-i}(a,t)\,da - \int_x^\omega p(a,t)da$. This equation determines the gain in life expectancy at age x if cause of death i were to be eliminated, i.e., the years of life that are potentially being lost due to cause i. Let $\Delta\text{PYLL}_i(x)$ represent the change in the PYLL at age x due to cause i between time t_1 and time t_2. Formally,

$$\Delta\text{PYLL}_i(x) = \text{PYLL}_i(x,t_2) - \text{PYLL}_i(x,t_1) \tag{2}$$

Assuming independence among causes of death, equation 2 can be written as follows

$$\begin{aligned}\Delta\text{PYLL}_i(x) &= \int_x^\omega [p_{-i}(a,t_2) - p_{-i}(a,t_1)] \left[\frac{q_i(a,t_2)+q_i(a,t_1)}{2}\right] da \\ &\quad - \int_x^\omega [p_i(a,t_2) - p_i(a,t_1)] \left[\frac{p_{-i}(a,t_2)+p_{-i}(a,t_1)}{2}\right] da,\end{aligned} \tag{3}$$

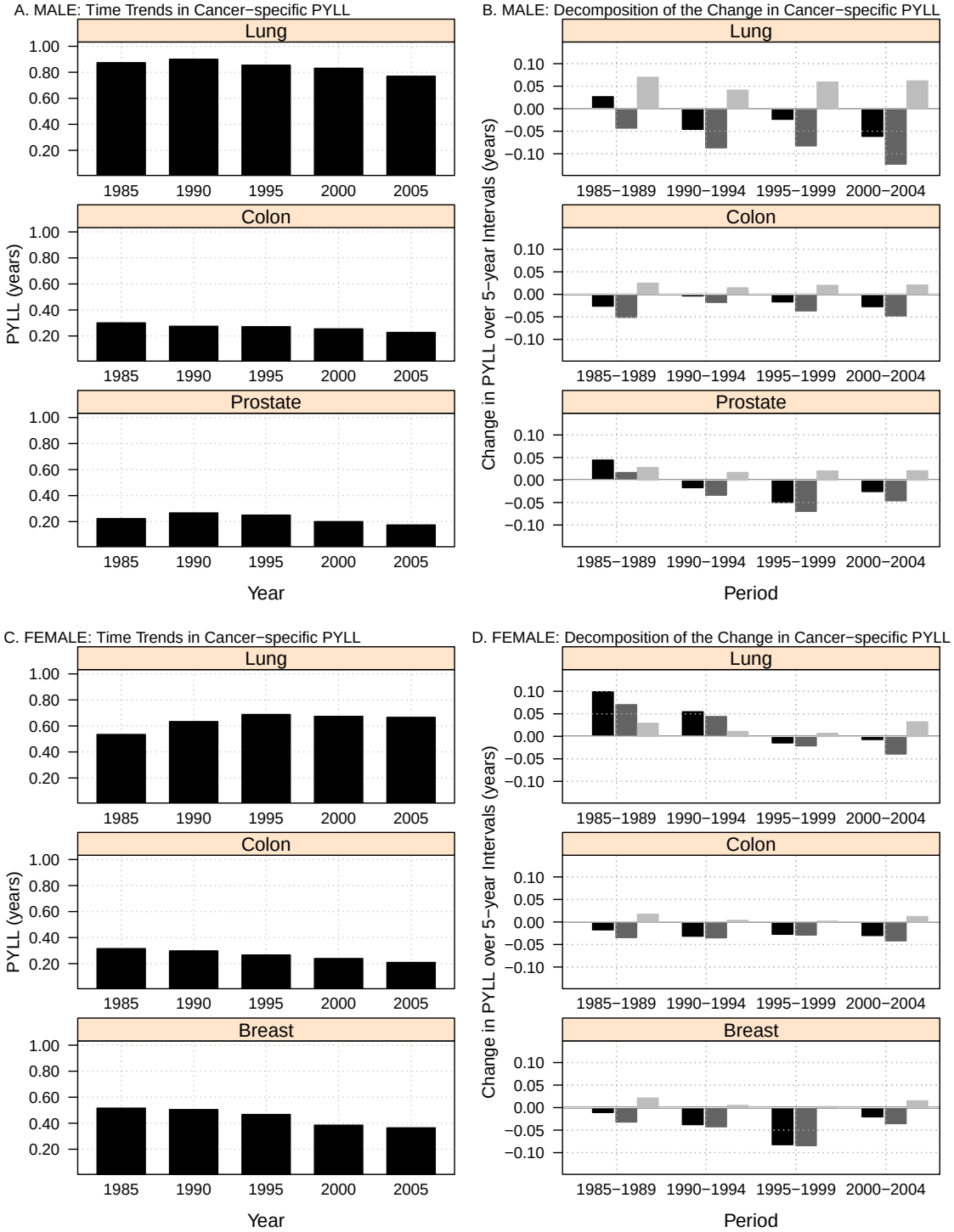
where $q_i(a,t) = 1 - p_i(a,t)$ (17). Equation 3 shows that the change in PYLL at age x due to cause i over the period between t_1 and t_2 equals the difference between changes in mortality for all other causes (first term) and mortality changes for cause i (second term). The negative sign on the second term of Equation 3 indicates that decreases in mortality rates from cause i contribute to reductions in the PYLL over the period between t_1 and t_2.

