Forecasting Future Mesothelioma Incidences

Modern Peto Model

October 4, 2011

RPC
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Executive Summary

- ARPC implemented the "Modern Peto" model
- Used nationally representative incidence data for males and females, 1973-2007
- Forecasted incidences for 2008-2050
- The estimated model fits the data well (R^2 = 85%)
- 72,012 additional mesothelioma cases are forecasted for the period 2008 through 2050 (actual number of cases from 1973 through 2007 was 85,419)

Data

- Mesothelioma Incidence Data
  - The National Cancer Institute (NCI) administers a data collection program called Surveillance, Epidemiology and End Results (SEER)
  - A division of the Centers for Disease Control and Prevention (CDC), called National Program of Cancer Registries (NPCR) publishes data referred to as United States Cancer Statistics (USCS)
- Population Data
  - Historical population counts were downloaded from the SEER website
- Mortality Tables
  - Social Security Administration

Data Processing

- The model requires incidences by single year of age, whereas some of the data is more aggregated
  - Used cubic spline interpolation to fill in missing data
- Disparate population coverage in the various datasets
  - Scaled SEER data to make them nationally representative
- SEER data might be biased given the nonrandom location of registries
  - Scaled SEER data to match the (unbiased) USCS data for the period of overlap
- Forecasted US population by age, from 2008 through 2050, using mortality tables

Modern Peto Model

- A model with epidemiological foundations
  - The incidence rate is determined by the cumulative weighted exposure to asbestos
- The model follows closely the literature
  - Hodgson et al. (2005)
  - Tan and Warren (2009)

Number of incidences

- $Y_{A,T}$: The number of incidences at age A and year T is a random variable that follows a Poisson-distribution with mean $\lambda_{A,T}$

$$\Pr\left(Y_{A,T} = y\right) = \frac{e^{-\lambda_{A,T}}\left(\lambda_{A,T}\right)^{y}}{y!} \qquad \text{for } y = 0,1,2,\ldots$$

- The likelihood of the data can be written as

$$L = \prod_{A,T} \frac{e^{-\lambda_{A,T}}\left(\lambda_{A,T}\right)^{Y_{A,T}}}{Y_{A,T}!}$$

Mean incidence rate

- Mean number of incidences is determined by the following formula

$$\lambda_{A,T} = (r_{A,T} + b) * Pop_{A,T}$$

  - $r_{A,T}$ incidence rate due to asbestos exposure
  - b background incidence rate
  - $Pop_{A,T}$ population size of age A in year T

Incidence rate due to asbestos exposure

- The incidence rate due to asbestos exposure is determined by a theoretical model of cumulative asbestos exposure

$$r_{A,T} = \sum_{t=0}^{A} D_{T-t} W_{A-t} * \max(t - L, 0)^{k}$$

  - D_T Overall population exposure in year T
  - W_A Exposure potential at age A
  - L Latency (assumed to be 10 years)
  - k exponent of time since exposure

Exposure to asbestos

- How to model the exposure variables?
  - Overall population exposure (D_T)
  - Age-specific exposure potential (W_A)
- D_T was assumed to be a non-parametric function
  - We picked 11 gridpoints: 1910, 1920, 1925, 1930, 1940, 1950, 1960, 1970, 1980, and 1990.
  - The 11 associated function values were estimated
  - Other function values were determined by piecewise cubic interpolation
- W_A was assumed to be a parametric beta function
  - This function has two free parameters. We assumed symmetry: $W_\alpha = W_\beta$, so only one parameter had to be estimated

Maximum Likelihood Estimation

- Estimate the model by maximum likelihood

$$L(\theta) = \prod_{A,T} \frac{e^{-\lambda_{A,T}(\theta)} \left(\lambda_{A,T}(\theta)\right)^{Y_{A,T}}}{Y_{A,T}!}$$

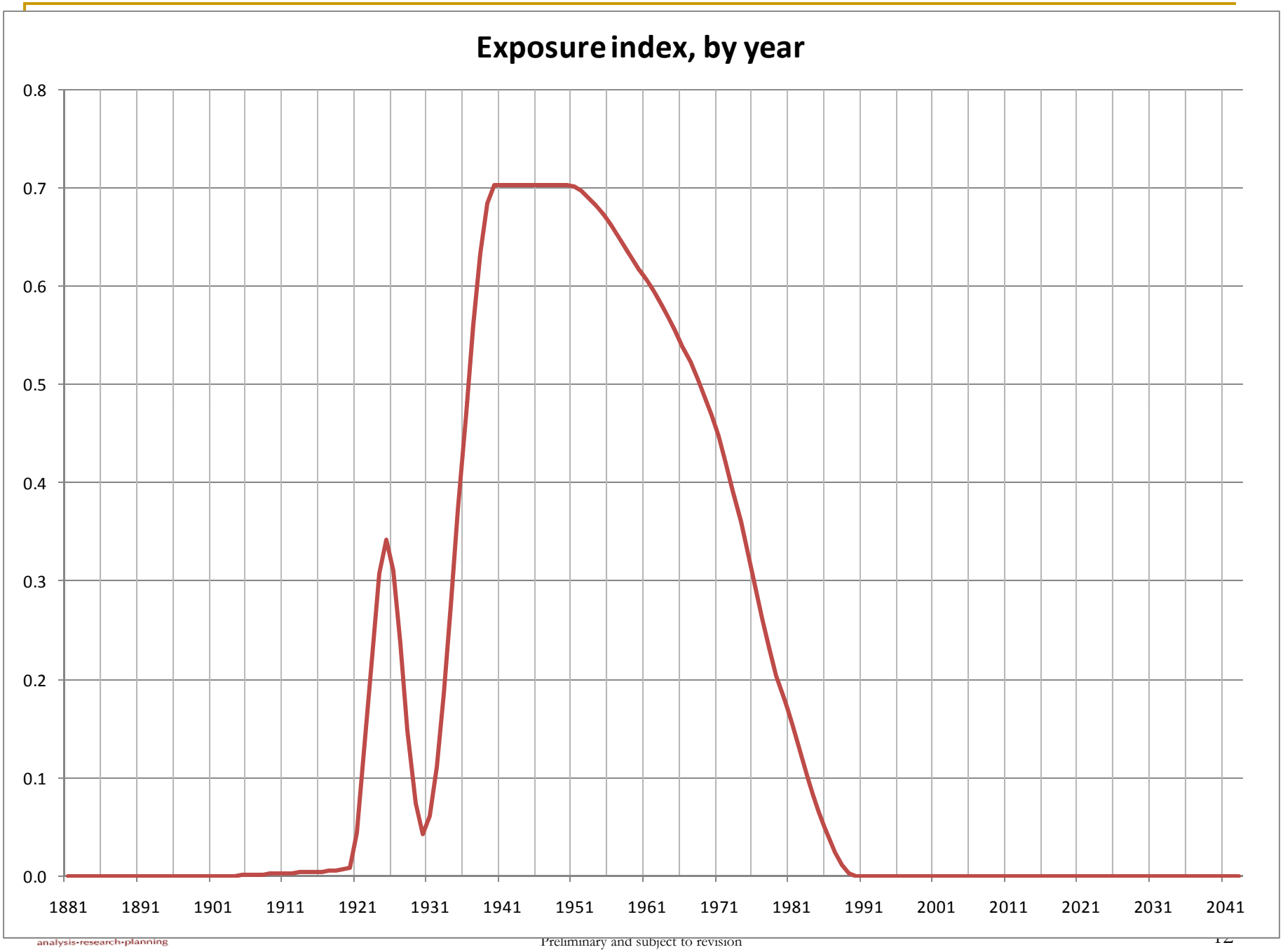
$$\log L(\theta) = \sum_{A,T} -\lambda_{A,T}(\theta) + Y_{A,T} \log\left(\lambda_{A,T}(\theta)\right) - \log\left(Y_{A,T}!\right)$$

