Age-Period-Cohort Analysis of Lung Cancer Mortality in Japan, 1960-1995

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The mortality data on lung cancer in Japan from 1960 to 1995 was analysed based on an age-period-cohort (APC) model. Though the APC model has an 'identifiable problem' caused by the relationship of age, period and cohort parameters, non-linear components of them revealed their original (separated) effects. They were: (1) non-linear age effects had a peak in 55-59 and 60-64 years old in males and 50-54 in females, (2) non-linear period effects were very small in both genders, (3) non-linear age and period effects were small enough to neglect compared with their linear effects, and (4) there were five parts of trends in Japanese lung cancer mortality in both genders in the non-linear birth cohort effects. The 1961-65 birth cohort effect seemed to increase differently from previous birth years. This trend should be monitored carefully.

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INTRODUCTION

In Japan, deaths caused by cancer have been increasing, and cancer has been the leading cause of death since 1981 3). Lung cancer especially is the leading cause of death in males and has the third highest mortality rate in females among all forms of cancer at the present. To reveal the temporal trends of age, period and birth cohort effects is of importance for providing clues or hypotheses for its aetiology. Components of age, period and birth cohort of death are three separate temporal factors related to the mortality of the cancer.

Each component bears a different biological meaning in the process of carcinogens with the multi-stage model 2,3). For example, exposure to early stage carcinogens (initiators) or diagnostic and therapeutic improvements will produce a period effect. Standard cross-sectional analysis of the trend, however, cannot separate age and period effects. In general, conventional birth cohort analysis is a mainly graphical approach and only can provide combined effects of the three time factors mentioned above. To differentiate them, a log linear model has been developed in the past two decades and applied to the analysis of various forms of cancer.

The earliest use of this form of modelling was Kermack et al 4) and Frost 5), and early works of development of this model were briefly summarized in Osmond and Gardner 6). Though Kupper 7,8) gave critiques of this model in the point of interpretation, this model has been developed by many authors. At present, the APC model is used for many studies 9-12) for its instructive usefulness.

In the APC model, the three time variables are not identifiable due to the exact linear relation:

birth year + age at death = calendar year at death (1)

Many methods have been developed to solve the problem, which are classified into roughly five groups at the present: (1) penalty function approach 6,10), (2) individual records approach 15), (3) autoregressive models 10), (4) Bayesian approach 17-19) and (5) estimable function approach 20,13,21,22) (deviation from linearity, curvature, drift). Once non-overlapping cohort or individual records looked to overcome 'nonidentifiability' 23,15),

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however, they did not solve it 24-26).

Estimable function approach was developed in three ways, (local) curvature approach 29 based drift model 27), non-linear component approach (deviation from linearity) 13 and extended curvature approach 22). In these three estimable function approaches, there is the relation where differences of successive non-linear components produce local curvatures. In the branch of this development, Osmond tried to predict future mortality based on the APC model 28 and Robertson and Bolye 29 tried a graphical approach. Tarone developed nonparametric evaluation of birth cohort trends 30 in the APC analysis. Recently, a few comparative studies recommended that the method based estimable function approach (5) was the most appropriate to the APC model 31,32).

In this study, mortality data of lung cancer in Japan over the period of 1960 to 1995 was analysed. Separated age, period and birth cohort effects were analysed and are presented using the APC model based on non-linear ‘deviation from linearity’ by Holford 13,33).

## MATERIALS AND METHODS

### Data Source

Lung cancer in this study was defined by the international detailed list code 162,163 (ICD-7) in 1960 and 1965, code 162 (ICD-8) in 1970 and 1975, code 162 (ICD-9) in 1980, 1985 and 1990, and code C33, C34 (ICD-10) in 1995. The cancer deaths data for the quinquennial years during 1960 to 1995 were obtained from Japanese Vital Statistics 1, summarized in a two-way, age by period contingency table with unequal person-years at risk in each cell in Table 1 in males and Table 2 in females. The death rates were calculated with the population data that were obtained from the eight successive national censuses of 1960, 1965, ..., 1990 and 1995 1. Age was divided into