Although the theoretical definition of life expectancy, PYLL, and ΔPYLL are given within the continuous-time framework, data are typically recorded in a discrete form. A period life table is a common source of discrete data and is often analyzed in order to approximate the continuous-time mortality process. A life table estimates a populations life expectancy based on its mortality rates and accounts for the age distribution of the population by transforming mortality rates into probabilities of survival.[23] Equation 3 can be estimated using life table notation as:

$$\begin{aligned}\Delta\text{PYLL}_i(x) \approx & \sum_{x\in\mathcal{A}} \left[{}_nL^{t_2}_{x,-i} - {}_nL^{t_1}_{x,-i}\right] \left[1 - \frac{{}_nL^{t_2}_{x,i} + {}_nL^{t_1}_{x,i}}{2n\cdot l_0}\right] \\ & - \sum_{x\in\mathcal{A}} \left[{}_nL^{t_2}_{x,i} - {}_nL^{t_1}_{x,i}\right] \left[\frac{{}_nL^{t_2}_{x,-i} + {}_nL^{t_1}_{x,-i}}{2n\cdot l_0}\right], \end{aligned} \tag{4}$$

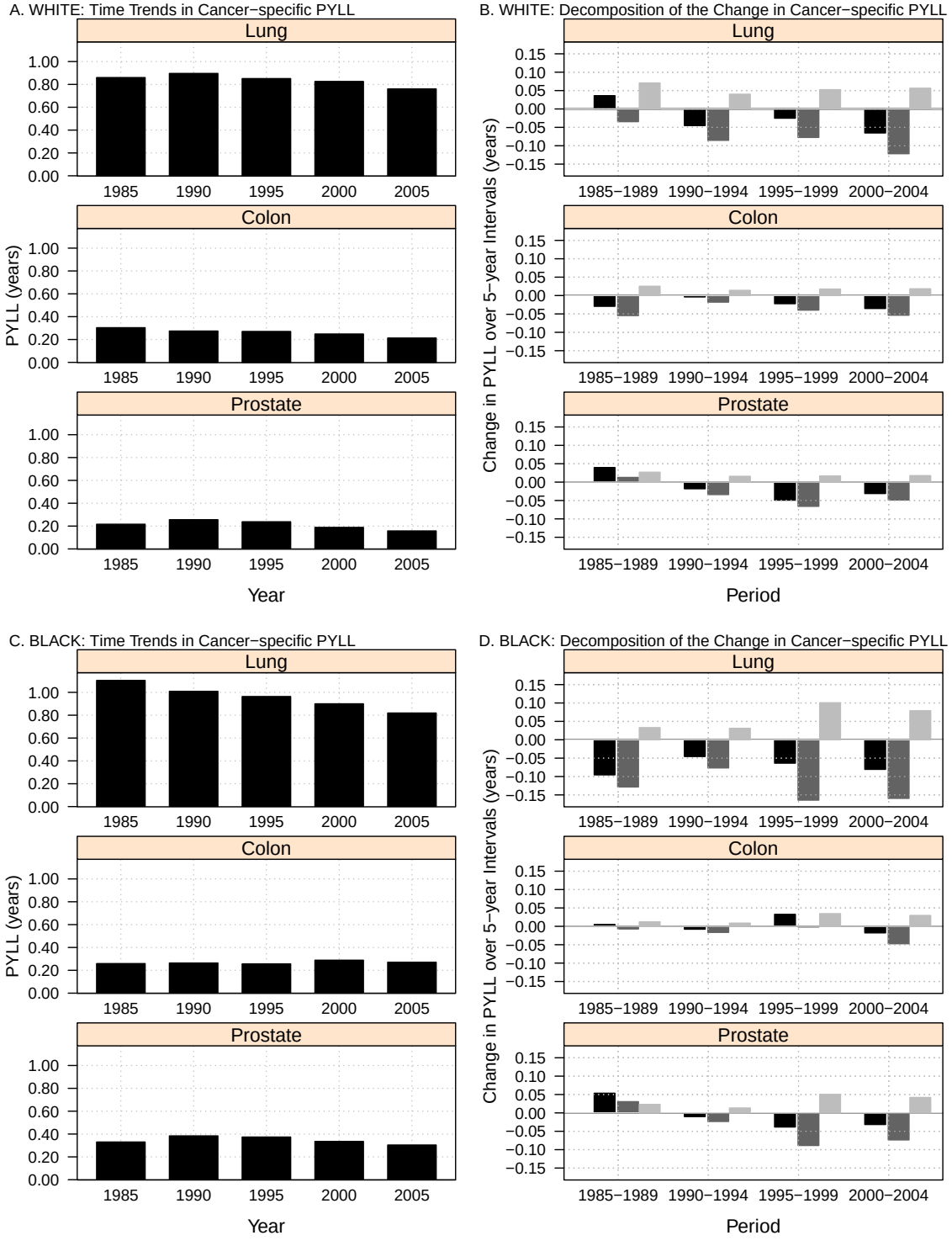
where $\mathcal{A}$ represents the set of age groups included in the analysis (e.g., $\mathcal{A} = 40{-}44, 45{-}49, \ldots, 70{-}79$); n is the length of the age interval; ${}_nL^t_{x,i}$ are the life table person-years lived between ages x and $x+n$ at time t for cause of death i; and l_0 corresponds to the life table radix. Equation 4, therefore, represents the difference between [1] the weighted difference in survival times when cancer is excluded and [2] the weighted difference in survival times when cancer is included. Additional details for estimating equation 4 can be found on Appendix 3 in Beltrán-Sánchez et al.[17] The computer code that implements equation 4 in this article is available at the author's website.

Supplementary Figure 1: Average Person-Years of Life Lost (PYLL) by Cancer Site, Sex, and Year, and Its Changes and Decomposition Over 5-Year Intervals: Modest Reduction in the Burden of Female Lung Cancer Since 1995, Consistent Reductions in the Burden of Female Colorectal Cancer Since 1985, and Large Reductions in the Burdens of Breast and Prostate Cancer Since 1995