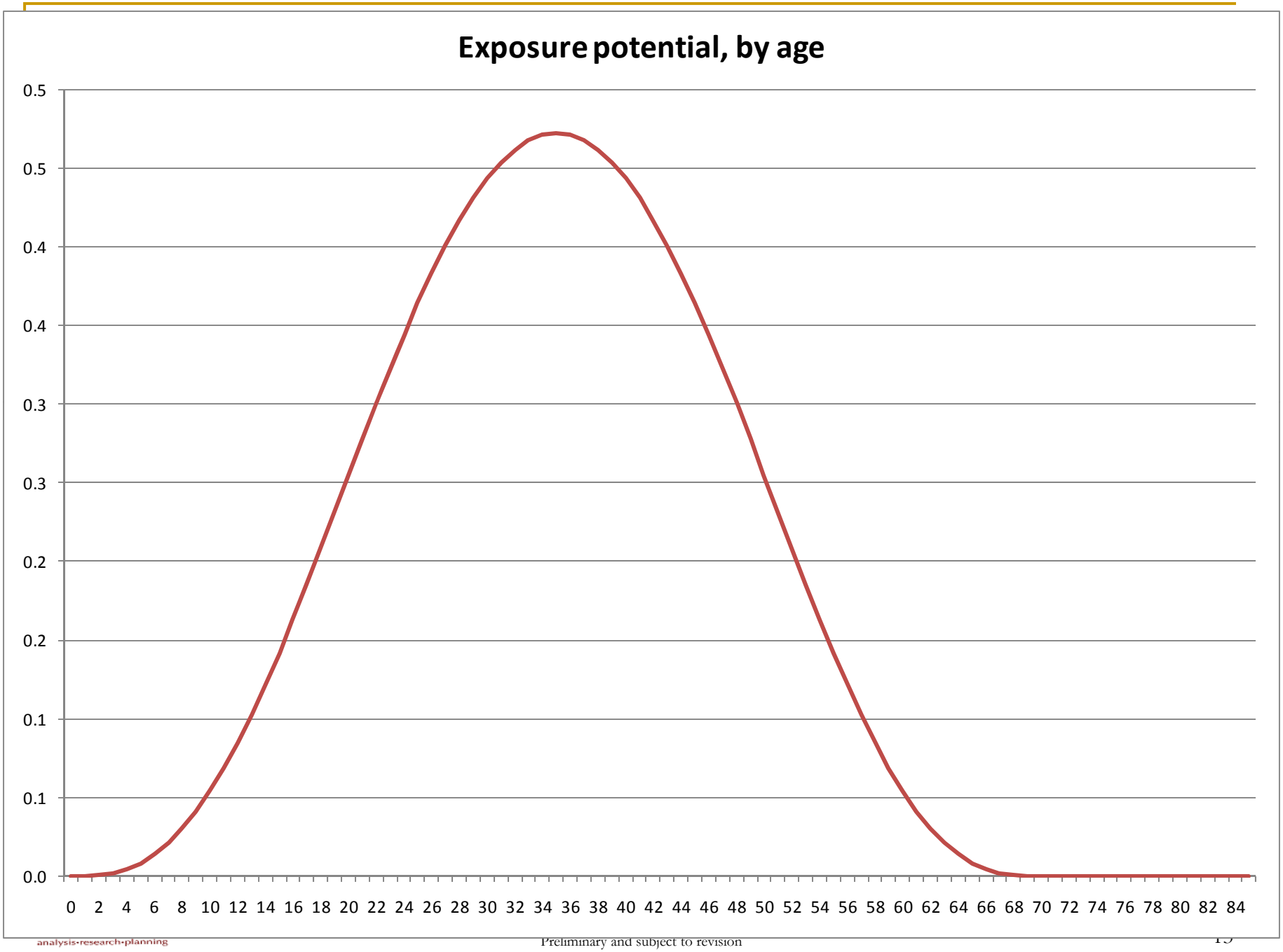
Parameter estimates

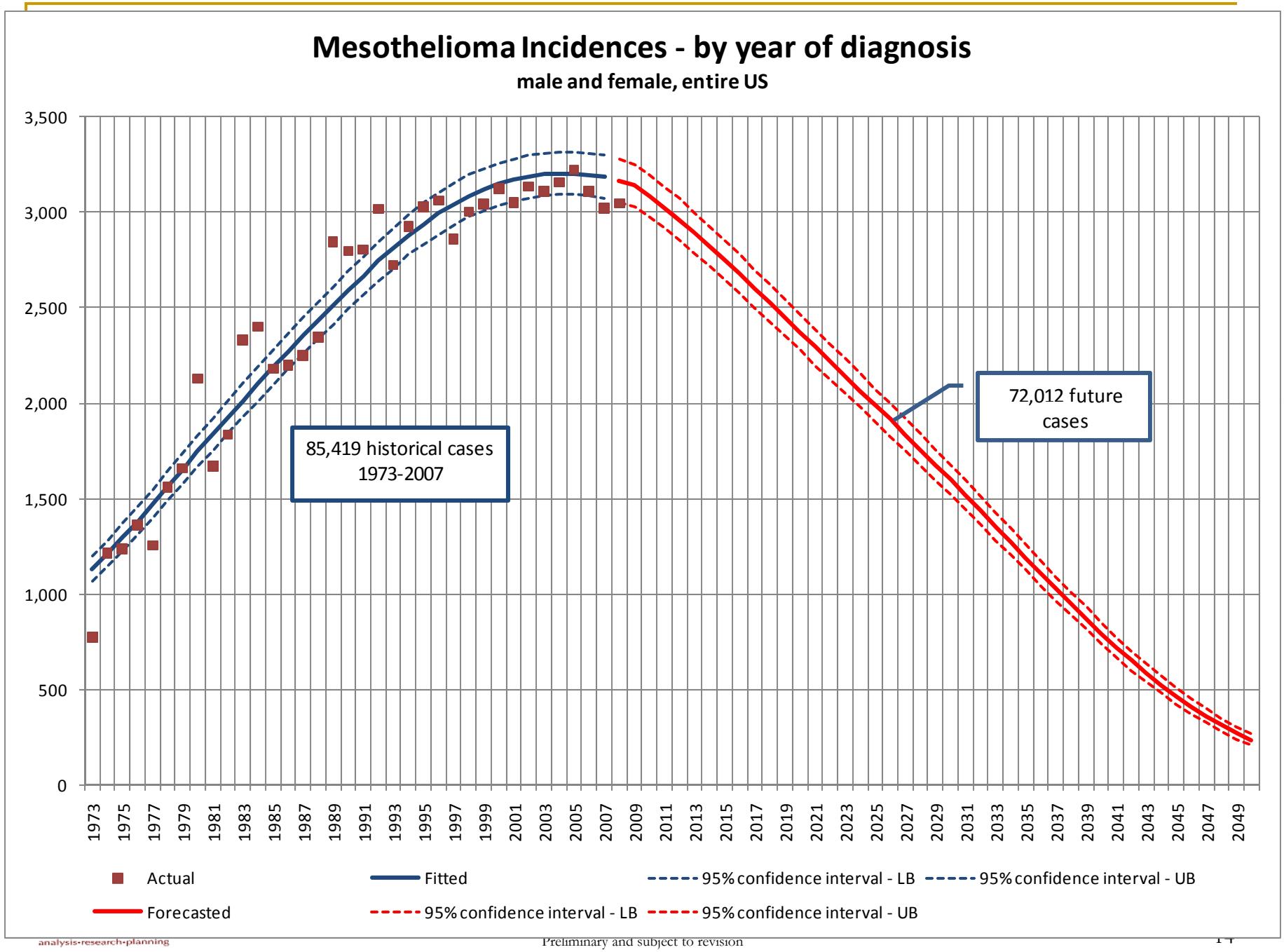
Number of observations: 3,255
Pseudo-R^2: 0.85

Parameter	Coefficient	95% Confidence Interval	
		Lower Bound	Upper Bound
D_1910	0.0029	0.0000	0.0638
D_1920	0.0082	0.0000	0.0727
D_1925	0.3422	0.0753	0.4358
D_1930	0.0428	0.0000	0.3468
D_1940	0.7019	0.5030	0.8748
D_1950	0.7019	0.5363	0.9008
D_1960	0.6171	0.4834	0.8016
D_1970	0.4690	0.3521	0.5911
D_1980	0.1795	0.1088	0.2607
D_1990	0.0000	0.0000	0.0000
W_alpha = W_beta	3.0387	2.7522	3.3391
k	1.8928	1.8434	1.9492
b	0.0566	0.0486	0.0639

Note: Confidence intervals determined by parametric bootstrap (200 random draws)


Exposure index, by year
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1881
1891
1901
1911
1921
1931
1941
1951
1961
1971
1981
1991
2001
2011
2021
2031
2041


Exposure potential, by age
0.5
0.5
0.4
0.4
0.3
0.3
0.2
0.2
0.1
0.1
0.0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78 80 82 84


Mesothelioma Incidences - by year of diagnosis
male and female, entire US
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
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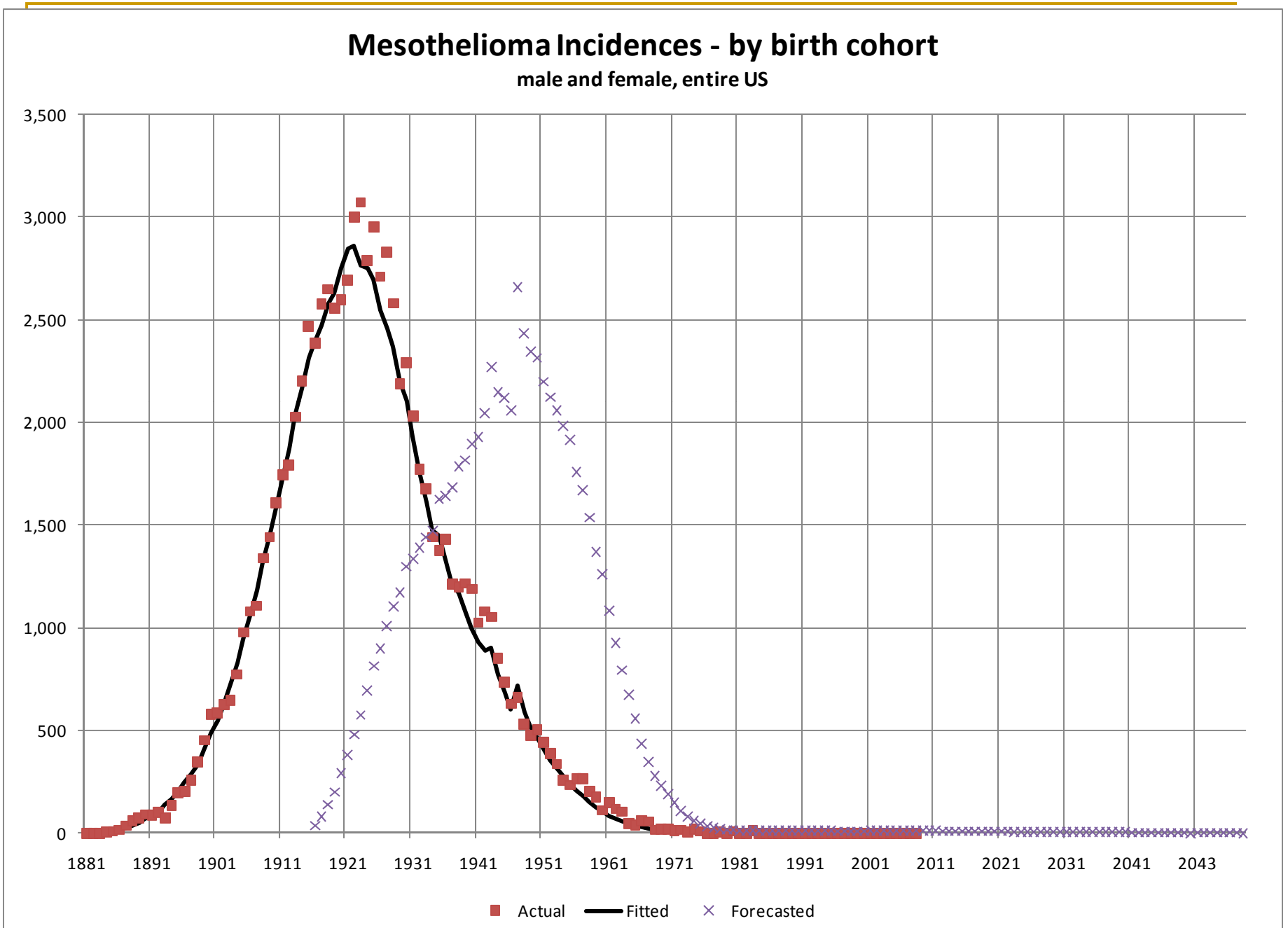
2005
2007
2009
2011
2013
2015
2017
2019
2021
2023
2025
2027
2029
2031
2033
2035
2037
2039
2041
2043
2045
2047
2049
85,419 historical cases
1973-2007
72,012 future
cases
Actual
Fitted
95% confidence interval - LB
95% confidence interval - UB
Forecasted
95% confidence interval - LB
95% confidence interval - UB


Mesothelioma Incidences - by birth cohort
male and female, entire US
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1881
1891
1901
1911
1921
1931
1941
1951
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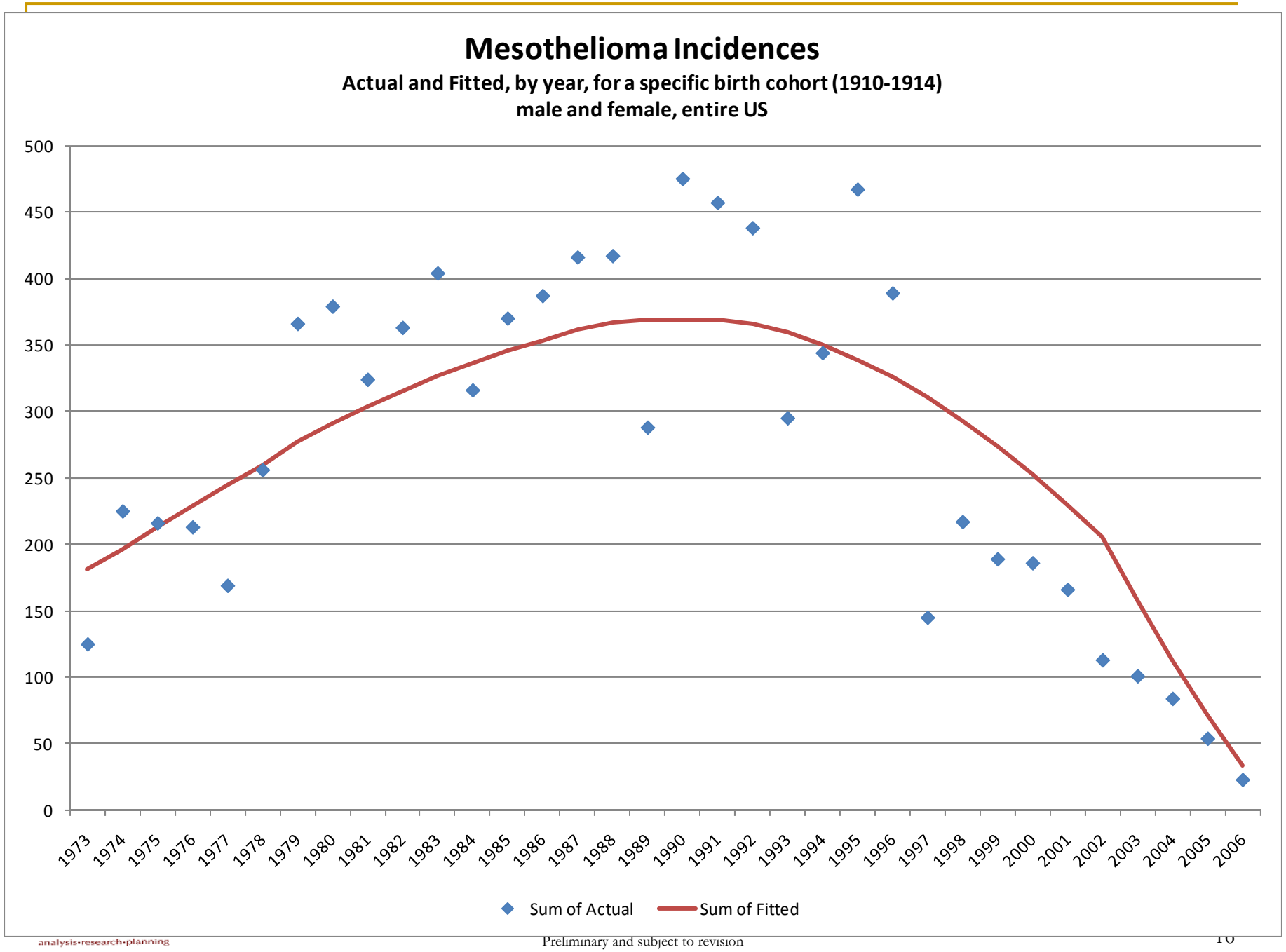
2021
2031
2041
2043
Actual
Fitted
Forecasted