### Table 1. Lung cancer mortality rates (per 100,000) among Japanese males, 1960-1995.

| Age(years) | 1960 | 1965 | 1970 | 1975 | 1980 | 1985 | 1990 | 1995 |
|------------|------|------|------|------|------|------|------|------|
| 30-34      | 0.694| 0.772| 0.769| 0.870| 0.872| 0.947| 1.002| 1.165|
| deaths     | 26   | 32   | 32   | 40   | 47   | 43   | 39   | 47   |
| expected   | (26) | (29) | (27) | (37) | (54) | (49) | (38) | (47) |
| 35-39      | 1.122| 1.788| 1.609| 1.862| 2.495| 2.895| 3.289| 2.597|
| deaths     | 31   | 67   | 66   | 78   | 114  | 156  | 148  | 101  |
| expected   | (47) | (73) | (78) | (76) | (105) | (149) | (131) | (102) |
| 40-44      | 2.726| 3.627| 4.551| 4.894| 5.027| 6.120| 6.750| 6.448|
| deaths     | 62   | 99   | 166  | 201  | 208  | 275  | 360  | 289  |
| expected   | (88) | (113)| (170)| (191)| (190)| (255)| (352)| (301) |
| 45-49      | 7.666| 8.451| 8.469| 11.432| 11.203| 11.283| 12.925| 14.311|
| deaths     | 173  | 188  | 225  | 416  | 450  | 451  | 578  | 757  |
| expected   | (180)| (199)| (251)| (393)| (448)| (435)| (567)| (765)|
| 50-54      | 15.779| 18.731| 20.141| 20.831| 26.365| 25.242| 22.977| 25.946|
| deaths     | 322  | 407  | 431  | 541  | 931  | 984  | 917  | 1140 |
| expected   | (329)| (389)| (422)| (551)| (888)| (980)| (930)| (1183)|
| 55-59      | 30.463| 32.013| 40.666| 43.886| 48.837| 53.609| 53.365| 47.119|
| deaths     | 549  | 618  | 825  | 903  | 1218 | 1818 | 2018 | 1831 |
| expected   | (549)| (674)| (772)| (882)| (1191)| (1854)| (1999)| (1858)|
| 60-64      | 46.537| 66.335| 71.533| 79.665| 96.021| 98.821| 112.972| 104.537|
| deaths     | 669  | 1078 | 1249 | 1533 | 1856 | 2321 | 3654 | 3761 |
| expected   | (680)| (1040)| (1259)| (1545)| (1808)| (2385)| (3616)| (3788)|
| 65-69      | 71.373| 93.119| 124.959| 139.352| 157.167| 179.061| 190.242| 202.257|
| deaths     | 733  | 1135 | 1741 | 2179 | 2726 | 3171 | 4165 | 6042 |
| expected   | (682)| (1111)| (1687)| (2182)| (2789)| (3207)| (4135)| (6100)|
| 70-74      | 86.942| 118.505| 156.627| 210.485| 252.723| 284.503| 300.337| 316.056|
| deaths     | 603  | 935  | 1501 | 2407 | 3316 | 4228 | 4675 | 6104 |
| expected   | (587)| (914)| (1498)| (2426)| (3318)| (4212)| (4782)| (6031)|
| 75-79      | 81.761| 126.142| 160.900| 238.261| 329.139| 403.130| 419.712| 454.564|
| deaths     | 308  | 570  | 854  | 1635 | 2784 | 4018 | 5022 | 5702 |
| expected   | (308)| (586)| (926)| (1651)| (2858)| (3939)| (5026)| (5600)|

* P<0.05, **P<0.01. Both were calculated from (obs-exp)^2/exp.
Table 2. Lung cancer mortality rates (per 100,000) among Japanese females, 1960-1995.