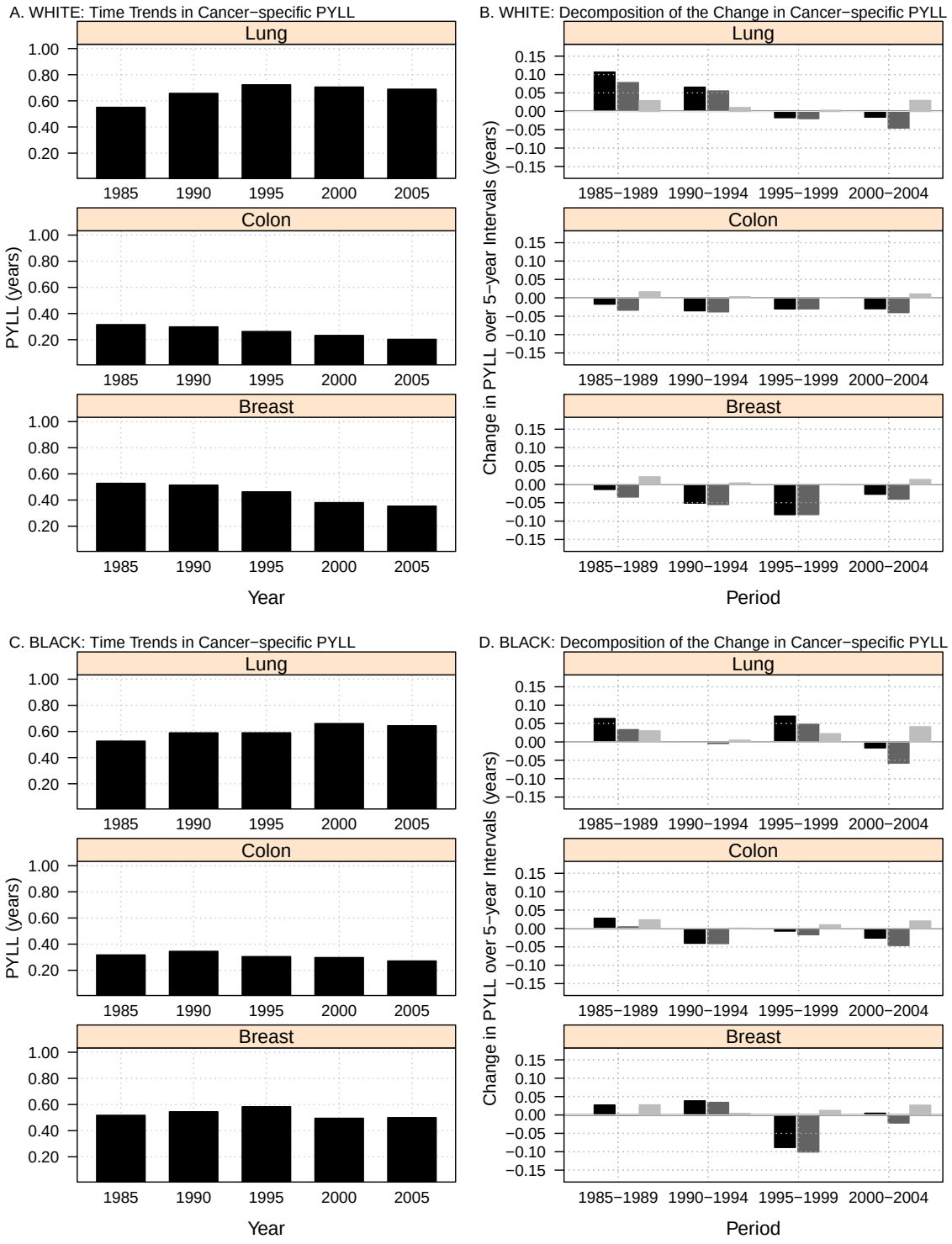
Average Person-Years of Life Lost (PYLL) for specific cancers by year for males (A) and females (C). Decomposition of changes in cancer-specific PYLL over 5-year intervals for males (B) and females (D). Black bars indicate the change in PYLL, dark grey bars indicate the change in PYLL due to changes in cancer-specific mortality rates, and light grey bars indicate the change in PYLL due to changes in other-cause mortality rates. We do not report any sampling uncertainty in PYLL or in the decomposition of PYLL because our calculations utilize registry and vital statistics data that fully capture the mortality experience of defined populations. Note: PYLL, the average years of life lost per U.S. adult, equals the gain in life expectancy in the absence of deaths from cancer.

Supplementary Figure 2: Male Average Person-Years of Life Lost (PYLL) by Cancer Site, Race and Year, and Its Changes and Decomposition Over 5-Year Intervals: Larger Reductions in the Burdens of Lung and Prostate Cancer for Black than White Males Since 1985