Mesothelioma Incidences
Actual and Fitted, by year, for a specific birth cohort (1910-1914)
male and female, entire US
500
450
400
350
300
250
200
150
100
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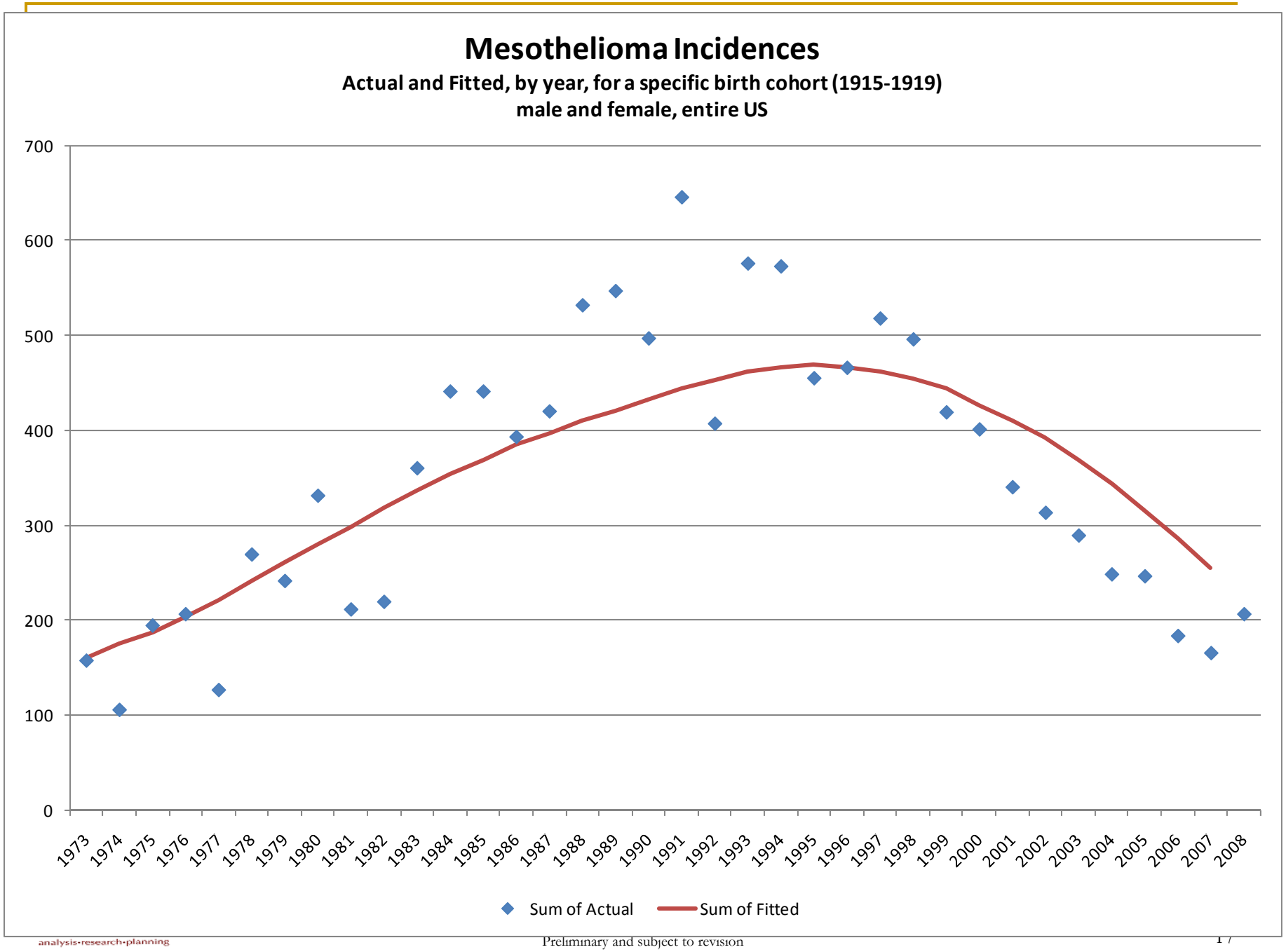
Sum of Actual
Sum of Fitted


Mesothelioma Incidences
Actual and Fitted, by year, for a specific birth cohort (1915-1919)
male and female, entire US
700
600
500
400
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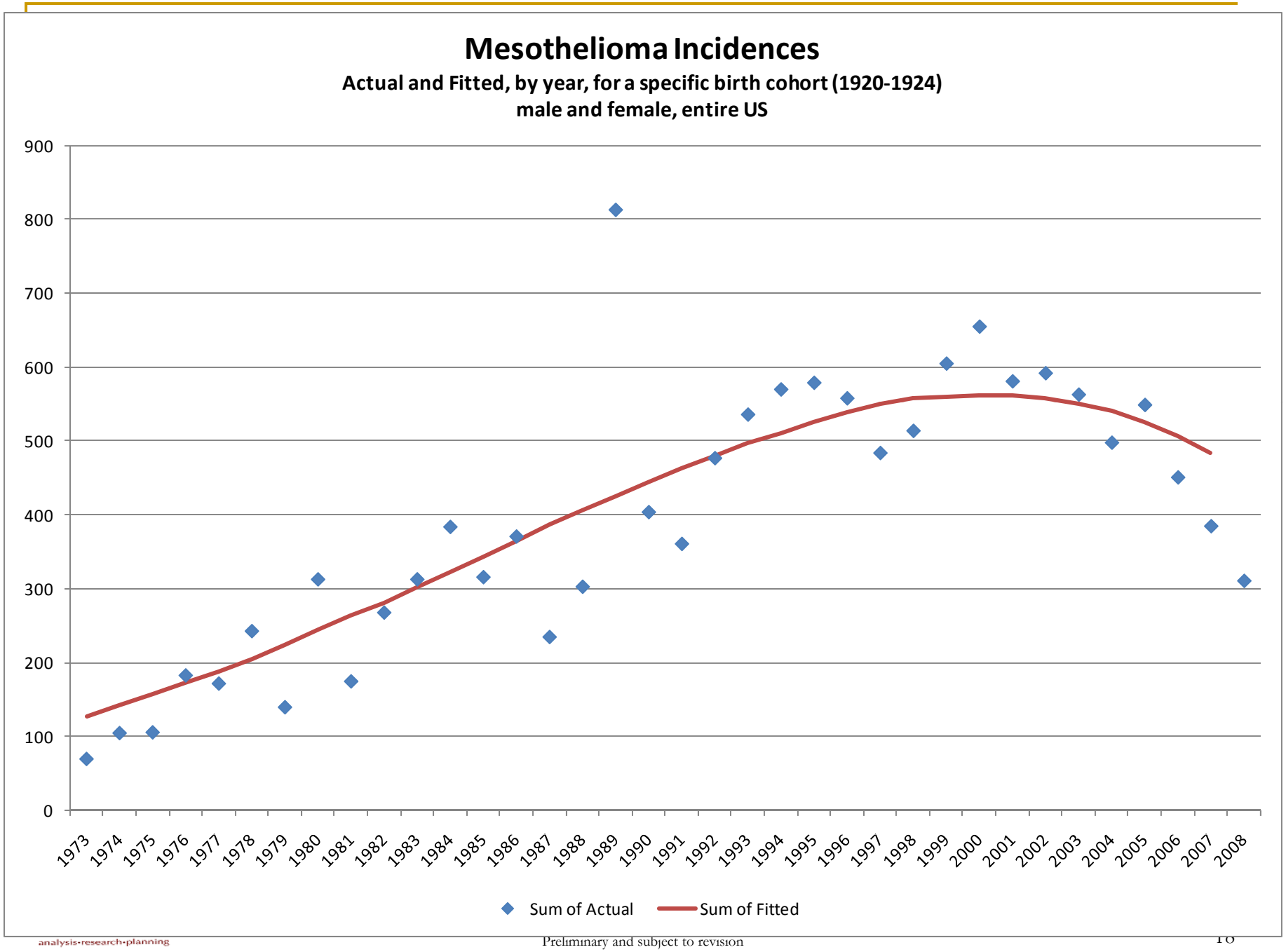
Sum of Actual
Sum of Fitted


Mesothelioma Incidences
Actual and Fitted, by year, for a specific birth cohort (1920-1924)
male and female, entire US
900
800
700
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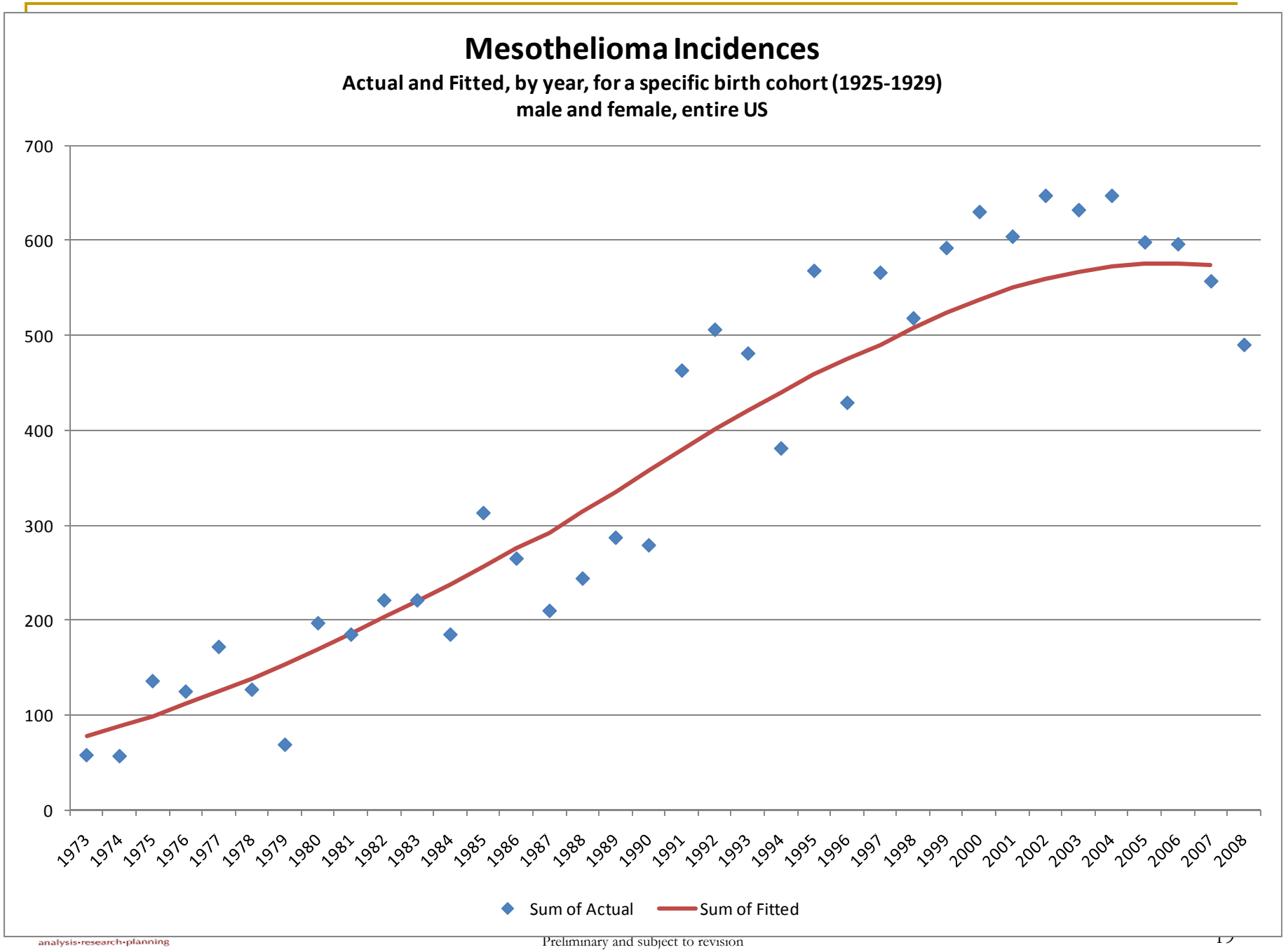
Sum of Actual
Sum of Fitted