| Age(years) | 1960    | 1965    | 1970    | 1975    | 1980    | 1985    | 1990    | 1995    |
|------------|---------|---------|---------|---------|---------|---------|---------|---------|
| 30-34      | 0.849   | 0.852   | 0.840   | 0.740   | 0.771   | 0.400   | 0.707   | 0.915   |
| deaths     | 32      | 35      | 35      | 34      | 41      | 18      | 27      | 36      |
| expected   | (22)*   | (26)*   | (28)*   | (34)*   | (46)*   | (38)**  | (28)*   | (36)*   |
| 35-39      | 1.252   | 1.786   | 1.205   | 1.743   | 1.702   | 1.779   | 1.979   | 1.728   |
| deaths     | 41      | 67      | 49      | 73      | 78      | 95      | 88      | 66      |
| expected   | (43)*   | (55)*   | (56)*   | (65)*   | (85)*   | (103)*  | (84)*   | (65)*   |
| 40-44      | 1.785   | 2.692   | 2.897   | 2.450   | 2.910   | 3.251   | 3.103   | 3.811   |
| deaths     | 49      | 87      | 106     | 100     | 121     | 149     | 164     | 169     |
| expected   | (66)*   | (84)*   | (90)*   | (100)*  | (125)*  | (148)*  | (179)*  | (153)*  |
| 45-49      | 4.922   | 3.893   | 5.184   | 5.420   | 5.122   | 5.308   | 5.689   | 7.231   |
| deaths     | 126     | 105     | 165     | 200     | 207     | 220     | 257     | 380     |
| expected   | (113)   | (140)** | (152)   | (177)   | (207)   | (239)   | (280)   | (353)   |
| 50-54      | 6.387   | 9.295   | 8.001   | 9.397   | 9.590   | 9.310   | 10.398  | 12.316  |
| deaths     | 138     | 231     | 211     | 296     | 349     | 373     | 424     | 551     |
| expected   | (166)*  | (226)*  | (239)*  | (277)*  | (347)*  | (373)*  | (424)*  | (522)*  |
| 55-59      | 10.495  | 14.144  | 14.201  | 15.942  | 15.899  | 16.349  | 15.665  | 18.179  |
| deaths     | 193     | 293     | 337     | 413     | 491     | 587     | 616     | 732     |
| expected   | (208)   | (300)   | (346)   | (397)   | (499)   | (573)   | (612)   | (726)   |
| 60-64      | 16.733  | 20.705  | 24.543  | 23.257  | 27.374  | 27.895  | 25.277  | 26.532  |
| deaths     | 250     | 356     | 482     | 544     | 687     | 844     | 885     | 1021    |
| expected   | (229)   | (364)   | (451)   | (571)   | (698)   | (807)   | (923)   | (1026)  |
| 65-69      | 22.057  | 27.839  | 32.017  | 35.847  | 42.112  | 43.276  | 42.736  | 41.764  |
| deaths     | 250     | 374     | 506     | 671     | 932     | 1044    | 1240    | 1414    |
| expected   | (226)   | (366)   | (504)   | (684)   | (931)   | (1052)  | (1215)  | (1453)  |
| 70-74      | 23.327  | 35.895  | 41.302  | 51.052  | 63.705  | 65.637  | 69.278  | 64.449  |
| deaths     | 203     | 343     | 483     | 727     | 1083    | 1352    | 1561    | 1768    |
| expected   | (208)   | (335)   | (475)   | (715)   | (1061)  | (1346)  | (1527)  | (1853)  |
| 75-79      | 25.434  | 41.767  | 46.659  | 58.493  | 84.390  | 94.314  | 99.618  | 109.032 |
| deaths     | 147     | 269     | 343     | 556     | 1000    | 1392    | 1811    | 2205    |
| expected   | (147)   | (264)   | (375)   | (593)   | (991)   | (1396)  | (1801)  | (2156)  |

* P<0.05, **P<0.01. Both were calculated from \((\text{obs-exp})^2/\exp\).

10 quinquennia; 30-34, 35-39, ..., 75-79 years old. Person-years in each census year were estimated by the population data in that year.

The diagonals of these tables (from upper left to lower right) define birth cohorts with five-year intervals, each of which is referred to by its central year. For example, individuals aged 30-34 who died in the 1960 calendar year, could have been born at any time between 1926 and 1930; this is the 1928 birth cohort. A total of 17 birth cohorts were obtained: 1883(1881-1885), 1888(1886-1890), ..., 1963(1961-1965).

