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U.S. National Healthcare Expenditures: Demonstration and Explanation of Cubic Growth Dynamics

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Abstract

U.S. national healthcare expenditures (NHE) increased from under 28 billion dollars in 1960 to over 1.35 trillion dollars in 2000. This enormous growth threatens the sustainability of the provision of healthcare. By definition, in any year, current NHE must equal population times consumer price index (CPI) times per capita CPI-adjusted constant dollar healthcare expenditures. Linear relationships were observed over time with total population ($r^2 > 0.99$), with CPI ($r^2 > 0.96$), and with per capita CPI-adjusted dollar healthcare expenditures ($r^2 > 0.98$). The finding that those three factors were well described by linear equations suggests that NHE growth should display cubic dynamics over time. NHE from 1960 through 2000 did display cubic growth dynamics ($r^2 > 0.99$). Moreover, actual NHE from 1960 through official U.S. government NHE projections in 2019 also displayed cubic growth dynamics ($r^2 > 0.99$). This model explains why U.S. NHE has displayed cubic growth dynamics and suggests that U.S. NHE will continue to display cubic growth dynamics as long as increases in population, CPI, and per capita CPI-adjusted constant dollar healthcare expenditures continue to increase reasonably linearly over time.

Keywords: Consumer Price Index, Cubic Dynamics, Economic Modeling, National Healthcare Expenditures, Per Capita Healthcare Expenditures, Population, United States

1. Introduction

Rising national healthcare expenditures (NHE) are consistently in the U.S. national political and economic spotlight [1-4]. NHE increased nearly 50-fold in the U.S. between 1960 and 2000, from under 28 billion dollars to over 1.35 trillion dollars per year (**Table 1**). This enormous growth in NHE threatens the sustainability of healthcare for many Americans since employers cannot afford the large ongoing increases in healthcare insurance premiums for their employees, healthcare insurance companies continuously seek to control their risk by excluding high risk patients and restricting covered benefits, governments cannot afford to provide unlimited benefits for its citizens by shifting the costs to future taxpayers, and very few individuals can afford to pay for their own healthcare should a significant injury or illness occur. This enormous growth in healthcare expenditures seriously undermines the sustainability of national discre-

tionary spending. A June 2010 Congressional Budget Office report stated, "Because health care costs will account for a significant share of the federal budget under current law, and the growth of those costs is a major contributor to the long-term fiscal pressures facing the country, policy options to restrain the growth of federal spending on health care will continue to attract considerable interest." (<http://www.cbo.gov/ftpdocs/115xx/doc11579/06-30-LTBO.pdf>).

Despite the impact and importance of rising NHE, very little regarding the dynamics of this enormously increasing and very important sector of the U.S. economy has been described [5]. By definition, in any given year, current NHE must equal population times consumer price index (CPI) times per capita CPI-adjusted constant dollar healthcare expenditures. Trends in these three factors must, therefore, influence total NHE. Trends in population, consumer price index, and per capita CPI-adjusted healthcare expenditures were explored to

determine if they might suggest or reveal a model explaining the underlying growth dynamics of U.S. NHE.

2. Method & Model

2.1. Data Sources

Three public and readily available sources of data for the years 1960 through 2000 were used in this analysis. Official estimates of the total U.S. population for those years (**Table 1**) were obtained from the U.S. Census Bureau (www.census.gov). Official estimates of the U.S. consumer price index (CPI) for those years (**Table 1**) were obtained from the U.S. Department of Labor, Bureau of Labor Statistics (www.bls.gov). Official estimates of total U.S. NHE in current dollars for those years (**Table 1**) were obtained from the U.S. Department of Health and Human Services, Centers for Medicare & Medicaid Services (www.cms.hhs.gov). Dividing the annual total NHE by that year's CPI gives the annual NHE in CPI-adjusted dollars. Dividing the annual NHE in CPI-adjusted dollars by the corresponding annual population gives the annual per capita CPI-adjusted healthcare expenditures. The relationship of annual population, CPI, and per capita CPI-adjusted healthcare expenditures over time, between 1960 and 2000, was examined.

2.2. Model

Figure 1 illustrates the relationship between total U.S. population and year. As shown, there is a strong linear relationship between total U.S. population and year. Linear regression between total population and year yielded the following equation:

$$POP_x = 2293408.2 X + 181774463 \quad (1)$$

where POP_x is the total U.S. population in year X, and X is the year, which varied from 0 for year 1960 to 40 for year 2000. The r^2 value for this linear regression was > 0.99 . Thus, the total U.S. population increased by approximately 2293408 individuals per year between the years 1960 and 2000. The least-squares estimate of the parameters in the regression equation:

$$POP_x = aX + A \quad (2)$$

is therefore, a is 2293408.2, and A is 181774463.