Mesothelioma Incidences
Actual and Fitted, by year, for a specific birth cohort (1925-1929)
male and female, entire US
700
600
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400
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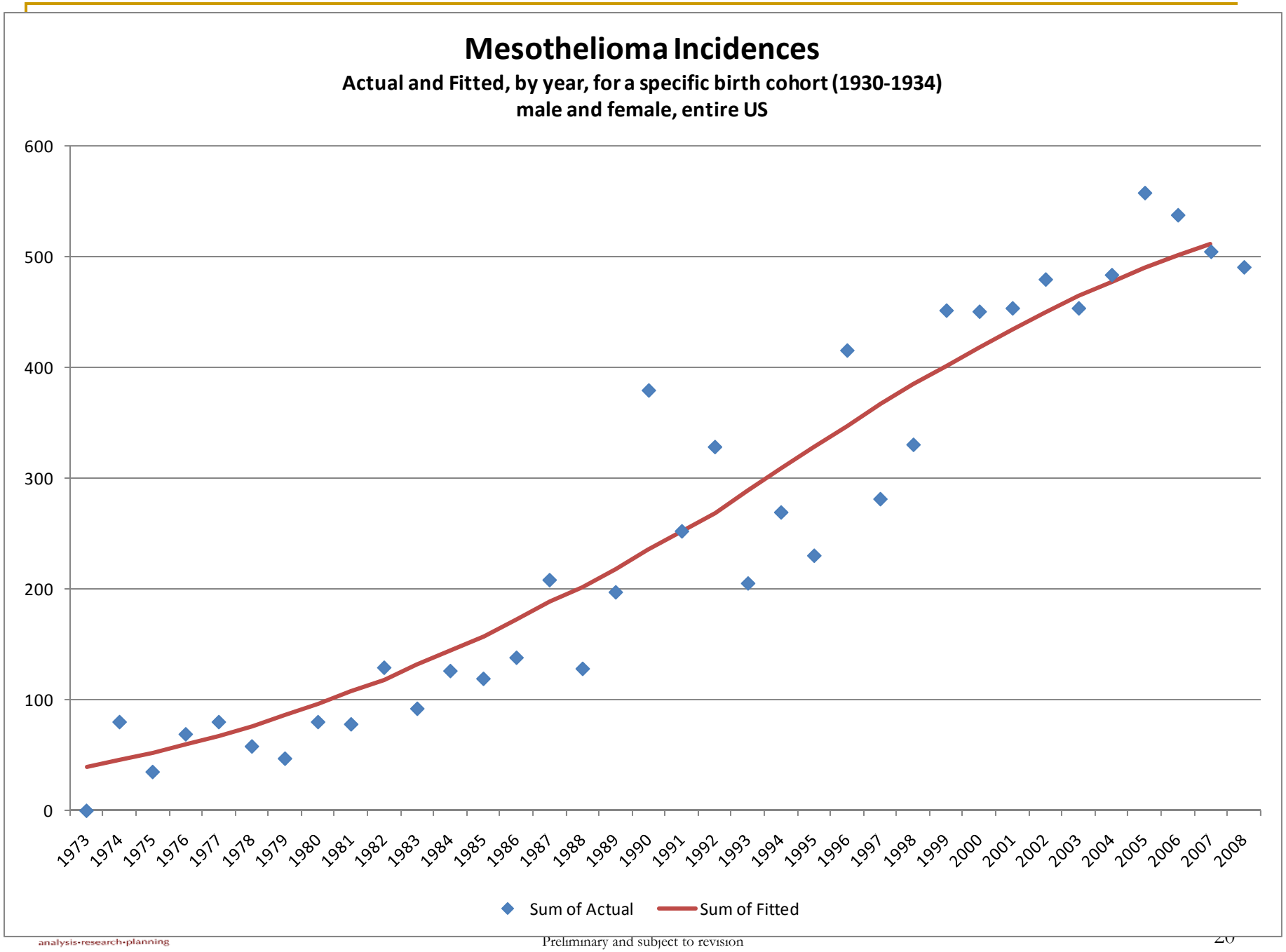
Sum of Actual
Sum of Fitted


Mesothelioma Incidences
Actual and Fitted, by year, for a specific birth cohort (1930-1934)
male and female, entire US
600
500
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1973
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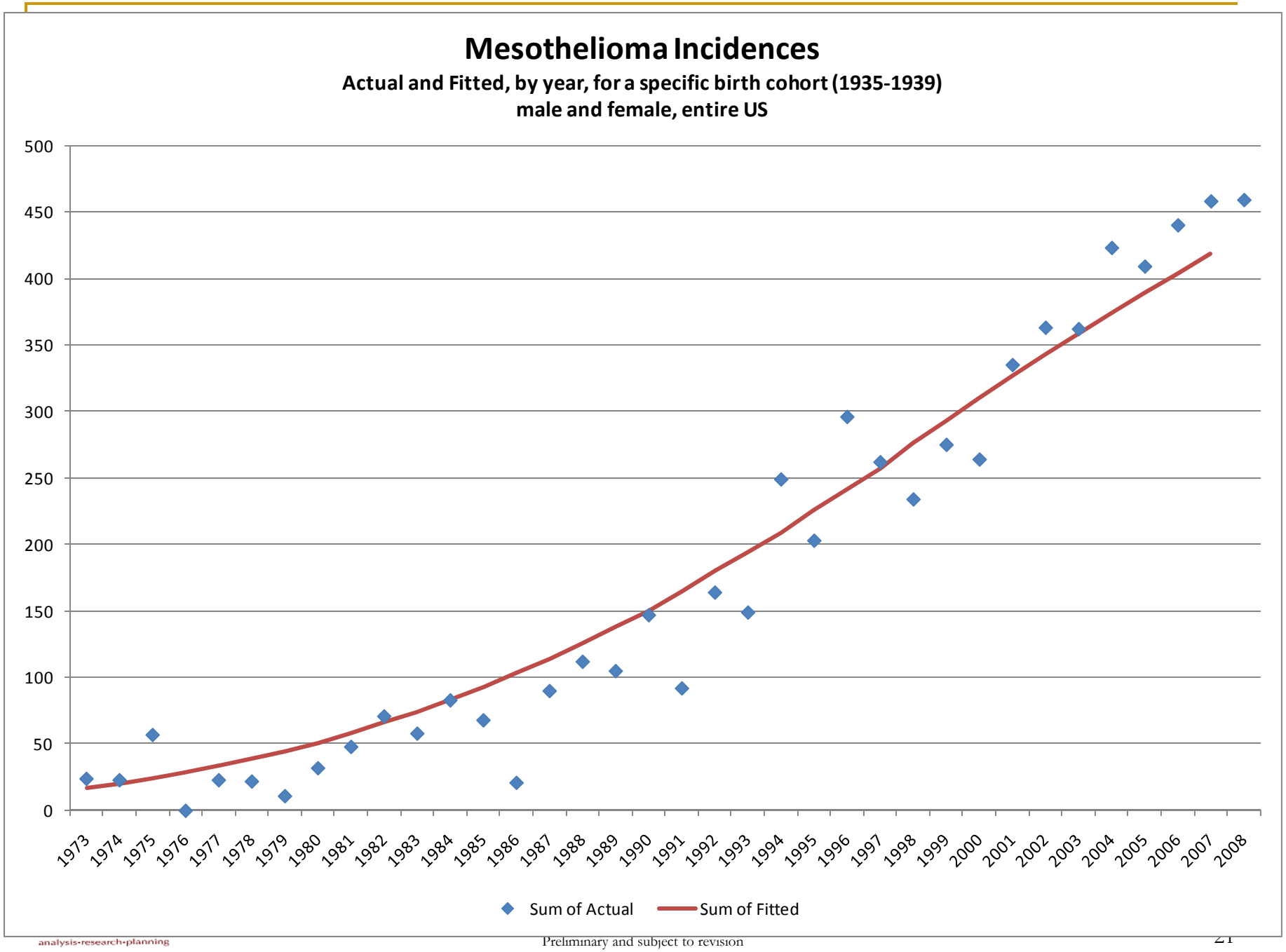
Sum of Actual
Sum of Fitted


Mesothelioma Incidences
Actual and Fitted, by year, for a specific birth cohort (1935-1939)
male and female, entire US
500
450
400
350
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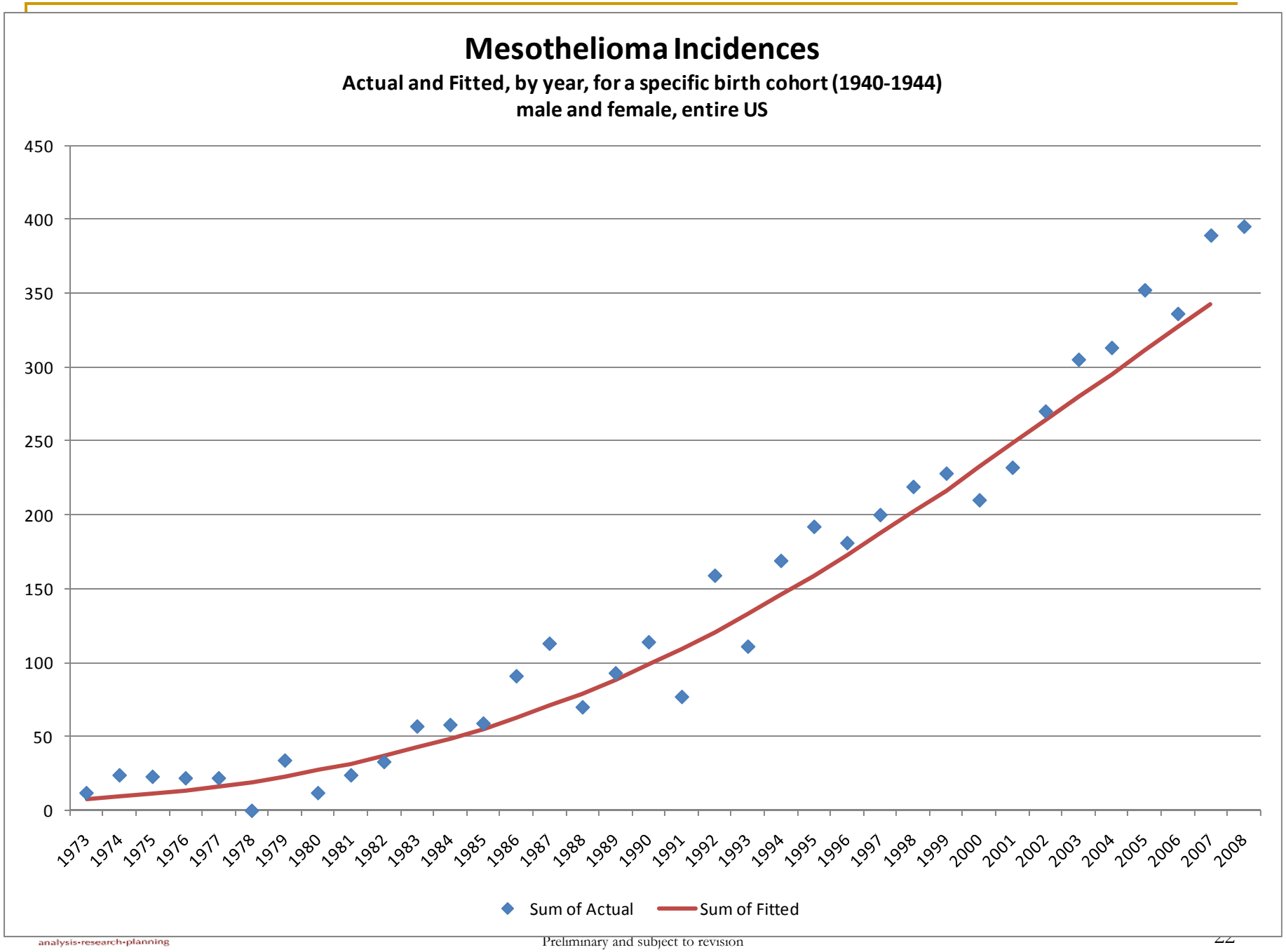
Sum of Actual
Sum of Fitted