Statistical Model

Assuming that a hazard model in which the hazard function \(\lambda_i(t)\) for the \(k\)-th cohort \((k=1, ..., K)\) of the proportional form,

\[
\lambda_i(t) = \exp(\gamma_i) \exp(\beta_i) \lambda_0(t),
\]

where \(t\) is the age of the individual, \(\gamma\), is the effect due to the \(k\)-th birth cohort, \(\beta_i\) is the effect due to the \(j\)-th period \((j=1, ..., J)\) and \(\lambda_0(t)\) is some underlying hazard function. When the number of person-years \(N_{ij}\) in the \((i, j)\) cell \((i=1, ..., I, j)\) are fixed, then the numbers of deaths \(d_{ij}\) have independent Poisson distributions and the APC model with additive effects on the logarithmic mortality rate is derived. The parametric form will be:

\[
\log \rho_i = \mu + \alpha_i + \beta_j + \gamma, \quad (3)
\]

\[
\sum \alpha_i = \sum \beta_j = \sum \gamma = 0, \quad (4)
\]

where \(\mu\) is the overall mean, \(\alpha_i\) denotes effect of the \(i\)-th age group, and \(\rho_i = E(d_{ij}/N_{ij})\). The relation between the three indices \(i, j\) and \(k\) is given by \(k=I+i+j\). This yields \(K=I+J-I\), immediately.

It is well known that the model with all three time factors have suffered from 'identifiable problem' due to the relation \(k=I+i+j\). To avoid this confusion, the non-linear components (deviation from linearity) of being estimable indices based on Holford \(10\) were adopted by removing the linear effects from
full effects. For a full effect \( a \), the non-linear component (deviation from linearity) of \( a \), is defined by,

\[
\tilde{a}_i = a_i - \omega(i, I) a_i^1,
\]

(5)

where \( \omega(x, y) = x - (y+1)/2 \) and \( a_i^{1} = \sum \omega(i, I) a_i / \sum \omega(i, I)^2 \).

Using \( A_s(i) \), \( s=1,...,1-2 \) which are orthogonal to the \( \omega(i, I) \), (i.e. \( \sum A_s(i) \omega(i, I) = 0 \) for every \( s \)), non-linear components of \( a_i \) are also derived to,

\[
\tilde{a}_i = \sum A_s(i) a_i^{s},
\]

(6)

where \( a_i^s \) represents the parameter associated with column of the \( I \times (1-2) \) design matrix in which each element is \( A_s(i) \). Non-linear period and cohort effects \( \beta_i \) and \( \gamma_i \) are derived in a similar manner with orthogonal components \( B_s(i) \), and \( C_s(i) \), respectively. All \( 2(I+1)I+3 \) parameters in the log linear components \( (\mu, \alpha^0, \alpha^\text{max}, ..., \alpha^I, \beta_0^0, \beta_0^1, ..., \beta_0^I, \gamma_0^0, \gamma_0^1, ..., \gamma_0^I) \), with corresponding overall design matrix being \( (1, \omega(i, I), A(i), ..., A_{i5}(i), \omega(j, J), B(i), ..., B_{j2}(i), \omega(k, K), C(i), ..., C_{k2}(i)) \) for any \( i \)-th row. Here we obtained the APC model with non-linear components,

\[
\log \rho_i = \mu + (\alpha + \omega(i, I) \alpha^0) + (B_{0} + \omega(j, J) B_{0}) + (\gamma_{0} + \omega(k, K) \gamma_{0}) + (\sigma + \omega(l, L) \sigma) + \epsilon_i.
\]

(7)

The identifiable problem extracted here is that if \( \alpha^0, B_0^0 \) and \( \gamma_0^0 \) were a solution of linear trends of the APC model then \( \alpha^0 + t, B_0^0 - t \) and \( \gamma_0^0 + t \) could be another solution for arbitrary \( t \). There arises the problem of identifiable parameters, whereas all non-linear components and the following combination of linear trends \( d_i, \alpha^0_i + d_i, B_0^0_i + (d_i - d_i) \gamma_0^0_i \) for arbitrary \( d_i, d_i \) were shown to be estimable. The maximum likelihood method was used to estimate parameters in this study. The goodness of fit was examined by the likelihood ratio statistic \( G^2 \) and by predicted values of death numbers.