Figure 2 illustrates the relationship between CPI and year. As shown, there is a reasonably linear relationship between CPI and year. The linear regression between CPI and year yielded the following equation:

$$CPI_x = 0.040218641 X + 0.0643875 \quad (3)$$

where CPI_x is the consumer price index in year X, and X

is the year, which varied from 0 for year 1960 to 40 for year 2000. The r^2 value for this linear regression was > 0.96 . Thus, the CPI increased by approximately 0.0402 per year between the years 1960 and 2000. Since the numbers in Equation 3 are constants, the following equation will be used:

$$CPI_x = bX + B \quad (4)$$

where b is 0.040218641, and B is 0.0643875.

Figure 3 illustrates the relationship between per capita CPI-adjusted healthcare expenditures and year. As shown, there is a near linear relationship between per capita CPI-adjusted healthcare expenditures and year. Linear regression between per capita CPI-adjusted healthcare expenditures and year yielded the following equation:

$$PCNHE_x = 60.181652 X + 335.2974 \quad (5)$$

where $PCNHE_x$ is the per capita CPI-adjusted healthcare expenditures in year X, and X is the year, which varied from 0 for year 1960 to 40 for year 2000. The r^2 value for this linear regression was > 0.98 . Thus, per capita

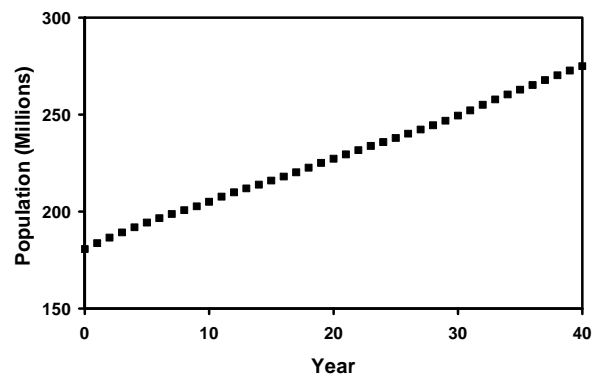


Figure 1. Total U.S. population for the years 1960 (year 0) through 2000 (year 40) is displayed. The r^2 value for the linear regression performed on this data was > 0.99 .

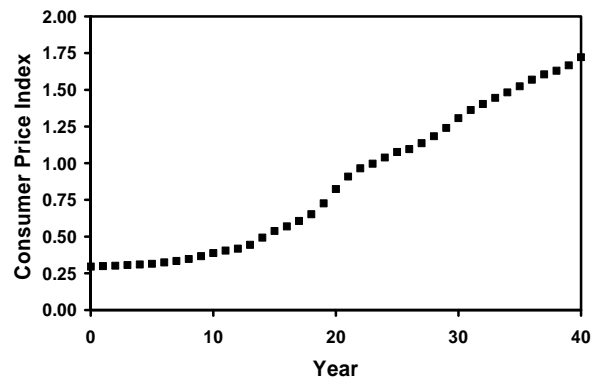


Figure 2. The consumer price index (CPI) for the years 1960 (year 0) through 2000 (year 40) is displayed. The r^2 value for the linear regression performed on this data was > 0.96 .

Table 1. United States national healthcare expenditures (NHE) in millions of dollars, population, consumer price index (CPI), and cubic modeled NHE in millions of dollars for the years 1960-2000.

Year	NHE	Population	CPI	Modeled NHE
1960	27,534	180,671,158	0.296	3924
1961	29,370	183,691,481	0.299	7615
1962	32,053	186,537,737	0.302	12,298
1963	34,910	189,241,798	0.306	18,008
1964	38,694	191,888,791	0.310	24,777
1965	42,173	194,302,963	0.315	32,639
1966	46,430	196,560,338	0.324	41,626
1967	52,062	198,712,056	0.334	51,774
1968	59,012	200,706,052	0.348	63,114
1969	66,396	202,676,946	0.367	75,680
1970	74,894	205,052,174	0.388	89,505
1971	83,265	207,660,677	0.405	104,623
1972	92,974	209,896,021	0.418	121,067
1973	103,034	211,908,788	0.444	138,870
1974	116,809	213,853,928	0.493	158,066
1975	133,124	215,973,199	0.538	178,688
1976	152,478	218,035,164	0.569	200,769
1977	172,826	220,239,425	0.606	224,342
1978	194,126	222,584,545	0.652	249,441
1979	219,940	225,055,487	0.726	276,099
1980	253,373	227,224,681	0.824	304,349
1981	293,592	229,465,714	0.909	334,226
1982	330,743	231,664,458	0.965	365,761
1983	364,676	233,791,994	0.996	398,988
1984	401,599	235,824,902	1.039	433,941
1985	430,284	237,923,795	1.076	470,653
1986	471,265	240,132,887	1.096	509,158
1987	512,973	242,288,918	1.136	549,487
1988	574,043	244,498,982	1.183	591,676
1989	638,794	246,819,230	1.240	635,757
1990	714,127	249,464,396	1.307	681,763
1991	781,608	252,153,092	1.362	729,728
1992	849,039	255,029,699	1.403	77,968
1993	912,485	257,783,000	1.445	831,667
1994	962,061	260,327,021	1.482	885,708
1995	1,016,271	262,803,276	1.524	941,841
1996	1,068,526	265,228,572	1.569	1,000,100
1997	1,124,915	267,784,000	1.605	1,060,517
1998	1,190,059	270,248,003	1.630	1,123,125
1999	1,265,158	272,690,813	1.666	1,187,959
2000	1,353,187	274,951,554	1.722	1,255,052