Mesothelioma Incidences
Actual and Fitted, by year, for a specific birth cohort (1940-1944)
male and female, entire US
450
400
350
300
250
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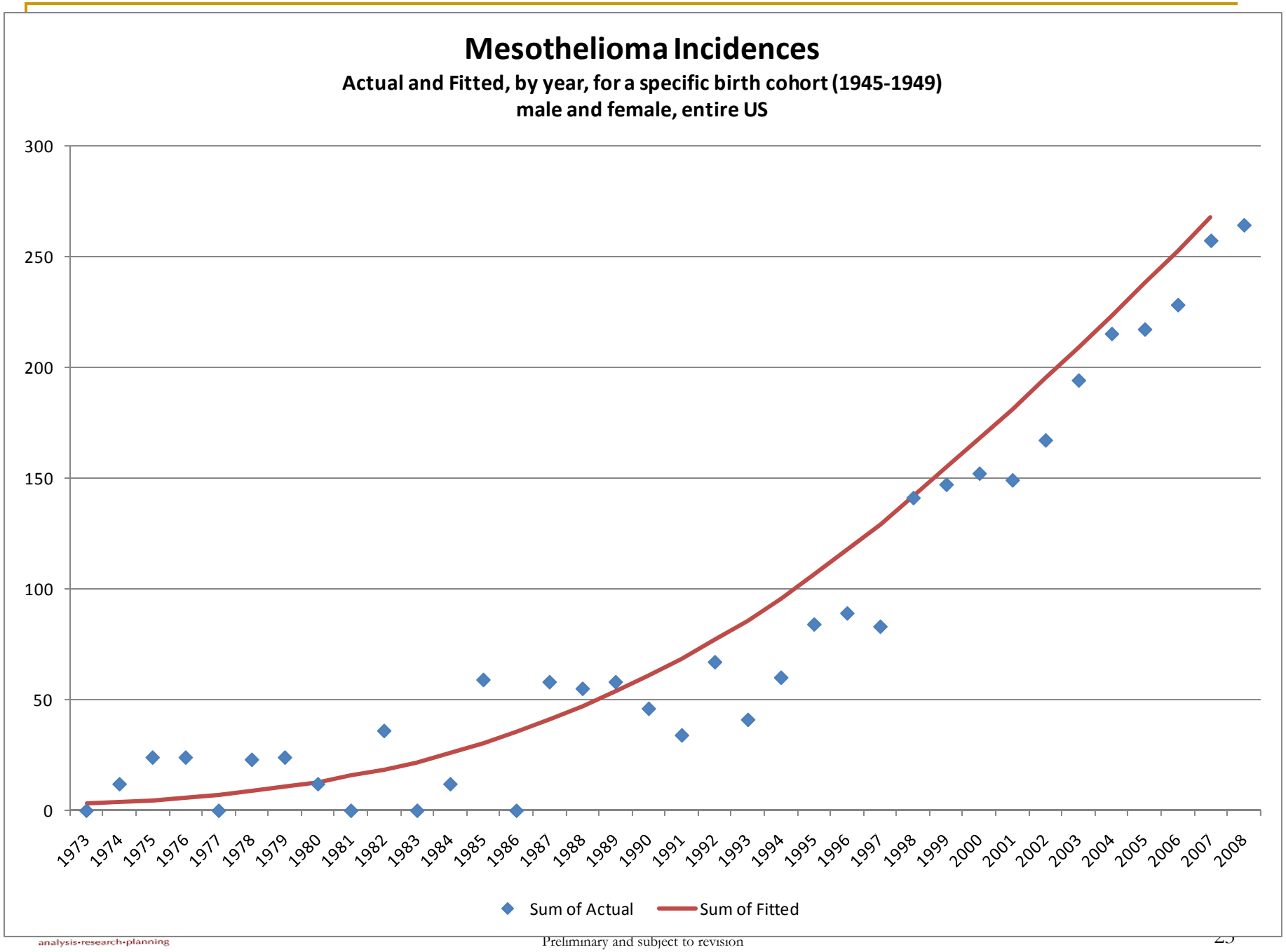
Mesothelioma Incidences
Actual and Fitted, by year, for a specific birth cohort (1945-1949)
male and female, entire US
300
250
200
150
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Sum of Actual
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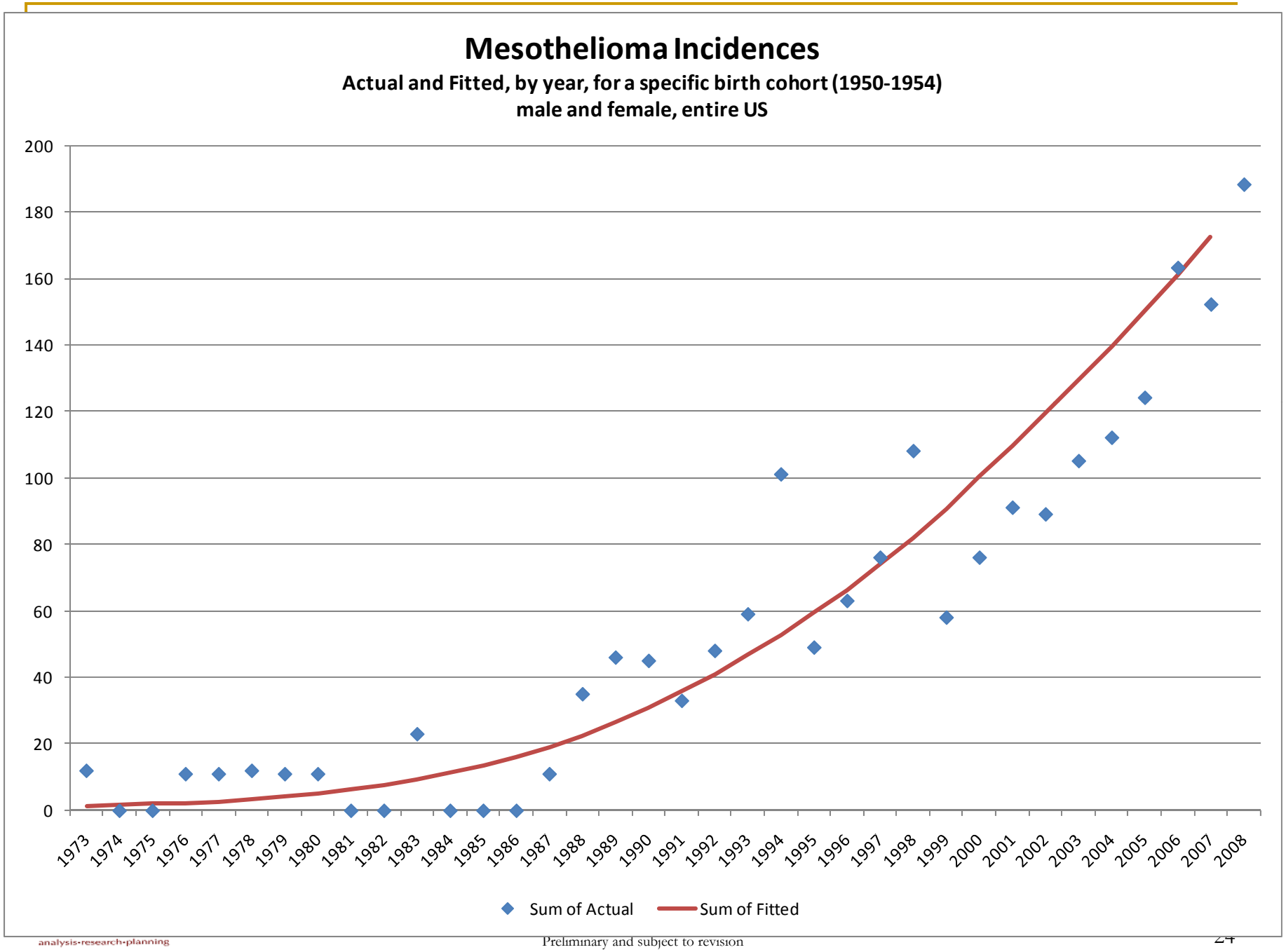
Mesothelioma Incidences
Actual and Fitted, by year, for a specific birth cohort (1950-1954)
male and female, entire US
200
180
160
140
120
100
80
60
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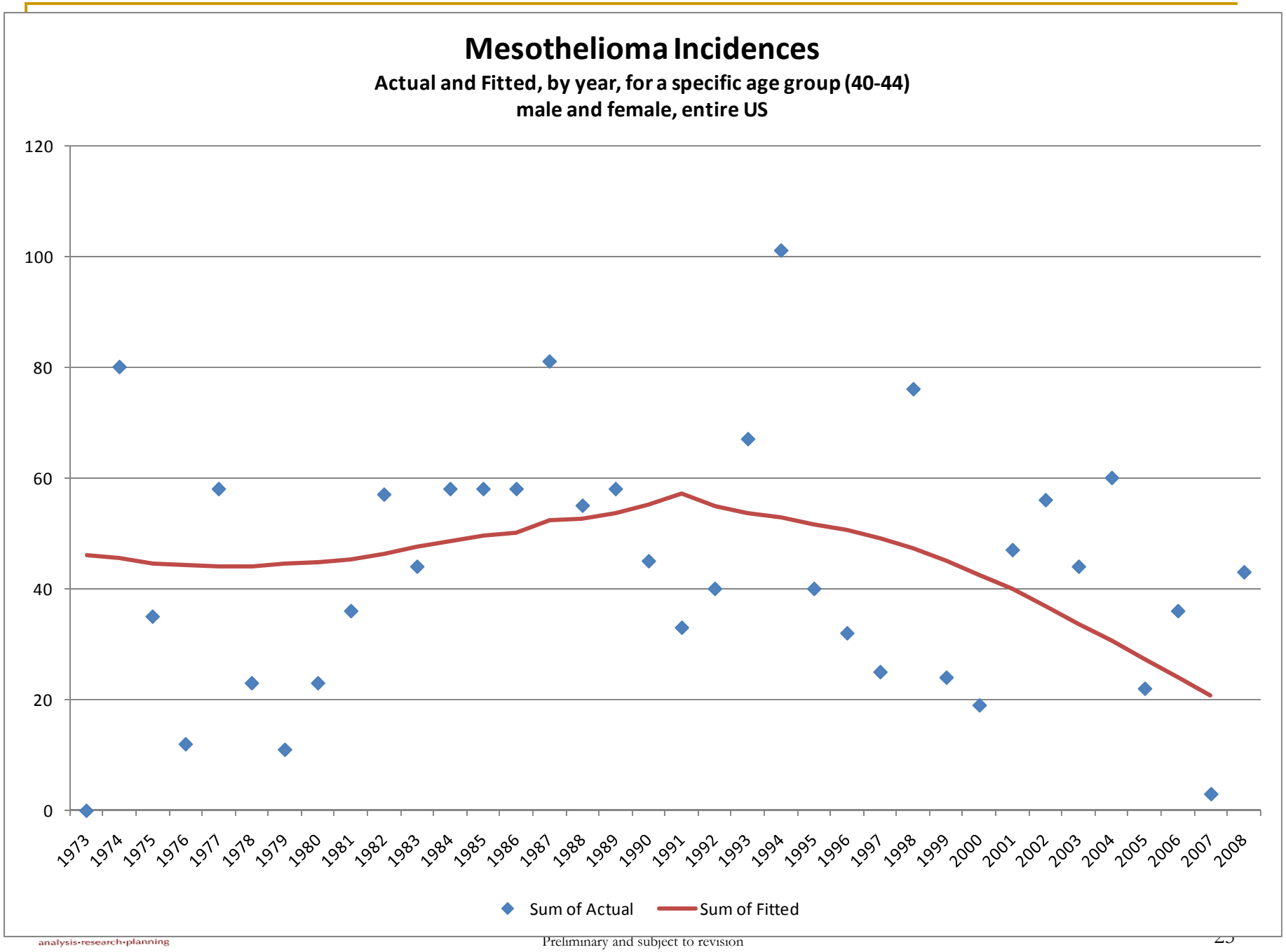
Sum of Actual
Sum of Fitted