RESULTS

The APC model gave a predicted value (in parentheses) in each cell as shown in Table 1 in males and Table 2 in females. The differences between observed and expected numbers of deaths from lung cancer were not excessive. Five out of eighty cells gave significant differences (\( P<0.05 \)) in both genders. Only one cell was \( P<0.01 \) in males and two were in females. The maximum of the differences between observed and expected numbers were 107(2.2% of expected value) in the cell of age 70-74 in 1990 in males, 85(4.6%) in the cell of age 70-74 in 1995 in females. The deviance was 81.6 with 48 degrees of freedom in males (\( P=0.001 \)), and 97.6 with 48 degrees of freedom in females (\( P<0.0001 \)). The \( \chi^2 \) values were significant, however this was partly due to the large number of deaths which enable us to detect even small departures from the model. Table 3 indicates a summary of the data when a subset of the factors is used. The proportion of the lack of fit which was not explained by age was 99.1% in males and 94.9% in females for the age-period-cohort models, as shown by \( R^2 \) in Table 3.

Estimated parameters derived from the APC model were shown in Table 4. Age 30-34, calendar year 1960 and birth cohort 1883 was set as a standard criterion for the comparison. Linear trends of \( \alpha^0, B_0^0 \) and \( \gamma_0^0 \) could not be separated, however projection by extinguishing one of three effects eased interpretation. Linear effects of age and period and their non-linear effects were obtained under the assumption that linear birth cohort effects were zero. Non-linear effect expresses the original change pattern in each effect, and full effect which is the sum of linear and non-linear effect expresses trends of the risk of lung cancer. The patterns of non-linear age effects were convex with maximal effects laying on the 55-59 and 60-64 age categories in males and aged 50-54 in females. Non-linear age effects were considered small enough to neglect compared with their linear effects. Non-linear period effects were originally small and close to zero. Full effects of age and period were considered to change linearly. To compare the gradients, the increasing risk of age is 6.45 times greater in males and 6.56 times greater in females than that of period.

Non-linear birth cohort effects indicated interesting patterns (Figure 1). These effects increased until the 1908 birth cohort in both genders. The parameters decreased from the 1908 birth cohort to 1938 in males and 1933 in females. They had a second increase period from 1938 to 1948 in males, and 1933-1943 in females. They decreased and showed upward at 1958 again. The birth cohort effect was observed to have five points

| Table 3. Summary chi square of age(A), period (P) and birth cohort(C) models for data in Table 1 and Table 2. |
|---------------------------------------------------------------|
| **Males** | **Females** |
| Model | df | \( G^2 \) | \( R^2 \) | \( G^2/df \) | df | \( G^2 \) | \( R^2 \) | \( G^2/df \) |
| A,P,C | 48 | 81.589 | 0.991 | 1.700 | 48 | 97.562 | 0.949 | 2.033 |
| A,P | 63 | 1223.824 | 0.993 | 19.426 | 63 | 519.567 | 0.731 | 8.247 |
| A,C | 54 | 140.462 | 0.985 | 2.601 | 54 | 118.451 | 0.939 | 2.194 |
| A | 70 | 9251.807 | 0.985 | 2.601 | 70 | 1929.221 | 0.939 | 2.194 |
Table 4. Age, period and cohort effects for age-period-cohort model.

Males

| Age (years) | AGE(L) | AGE(N) | Age effects | Birth cohort effects(N) |
|-------------|--------|--------|-------------|------------------------|
| 30-34       | 0.000  | 0.000  | 0.000       | 0.779                  |
| 35-39       | 0.622  | 0.273  | 0.895       | 0.778                  |
| 40-44       | 1.244  | 0.412  | 1.656       | 0.838                  |
| 45-49       | 1.866  | 0.498  | 2.364       | 0.854                  |
| 50-54       | 2.488  | 0.553  | 3.040       | 0.881                  |
| 55-59       | 3.110  | 0.573  | 3.683       | 0.873                  |
| 60-64       | 3.732  | 0.563  | 4.295       | 0.702                  |
| 65-69       | 4.354  | 0.467  | 4.821       | 0.515                  |
| 70-74       | 4.975  | 0.272  | 5.247       | 0.331                  |
| 75-79       | 5.597  | -0.053 | 5.544       | 0.000                  |

L denotes linear effects and N denotes non-linear effects. \( \mu = 12.653 \).