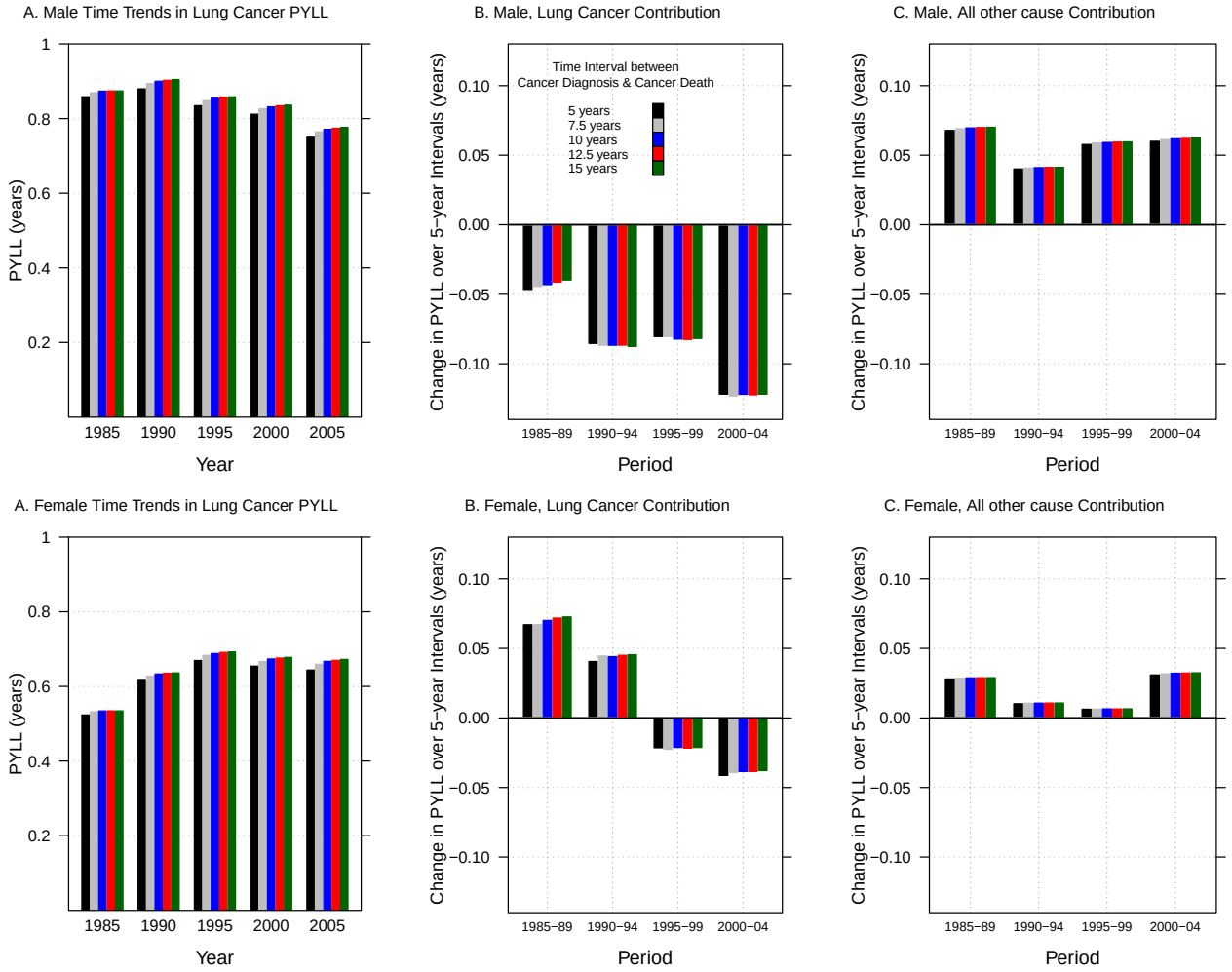
Male average person-years of life lost (PYLL) for specific cancers by year for whites (A) and blacks (C). Decomposition of changes in cancer-specific PYLL over 5-year intervals for whites (B) and blacks (D). Black bars indicate the change in PYLL, dark grey bars indicate the change in PYLL due to changes in cancer-specific mortality rates, and light grey bars indicate the change in PYLL due to changes in other-cause mortality rates. We do not report any sampling uncertainty in PYLL or in the decomposition of PYLL because our calculations utilize registry and vital statistics data that fully capture the mortality experience of defined populations. Note: PYLL, the average years of life lost per U.S. adult, equals the gain in life expectancy in the absence of deaths from cancer.