Mesothelioma Incidences
Actual and Fitted, by year, for a specific age group (40-44)
male and female, entire US
120
100
80
60
40
20
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1973
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Sum of Actual
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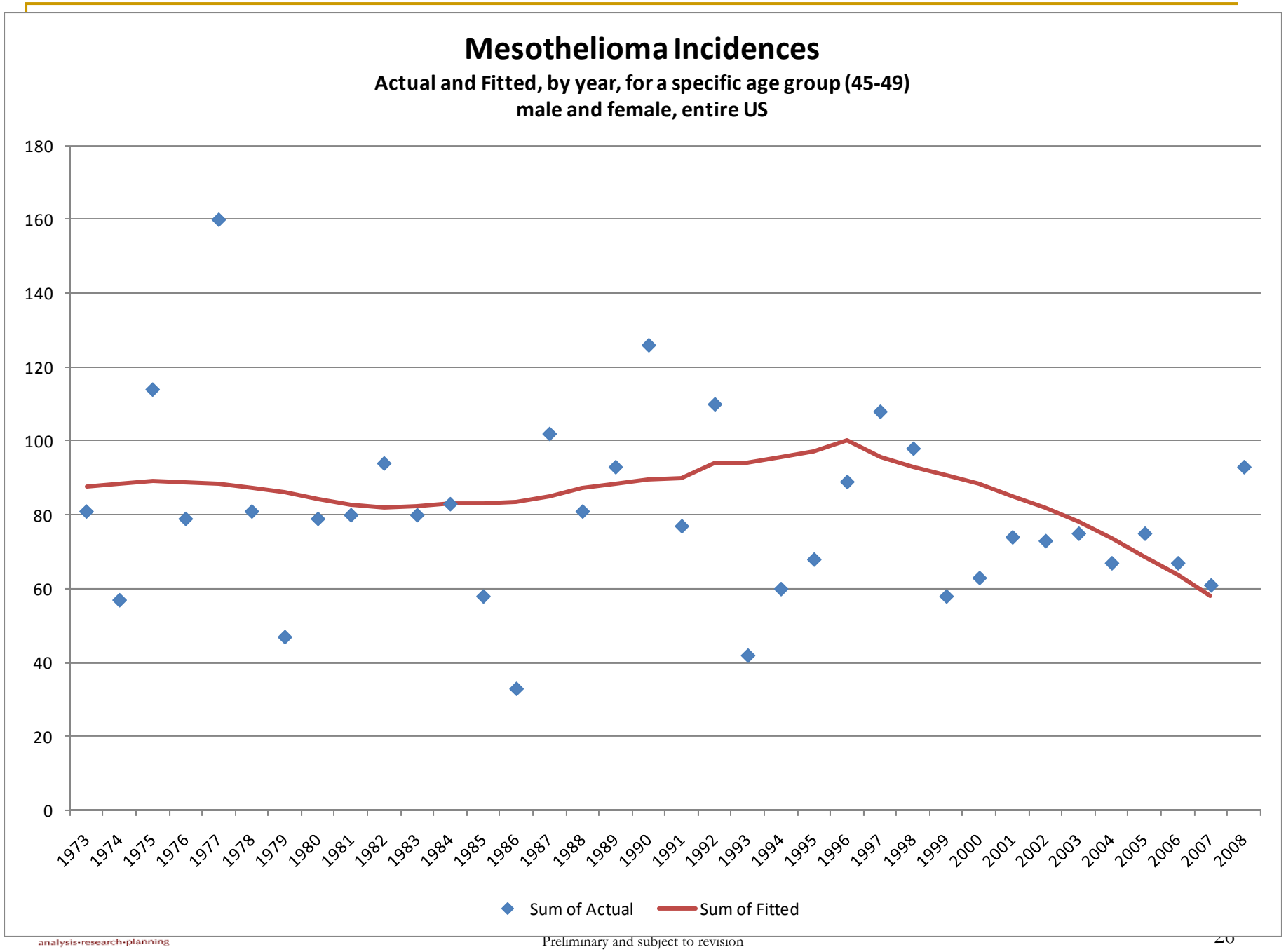
Mesothelioma Incidences
Actual and Fitted, by year, for a specific age group (45-49)
male and female, entire US
180
160
140
120
100
80
60
40
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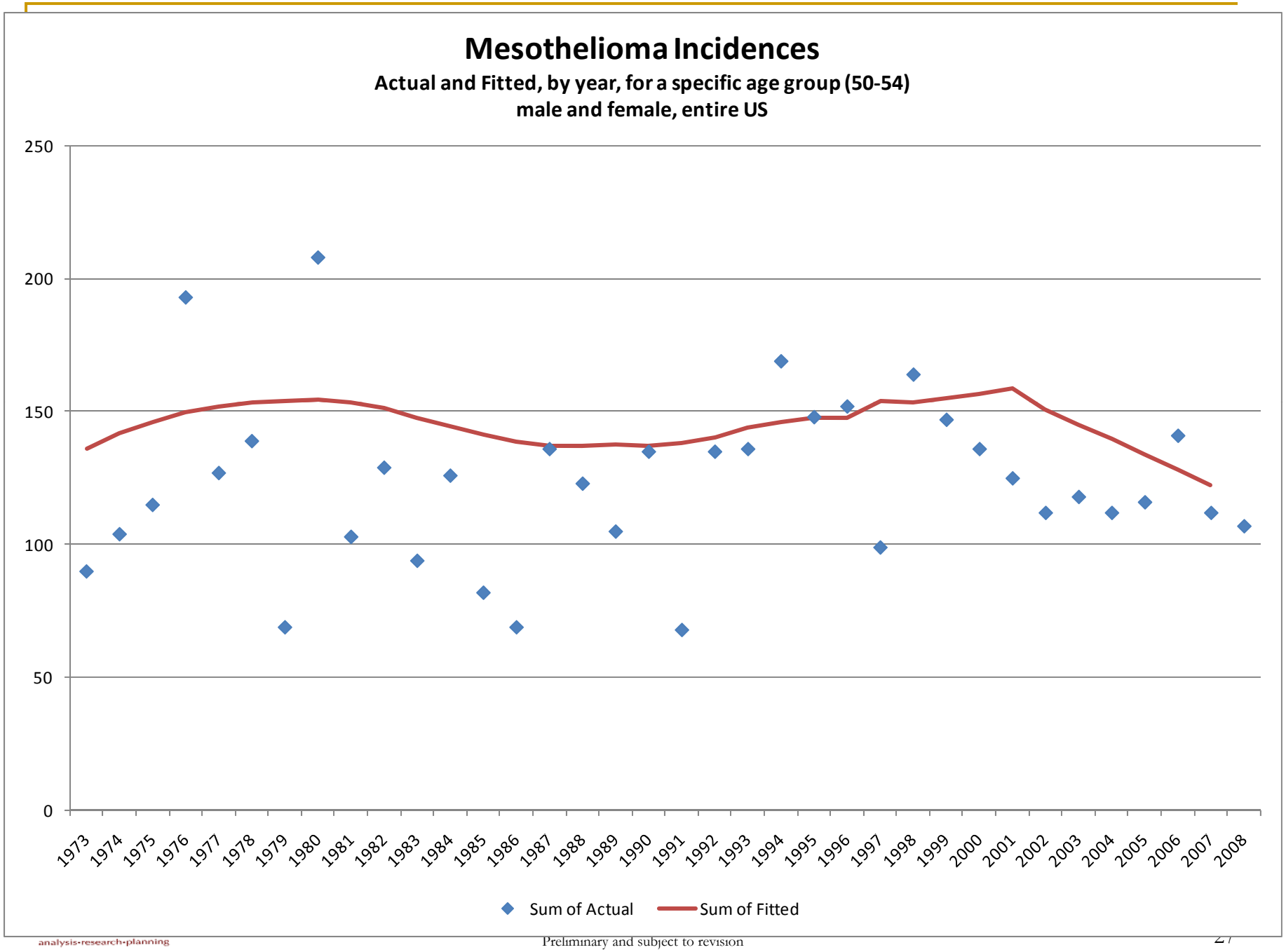
Sum of Actual
Sum of Fitted


Mesothelioma Incidences
Actual and Fitted, by year, for a specific age group (50-54)
male and female, entire US
250
200
150
100
50
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1973
1974
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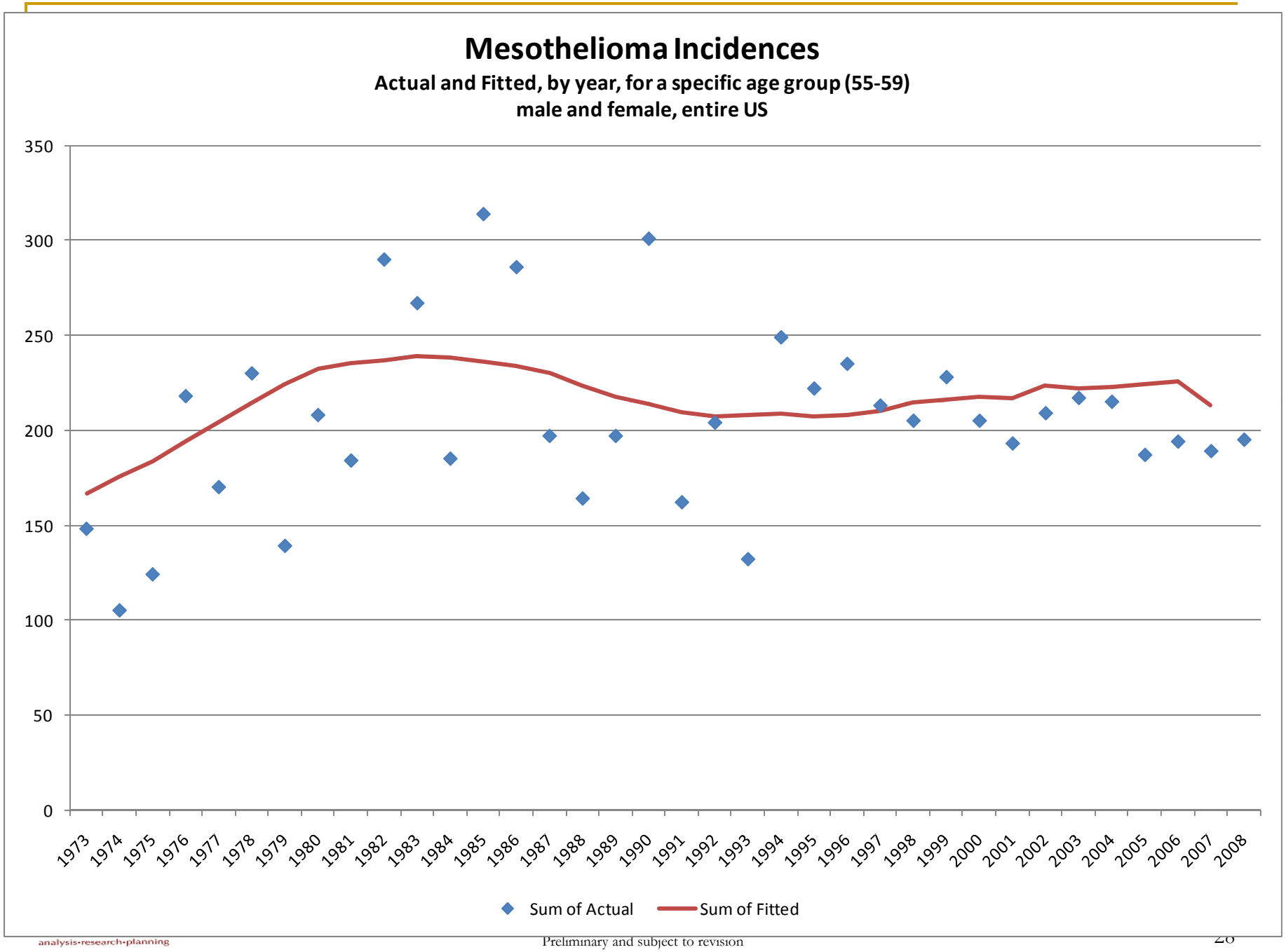
Sum of Actual
Sum of Fitted