Means of non-linear age, period and cohort effects are 0.356, 0.004 and 0.593, respectively.

Females

| Age (years) | AGE(L) | AGE(N) | Age effects | Birth cohort effects(N) |
|-------------|--------|--------|-------------|------------------------|
| 30-34       | 0.000  | 0.000  | 0.000       | 0.588                  |
| 35-39       | 0.479  | 0.271  | 0.750       | 0.664                  |
| 40-44       | 0.957  | 0.290  | 1.247       | 0.767                  |
| 45-49       | 1.436  | 0.397  | 1.832       | 0.794                  |
| 50-54       | 1.914  | 0.451  | 2.365       | 0.810                  |
| 55-59       | 2.393  | 0.424  | 2.816       | 0.750                  |
| 60-64       | 2.871  | 0.384  | 3.255       | 0.614                  |
| 65-69       | 3.350  | 0.293  | 3.643       | 0.488                  |
| 70-74       | 3.828  | 0.192  | 4.021       | 0.292                  |
| 75-79       | 4.307  | 0.067  | 4.374       | 0.000                  |

L denotes linear effects and N denotes non-linear effects. \( \mu = 12.653 \).

Means of non-linear age, period and cohort effects are 0.277, 0.040 and 0.531, respectively.

DISCUSSION

It is unfortunate that Japan has not started a cancer registry system at the national level. As a result, for a longer trend analysis, mortality seems to be the only indicator. The most prominent weakness of mortality data is the impossibility of separating factors of incidence and improvement of medical technology (length of case-fatality). In the case of lung cancer, incidence rate and mortality rate are considered to be almost parallel because of the little improvement in medicine for survival.
In the APC model, the interpretation of changes of pattern of birth cohort effects is difficult. One way to interpret is to observe the pattern of change of non-linear effects.

Full effects of age and period were shown to change linearly because of small influence of their non-linear effects compared with linear ones. Averaged change rate of full effects of age and period by moving five years were 0.544 and 0.107, respectively. Increasing risk by aging was almost five times larger than that by changing period. In contrast, non-linear birth cohort effects had enough values not to be neglected. The birth cohort effects had unique patterns, differently from age and period effects.

Non-linear birth cohorts between the periods with minimal values and maximal values (1938-1948 in males and 1933-1943 in females) had peculiar patterns. Persons who were born in those periods had their main growth period in the middle of World War II (1940-1945). There may be some characteristics for these changing patterns. The first pattern, before 1903 in males and before 1908 in females, might be considered rapid modernization in Japan in the Meiji era. The second pattern of change to decrease in 1903-1938 in males and in 1908-1933 in females, were considered as the first success of activities of promoting hygiene and public health in Japan. The third pattern of change to increase in 1938-1948 in males and in 1933-1943 in females, might be due to wars in the early Showa era. The peculiarity in this period was also reported for diabetes mellitus, ischemic heart disease, cirrhosis of the liver and suicide. The fourth pattern of decrease in 1948-1958 in males and in 1943-1958 in females might be improvement of hygiene and public health after World War II. The fifth pattern after 1958 should be interpreted cautiously. After 1960, Japan faced a so-called 'high speed economic growth period'. Because of the high industrial growth in this period, the environmental pollution by chrome, nickel, asbestos and nitrosamines were
higher level than at present, (but the nitrosoxide level has
remained almost a constant level) 35. Many everyday foods
containing chemical substances with high fat and high choles-
terol 36 have also emerged in this period. Based on these points,
monitoring may be necessary for 1958 birth cohort and later.
In this analysis, however, the effect of 1958 birth cohort is the
last time frame that was analysed. The possibility that the result
was caused by a random fluctuation cannot be denied, because
the effect of the 1958 birth cohort was only estimated from the
one cell, that was 30-34 years old in 1995.