Supplementary Figure 3: Female Average Person-Years of Life Lost (PYLL) by Cancer Site, Race and Year, and Its Changes and Decomposition Over 5-Year Intervals: More Consistent Reductions in the Burdens of Colorectal and Breast Cancer for White than Black Females Since 1985



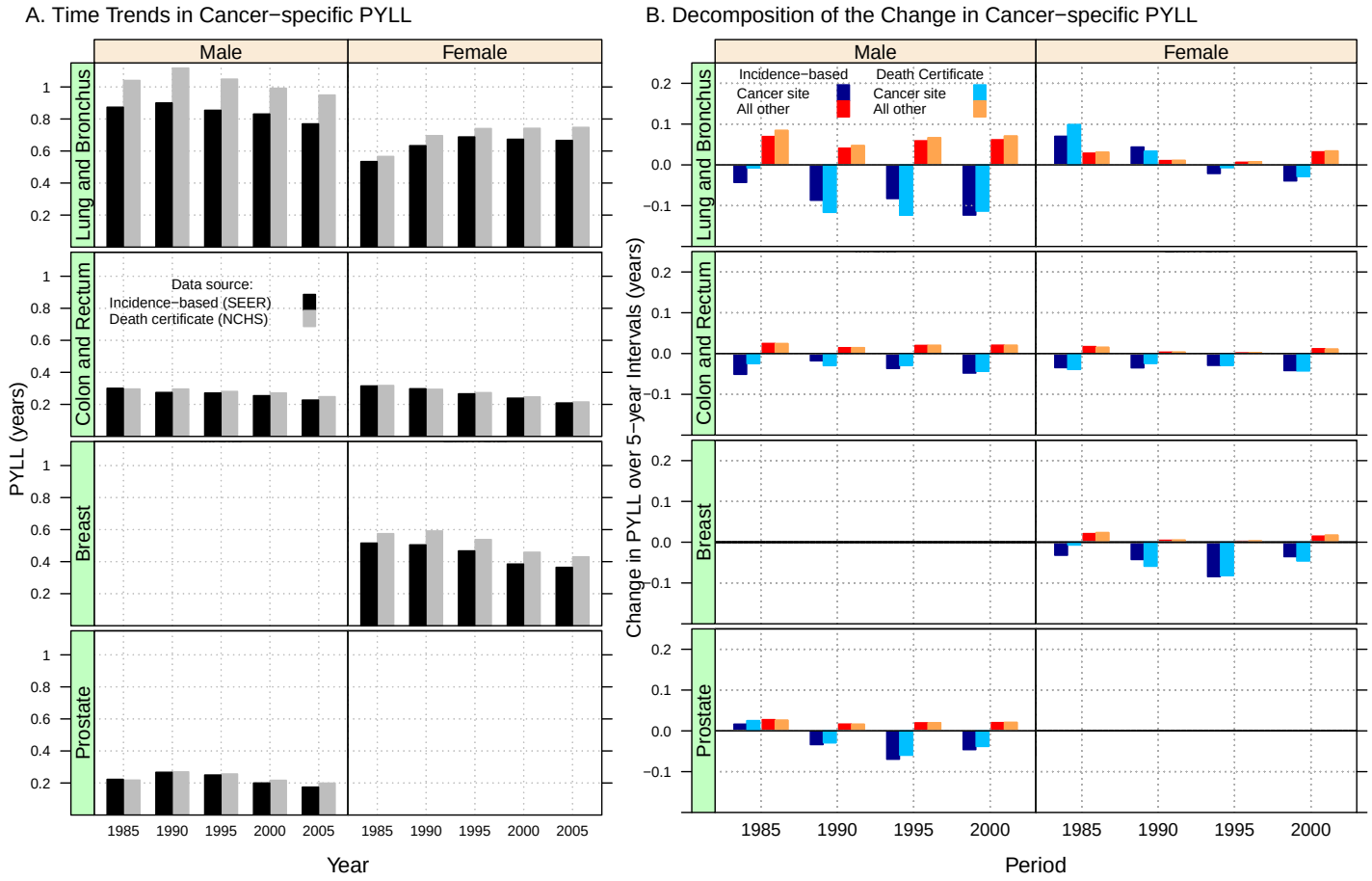
Female average person-years of life lost (PYLL) for specific cancers by year for whites (A) and blacks (C). Decomposition of changes in cancer-specific PYLL over 5-year intervals for whites (B) and blacks (D). Black bars indicate the change in PYLL, dark grey bars indicate the change in PYLL due to changes in cancer-specific mortality rates, and light grey bars indicate the change in PYLL due to changes in other-cause mortality rates. We do not report any sampling uncertainty in PYLL or in the decomposition of PYLL because our calculations utilize registry and vital statistics data that fully capture the mortality experience of defined populations. Note: PYLL, the average years of life lost per U.S. adult, equals the gain in life expectancy in the absence of deaths from cancer.