Mesothelioma Incidences
Actual and Fitted, by year, for a specific age group (55-59)
male and female, entire US
350
300
250
200
150
100
50
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1973
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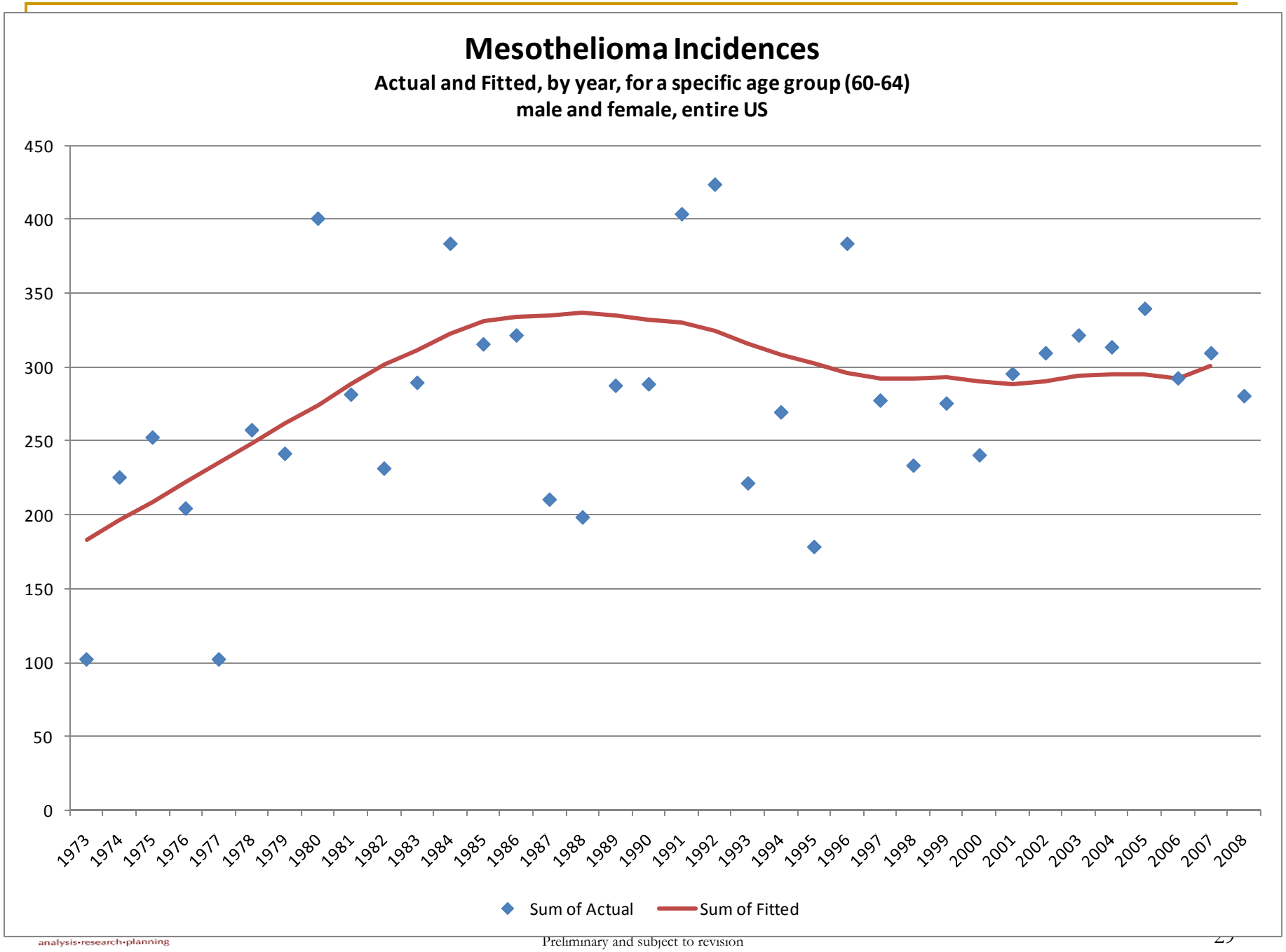
Mesothelioma Incidences
Actual and Fitted, by year, for a specific age group (60-64)
male and female, entire US
450
400
350
300
250
200
150
100
50
0
1973
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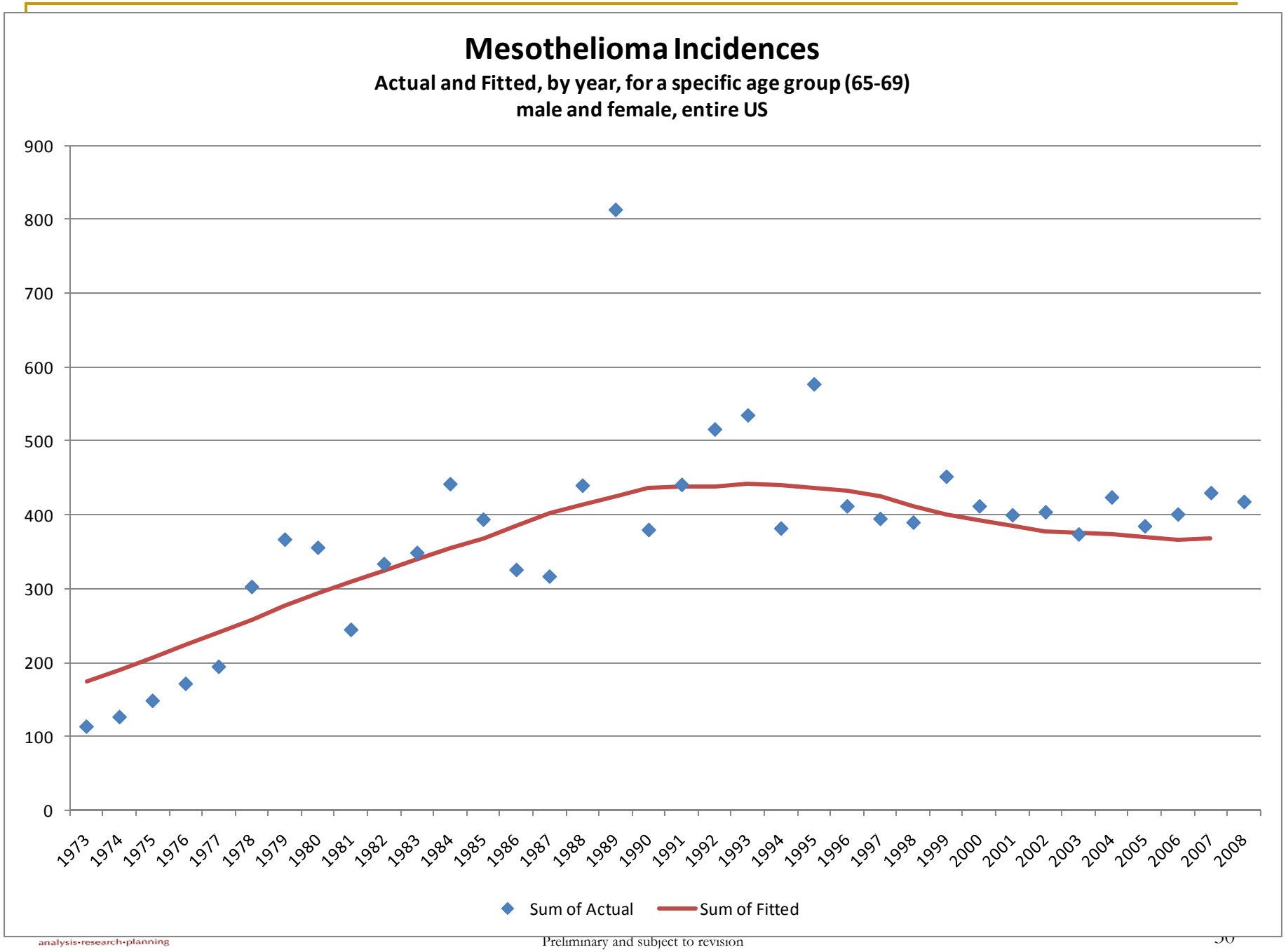
Sum of Actual
Sum of Fitted


Mesothelioma Incidences
Actual and Fitted, by year, for a specific age group (65-69)
male and female, entire US
900
800
700
600
500
400
300
200
100
0
1973
1974
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1979
1980
1981
1982
1983
1984
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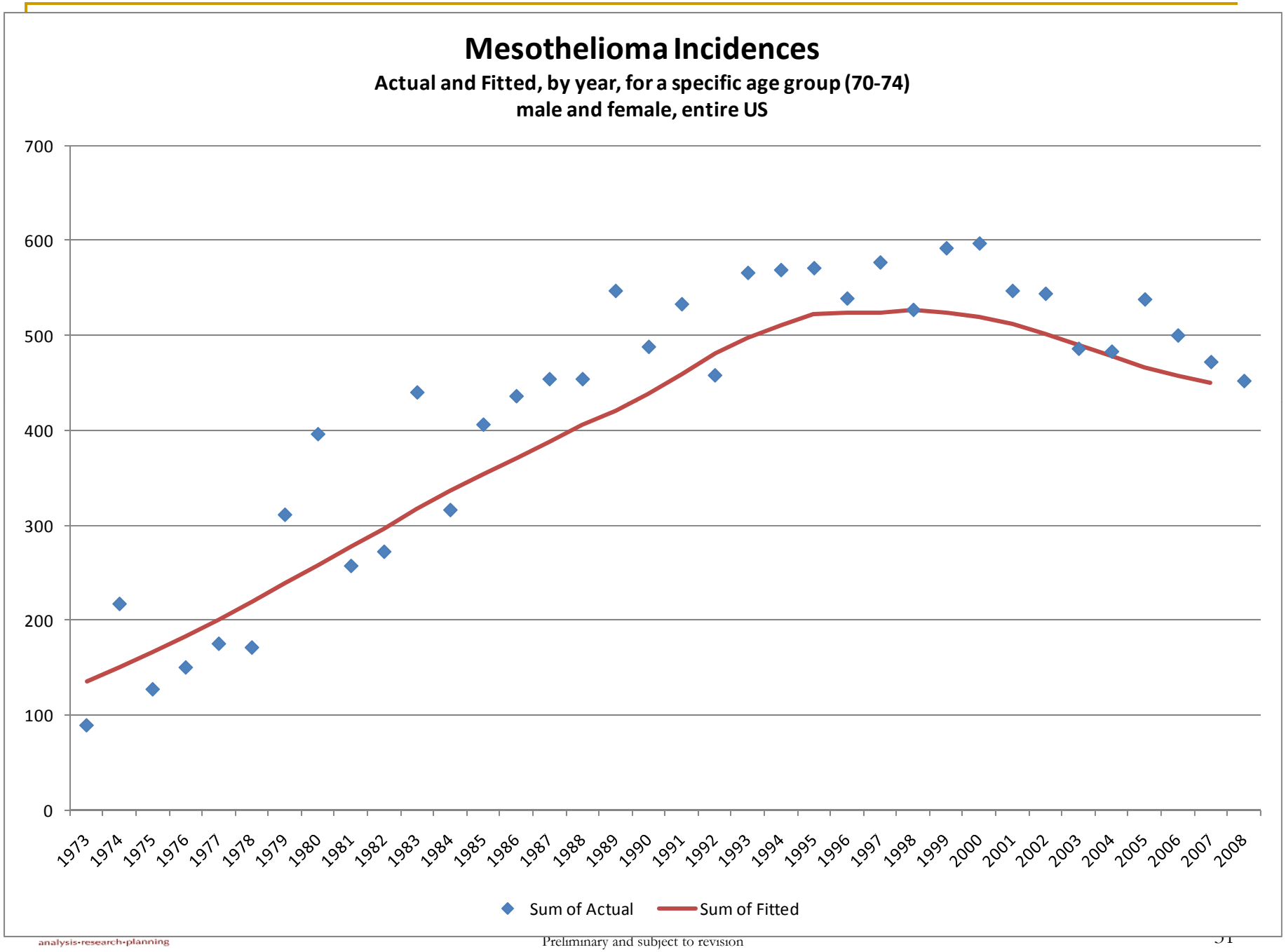
Sum of Actual
Sum of Fitted