To analyse temporal trends of mortality and incidence rates,
APC analysis is one of the more popular tools. However con-
ventional APC analysis has suffered from the identifiable prob-
lem, which causes difficulties with interpretation of the results,
because of an unreasonable additional assumption. The method
to separate common linear effects and original non-linear
effects is reasonable in the technical sense. To interpret the
results is still not easy, however, meaningful reasonable results
can be obtained. Conventional univariate analysis based on
standardised mortality ratio (SMR) or comparative mortality
figure (CMF) in period effects (differences of both indices
were examined 37) and standardised cohort mortality ratio
(SCMR) or comparative cohort mortality figure (CCMF) in
birth cohort effects is the other tools. These methods clarify the
trend of only one of the effects by using the above annual
indices. So these results have been believed to easily interpret-
ated. However these methods could not separate the three linear
effects of age period and cohort.

Hamajima et al 38 developed another model based on a
Weibull hazard function with each birth cohort effect as a con-
stant to analyse the single birth cohort effect and to predict the
future risks. According to the Hamajima model, the birth
cohort effect of 1896-1900 and 1931-35 were 0.0805 and
0.2181, respectively. The corresponding logarithms of the full
birth cohort effects in males in the APC model were 1.0854
and 1.9209, respectively. The increasing birth cohort effect is
2.57 times in the Hamajima model, and 2.31 times in our
model, which are almost equivalent. The advantages in using
the APC model compared to his model are: (1)The assumption
in our model is less strict meaning not to have common mortal-
ity distribution on each year,(2) The birth cohort effects in our
model are estimated by considering the other two effects
simultaneously.

As is well known, lung cancer is related to cigarette smok-
ing. Recently the quantitative relationship between cumulative
cigarette consumption and lung cancer mortality was recog-
nized by linear regression analysis between the estimated
adjusted cumulative cigarette consumption and the lung cancer
death rate in each age group (20-24,...,70-74) 39). Consideration
between cigarette smoking and lung cancer based on our
model is interesting. With the exception of the period during
World War II, cigarette sales in Japan have steadily increased
and smoking prevalence has been decreasing in males and
almost constant in females since the 1960's when statistics
started to be gathered(Figure. 3). To simplify this situation,
annual smoking amounts can be estimated by the product of
national cigarette sales and smoking prevalence. The respec-
tive vales were 107.4 billion, 75.9% in males, 12.4% in
females in 1960, and 328.9 billion, 60.4% in males and 13.3%
in females in 1992. These logarithms of changes are 0.89 in
males and 1.19 in females. Our period effect in 1995 is 0.859
in males and 0.666 in females. In males the APC model was

![Figure 3. The trend of national cigarette sales and smoking prevalence in Japan.](image-url)

...
considered to support the relation. The factors that cause this difference in females might be the daily smoking amounts per day or the method of inhaling.

Another interesting problem is that of area difference. In our model we consider Japan as a unit, though there is considered to be area variation. According to Kano et al. 40, Saitama males and Fukushima males had the highest lung cancer death rate in 1960 and Okinawa males and Oita females in 1980. The major change of age-adjusted death rates from 1960-1980 were observed in Kagoshima, Tokushima and Wakayama, in males; and Shimane, Oita and Kagawa in females.

APC analysis based on estimable function could separate linear effects and non-linear effects. Linear effects are recognized as common effects (impossible to separate). Non-linear effects are original effects of time factors. The best way to interpret the APC model at the present is to reveal changing patterns with estimable parameters, and if necessary, to add linear effects obtained by one of three effects extinguished to zero. This method shows that the APC analysis produces more precise and reasonable results than conventional analyses (summarised indices or two parameters AP, AC model). Estimators from conventional analyses have non-negligible problems: (1) The pattern depends on the ways of taking a standard population, (2) Incomplete cells based on missing values in the birth cohort gave less precise SCMRs (CCMFs), (3) Two way model (age-period, or age-cohort) gave no information for the other component. The APC model overcomes these ambiguities. So, this model is considered effective although there have been many criticisms.

CONCLUSION

The mortality of lung cancer in Japan based on the APC model revealed that there are five changing patterns in the birth cohort effects in Japanese lung cancer mortality. The 1938, 1943 and 1948 birth cohort in males and 1933, 1938 and 1943 birth cohort in females were peculiar patterns. Successive birth cohorts need to be monitored for increased risk. Future prevention activities will be based on need, if risk increases in these birth cohorts.

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