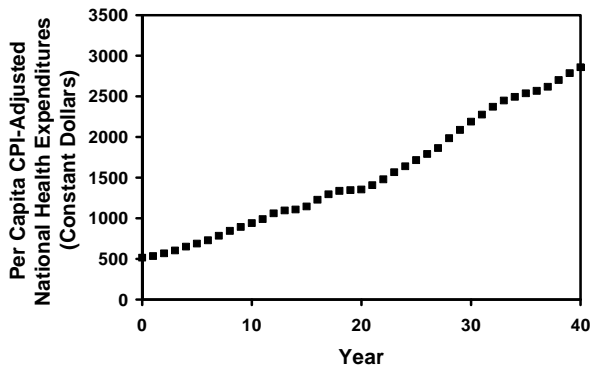


Figure 3. Per capita CPI-adjusted constant dollar U.S. healthcare expenditures for the years 1960 (year 0) through 2000 (year 40) is displayed. The r^2 value for the linear regression performed on this data was > 0.98 .

CPI-adjusted healthcare expenditures increased by approximately \$60.18 per year between the years 1960 and 2000. Since the numbers in Equation (5) are constants, the following equation can be used:

$$PCNHE_x = cX + C \tag{6}$$

where c is 60.181652, and C is 335.2974.

For any given year, the following relationship is valid:

$$NHE_x = (POP_x) \times (CPI_x) \times (PCNHE_x) \tag{7}$$

where NHE_x is national healthcare expenditures in current dollars in year X , POP_x is the total U.S. population in year X , CPI_x is the consumer price index in year X , and $PCNHE_x$ is the per capita CPI-adjusted healthcare expenditures in year X . Substituting the linear regression derived equations for POP_x , CPI_x , and $PCNHE_x$ into Equation (7) yields:

$$NHE_x = (aX + A) \times (bX + B) \times (cX + C) \tag{8}$$

Multiplying out the terms in Equation (8) yields the following equation:

$$NHE_x = abcX^3 + (Abc + aBc + abC)X^2 + (ABC + AbC + aBC)X + ABC \tag{9}$$

Equation (9) suggests that NHE should be described by a cubic function over time as long as POP, CPI, and PCNHE are reasonably described by linear equations. Accordingly, a cubic polynomial fit of national healthcare expenditures (**Table 1**) over time was performed. That analysis demonstrated that NHE between 1960 and 2000 conformed to a cubic function, and the r^2 value of that fit was >0.99 .

Equation (7) was used to model or predict annual values of NHE for each year from 1960 to 2000 by calculating the product of the derived Equations (1), (3), and (5). These values are also shown in **Table 1**. **Figure 4** displays a plot of actual and modeled NHE from 1960 to

2000. This cubic model of NHE growth, based on the product of the three derived linear equations from 1960 to 2000 data, correlated very well with actual NHE from 1960 to 2000, with an r^2 value of that fit >0.99 .

Since this model predicts that NHE growth should display cubic dynamics, combined actual (1960 to 2008) and official U.S. government predictions (2009 to 2019) of NHE (www.cms.hhs.gov) were plotted in **Figure 5**. A cubic polynomial fit of national healthcare expenditures over that time period was performed. That analysis demonstrated that actual and projected NHE between 1960 and 2019 also conformed to a cubic function, and the r^2 value of that fit was >0.99 .

3. Discussion

A model of NHE based on the fact that in any year, current NHE must equal population times CPI times per capita CPI-adjusted constant dollar healthcare expenditures (Equation 7) was developed and analyzed. Equation 7 is a truism; that is, Equation 7 can be algebraically

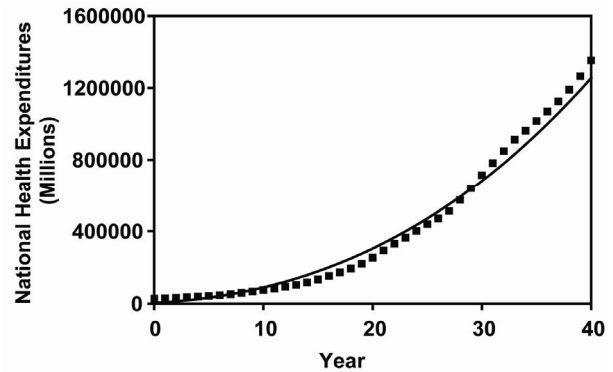


Figure 4. Actual (squares) and modeled (solid line) national health expenditures (in current millions of dollars) for year 0 (1960) through year 40 (2000).