Mesothelioma Incidences
Actual and Fitted, by year, for a specific age group (70-74)
male and female, entire US
700
600
500
400
300
200
100
0
1973
1974
1975
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1981
1982
1983
1984
1985
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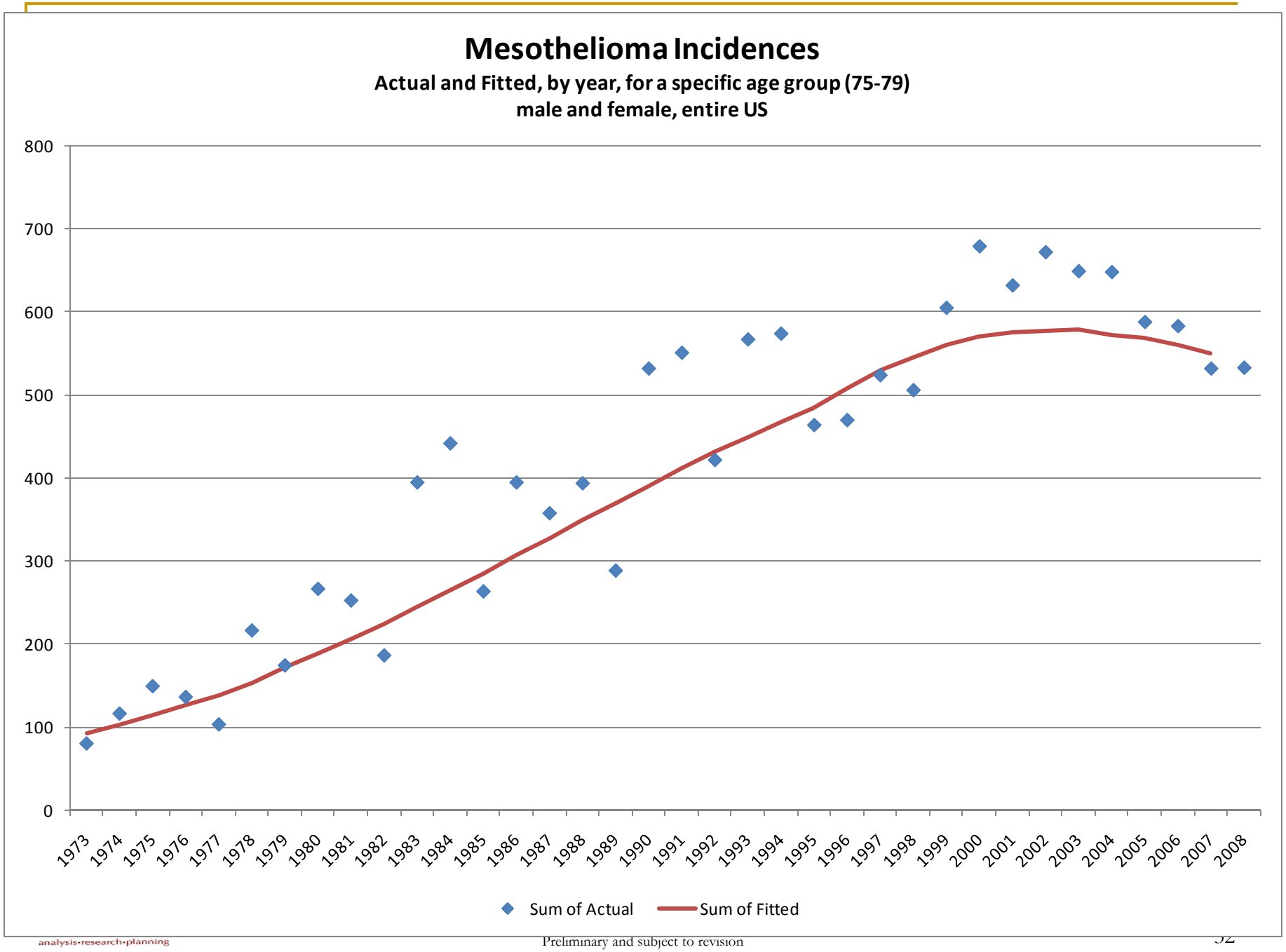
2008
Sum of Actual
Sum of Fitted


Mesothelioma Incidences
Actual and Fitted, by year, for a specific age group (75-79)
male and female, entire US
800
700
600
500
400
300
200
100
0
1973
1974
1975
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1981
1982
1983
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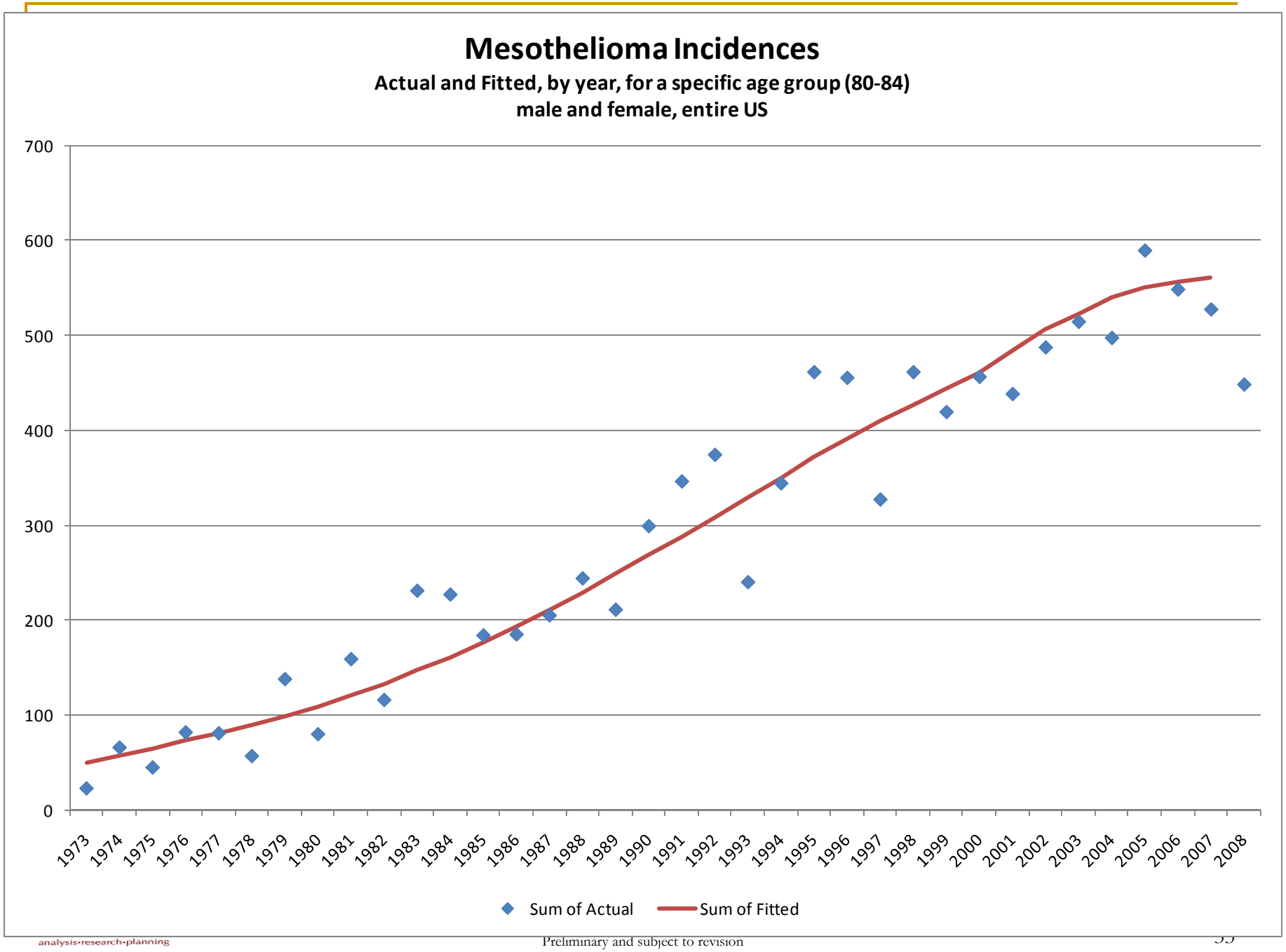
Sum of Actual
Sum of Fitted


Mesothelioma Incidences
Actual and Fitted, by year, for a specific age group (80-84)
male and female, entire US
700
600
500
400
300
200
100
0
1973
1974
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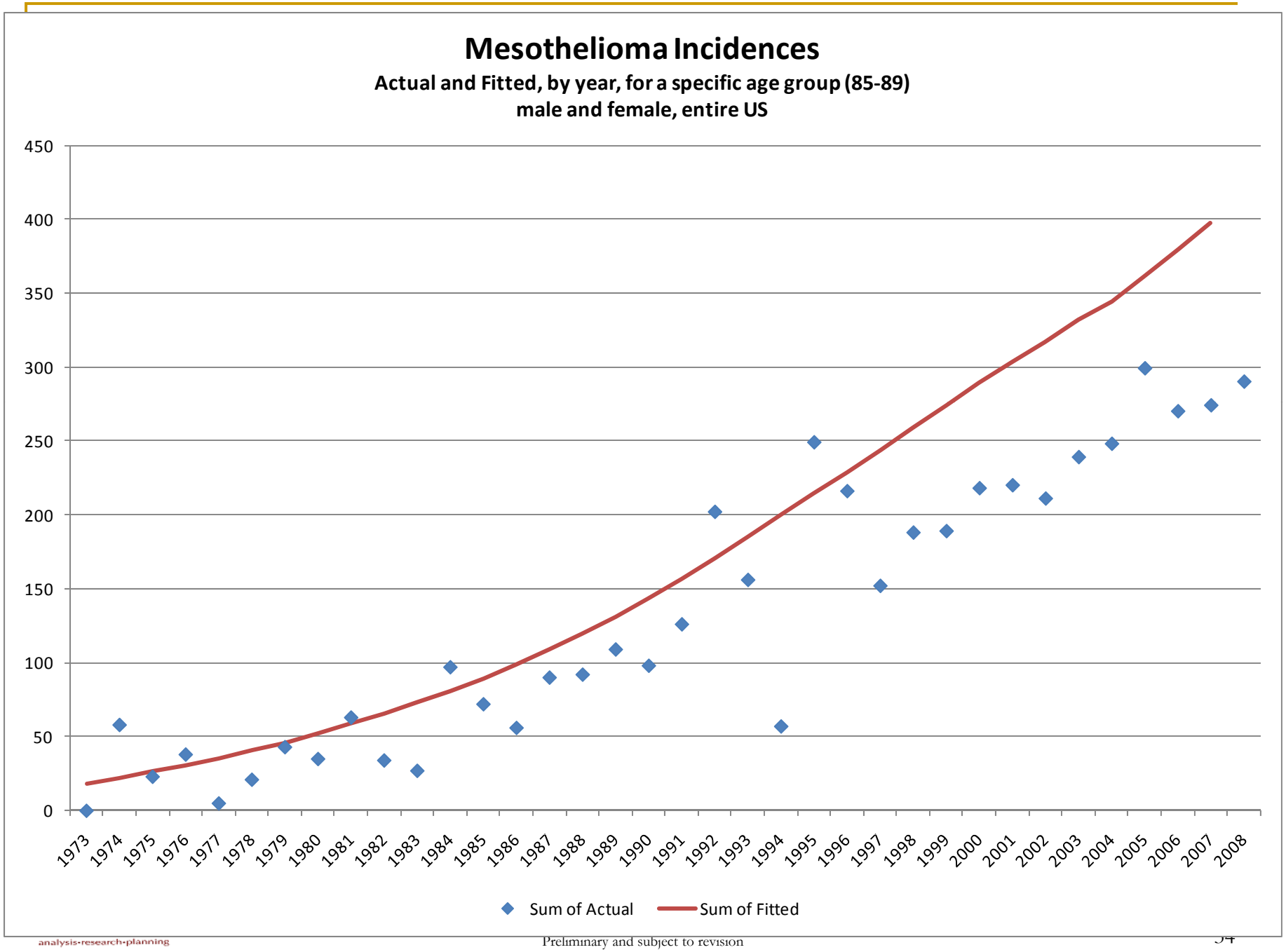
2007
2008
Sum of Actual
Sum of Fitted


Mesothelioma Incidences
Actual and Fitted, by year, for a specific age group (85-89)
male and female, entire US
450
400
350
300
250
200
150
100
50
0
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
Sum of Actual
Sum of Fitted

References

- Bell, F. C., and Miller, M. L. “Life Tables for the US Social Security Area 1900-2100”
- Hodgson, J., McElvenny, D., Darnton, A., Price, M., and Peto, J. (2005) “The Expected Burden of Mesothelioma Mortality in Great Britain from 2002 to 2050,” *British Journal of Cancer* 4, 587-593
- Nicholson W. J., Perkel, G., and Selikoff, I. J. (1982) “Occupational Exposure to Asbestos: Population at Risk and Projected Mortality – 1980-2030,” *American Journal of Industrial Medicine* 3, 259-311
- Peto, J., Henderson, B. E., and Pike, M. C. (1981) “Trends in Mesothelioma Incidence in the United States and the Forecast Epidemic Due to Asbestos Exposure during World War II”
- Tan, E., and Warren, N. (2009), “Projection of Mesothelioma Mortality in Great Britain,” prepared by Health and Safety Laboratory for the Health and Safety Executive 2009