Supplementary Figure 4: Lung Cancer Average Person-Years of Life Lost (PYLL) for Males and Females and Their Decomposition Over 5-Year Intervals by Alternate Time Intervals Between Diagnosis of Cancer and Cancer Death, 1985−2005



A. Time trends in average person-years of life lost (PYLL) for lung cancer by time between diagnosis of cancer and cancer death. B. Contribution of lung cancer mortality rates to the change in PYLL over 5-year intervals. C. Contribution of all other cause mortality rates to the change in PYLL over 5-year intervals.

Supplementary Figure 5: Average Person-Years of Life Lost (PYLL) and Its Decomposition Over 5-Year Intervals over Time by Cancer Site, Sex and Mortality Data Source, 1985−2005



A. Time trends in average person-years of life lost (PYLL) for for specific cancers by sex and mortality data source. B. Decomposition of changes in cancer-specific PYLL over 5-year intervals.

Table 1: Cause of Death by International Classification of Disease (ICD)

Cancer	ICD-8 (1968-1978)	ICD-9 (1979-1994)	ICD-10 (1995+)
Breast	174	174	C50
Colon and Rectum	153, 154	153, 154	C18, C19, C20
Lung and Bronchus	162, 163	162, 163	C33, C34, C38.4, C45.0
Prostate	185	185	C61

Table 2: Trends in Average Person-Years of Life Lost (PYLL) by Cancer Site and Sex and Its Changes and Decomposition Over 5-Year Intervals 1985-2005

			Male						Female		
				Contribution to Δ PYLL						Contribution to Δ PYLL	
Year	PYLL	Period	Δ PYLL (2)-(3)	Other (2)	Cancer (3)	Year	PYLL	Period	Δ PYLL (2)-(3)	Other (2)	Cancer (3)
Lung						Lung					
1985	0.87	1985-89	0.03	0.07	0.03	1985	0.53	1985-89	0.10	0.03	0.10
1990	0.90	1990-94	-0.05	0.04	-0.05	1990	0.63	1990-94	0.05	0.01	0.05
1995	0.85	1995-99	-0.02	0.06	-0.02	1995	0.69	1995-99	-0.01	0.01	-0.01
2000	0.83	2000-04	-0.06	0.06	-0.06	2000	0.67	2000-04	-0.01	0.03	-0.01
2005	0.77					2005	0.67				
CRC						CRC					
1985	0.30	1985-89	-0.03	0.02	-0.03	1985	0.32	1985-89	-0.02	0.02	-0.02
1990	0.27	1990-94	0.00	0.01	0.00	1990	0.30	1990-94	-0.03	0.00	-0.03
1995	0.27	1995-99	-0.02	0.02	-0.02	1995	0.27	1995-99	-0.03	0.00	-0.03
2000	0.25	2000-04	-0.03	0.02	-0.03	2000	0.24	2000-04	-0.03	0.01	-0.03
2005	0.23					2005	0.21				
Prostate						Breast					
1985	0.22	1985-89	0.04	0.03	0.04	1985	0.52	1985-89	-0.01	0.02	-0.01
1990	0.27	1990-94	-0.02	0.02	-0.02	1990	0.51	1990-94	-0.04	0.00	-0.04
1995	0.25	1995-99	-0.05	0.02	-0.05	1995	0.47	1995-99	-0.08	0.00	-0.08
2000	0.2	2000-04	-0.03	0.02	-0.03	2000	0.39	2000-04	-0.02	0.02	-0.02
2005	0.17					2005	0.36				

Note: Δ=Change in; Other=All Other Causes.