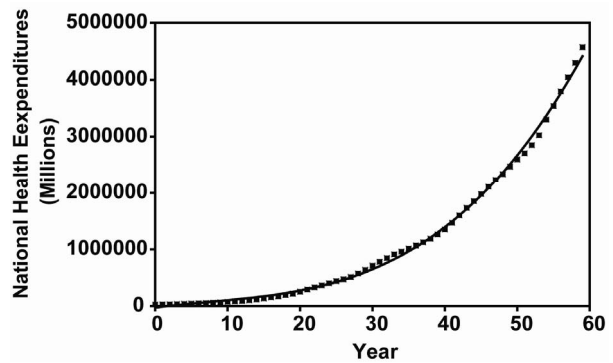


Figure 5. Actual (1960 to 2008) and projected (2009 to 2019) (squares) and best cubic fit (solid line) national health expenditures (in current millions of dollars) for year 0 (1960) through year 59 (2019).

simplified to state that for any given year, NHE must equal NHE. However, the point of this model was to separate NHE into three distinct components; population, CPI, and per capita CPI-adjusted constant dollar healthcare expenditures. There is no *a priori* reason why each of these three components should increase linearly over time as was demonstrated in this analysis. Since population, CPI, and per capita CPI-adjusted constant dollar healthcare expenditures did increase reasonably linearly over time between 1960 and 2000, this model suggested that NHE growth should display cubic growth dynamics. Indeed, NHE growth did display cubic dynamics from 1960 to 2000. Moreover, actual and projected NHE growth from 1960 to 2019 also displayed cubic dynamics. This analysis also suggests that future U.S. NHE growth will remain cubic as long as increases in population, CPI, and per capita CPI-adjusted constant dollar healthcare expenditures remain reasonably linear over time. Cubic growth is important to distinguish from exponential growth.

Although explaining the cubic growth of U.S. NHE, this model does not accurately predict future NHE. We performed multiple analyses to determine whether knowing that NHE increases cubically over time would allow accurate prediction of future NHE. For example, determining the cubic equation that best fit NHE's from 1960 to 1980 does not allow an accurate prediction of NHE in 1990. The reason for this failure to accurately predict is that each new data point of population, CPI, and per capita CPI-adjusted constant dollar healthcare expenditures does alter the corresponding linear equation slightly. The slightly altered linear equations will still accommodate all prior data points and produce a well-fitted cubic function describing their product of previous years' NHE. However, when the three slightly altered linear equations are multiplied together, their product will not accurately predict future NHE due to the compounding of errors. This dichotomy of hypotheses or models, those that accommodate and explain past data while failing to predict future data, is well-recognized in science [6-10]. A classic example of this dichotomy is Darwin's theory of evolution by natural selection. Darwin's theory explains the appearance and extinction of past species, but can not predict the future course of evolution [8]. Although unable to predict future NHE, appreciation of the cubic dynamics describing NHE may provide healthcare policy makers an improved framework upon which to assess and monitor the impact of healthcare policy changes.

Orszag and Ellis [11] suggested that "our country's financial health will in fact be determined by the growth rate of per capita health care costs." In this model of U.S. NHE growth used to predict cubic dynamics, one might

assume that population growth and CPI growth were relatively outside the influence of the U.S. healthcare system. The remaining factor, constant dollar per capita healthcare expenses, is consistent with the assertion made by Orszag and Ellis [11]. While inflation adjusted total per capita healthcare expenses have increased over time [12], some public sector (Medicare) per capita healthcare expenses have been claimed to have actually declined [13]. Nevertheless, the impact of escalating health care spending on the U.S. economy will continue to be debated [14-16].

4. Conclusions

Rising healthcare costs impacts all sectors of the U.S. economy and is eroding the sustainability of U.S. federal discretionary spending. Indeed, increasing healthcare costs are not exclusively a U.S. economic problem; escalating healthcare costs are a global problem. While this analysis does not attempt to show how to decrease the rate of healthcare cost growth, it does suggest that inflation-adjusted per capita healthcare costs is perhaps the best measure to track and monitor NHE growth. Moreover, this analysis suggests that healthcare policy changes that merely shift the cost of healthcare expenses will have little impact on NHE growth.

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