Table 3: Trends in Average Person-Years of Life Lost (PYLL) by Cancer Site, Sex and Race and Its Changes and Decomposition Over 5-Year Intervals 1985-2005

Male						Female					
				Contribution to Δ PYLL						Contribution to Δ PYLL	
Year	PYLL	Period	Δ PYLL (2)-(3)	Other (2)	Cancer (3)	Year	PYLL	Period	Δ PYLL (2)-(3)	Other (2)	Cancer (3)
White Lung						White Lung					
1985	0.86	1985-89	0.04	0.07	0.03	1985	0.55	1985-89	0.11	0.03	-0.08
1990	0.90	1990-94	-0.05	0.04	0.09	1990	0.66	1990-94	0.07	0.01	-0.06
1995	0.85	1995-99	-0.03	0.05	0.08	1995	0.72	1995-99	-0.02	0.00	0.02
2000	0.83	2000-04	-0.07	0.06	0.12	2000	0.71	2000-04	-0.02	0.03	0.05
2005	0.76			2005	0.69						
White CRC						White CRC					
1985	0.3	1985-89	-0.03	0.03	0.05	1985	0.31	1985-89	-0.02	0.02	0.03
1990	0.27	1990-94	0.00	0.01	0.02	1990	0.30	1990-94	-0.04	0.00	0.04
1995	0.27	1995-99	-0.02	0.02	0.04	1995	0.26	1995-99	-0.03	0.00	0.03
2000	0.25	2000-04	-0.04	0.02	0.05	2000	0.23	2000-04	-0.03	0.01	0.04
2005	0.21			2005	0.20						
White Prostate						White Breast					
1985	0.22	1985-89	0.04	0.03	-0.01	1985	0.53	1985-89	-0.01	0.02	0.03
1990	0.26	1990-94	-0.02	0.02	0.03	1990	0.51	1990-94	-0.05	0.00	0.05
1995	0.24	1995-99	-0.05	0.02	0.07	1995	0.46	1995-99	-0.08	0.00	0.08
2000	0.19	2000-04	-0.03	0.02	0.05	2000	0.38	2000-04	-0.03	0.01	0.04
2005	0.16			2005	0.35						
Black Lung						Black Lung					
1985	1.10	1985-89	-0.10	0.03	0.13	1985	0.53	1985-89	0.06	0.03	-0.03
1990	1.01	1990-94	-0.05	0.03	0.08	1990	0.59	1990-94	0.00	0.00	0.00
1995	0.96	1995-99	-0.06	0.10	0.16	1995	0.59	1995-99	0.07	0.02	-0.05
2000	0.90	2000-04	-0.08	0.08	0.16	2000	0.66	2000-04	-0.02	0.04	0.06
2005	0.82			2005	0.64						
Black CRC						Black CRC					
1985	0.26	1985-89	0.00	0.01	0.01	1985	0.32	1985-89	0.03	0.02	0.00
1990	0.26	1990-94	-0.01	0.01	0.02	1990	0.35	1990-94	-0.04	0.00	0.04
1995	0.26	1995-99	0.03	0.03	0.00	1995	0.30	1995-99	-0.01	0.01	0.02
2000	0.29	2000-04	-0.02	0.03	0.05	2000	0.30	2000-04	-0.03	0.02	0.05
2005	0.27			2005	0.27						
Black Prostate						Black Breast					
1985	0.33	1985-89	0.05	0.02	-0.03	1985	0.52	1985-89	0.03	0.03	0.00
1990	0.38	1990-94	-0.01	0.01	0.02	1990	0.54	1990-94	0.04	0.00	-0.03
1995	0.37	1995-99	-0.04	0.05	0.09	1995	0.58	1995-99	-0.09	0.01	0.10
2000	0.34	2000-04	-0.03	0.04	0.07	2000	0.49	2000-04	0.00	0.03	0.02
2005	0.30			2005	0.50						

Note: Δ=Change in; Other=All Other Causes.