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A Note on Utilizing the Geometric Mean: When, Why and How the Forensic Economist Should Employ the Geometric Mean

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Abstract *Forensic Economists often utilize the arithmetic average for calculating growth rates to estimate economic damages. While it may be convenient to calculate the arithmetic average, it is mathematically inaccurate when such a rate is compounded. In such cases, it is incumbent upon the Forensic Economist to employ the geometric mean. In this note, we outline the when, why and how to employ the accurate use of the geometric mean.*

Introduction

A Forensic Economist (“FE”) often assumes that all practitioners understand simple mathematical concepts. For example, we assume that the FE understands that median earnings differ from mean earnings and that mean earnings will be greater than median earnings because outliers exist in mean earnings. Likewise, we assume that the practicing FE understands the difference between a geometric and arithmetic mean. While we believe most FEs understand this difference, the reality is that an arithmetic mean is often used when the application of a geometric mean is required.

Brookshire and Slesnick (1991), in a survey of economists, point out that 33.3% of the economists responding said they used the arithmetic mean and 30.3% used the geometric mean. When this survey was first conducted in 1990, the convenience factor might have been very relevant since computing power and a simple but sophisticated spreadsheet were not as commonplace as today. Pelaez (1991) and Haydon and Webb (1992) specifically discuss utilizing the geometric mean or geometric value. Many authors

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just talk about the historical average without specifying the use of the geometric or the arithmetic mean, but their formulas suggest they are employing the geometric mean.

Ireland (2002 and 2006) suggests that the justification for utilizing the arithmetic mean rather than the geometric mean is that the difference between the two is usually too small to justify the additional work or the potential confusion when explaining the difference to a jury or trier-of-fact. Bonham and La Croix (1992) remind us that, if a forensic economist is going to use a simple forecasting method (such as averages) because it is easier to explain to a jury, then the economist must employ the proper methodology. While the difference between the two means may be small, it is nevertheless mathematically incorrect to use the arithmetic mean when the geometric mean is required. In addition the wider the variation of growth rates from year to year and the longer the time frame being examined, the larger the difference between the geometric and arithmetic means.

The purpose of this note is to explain the circumstances in which the geometric mean should be used and illustrate why the arithmetic mean overstates damages. Additionally, this note will provide tables that demonstrate how the geometric mean will always be less than the arithmetic mean.

When to Utilize the Geometric Mean

In determining economic losses for an injured or deceased individual, the FE often calculates averages of growth rates for earnings. Also, averages of growth rates are required in the utilization of various components of the Consumer Price Index (“CPI”), often to project future costs of a Life Care Plan. A third area is the estimation of discount rates to adjust the future earning or cost projections to their present value. When determining these various rates, the FE typically calculates an average rate based on actual annual historical percentage changes.

By definition, the arithmetic mean is applicable when several observations are added together to produce a total; subsequently the FE seeks to determine *if all the quantities had the same value, what would that value have to be in order to achieve the same total?* The arithmetic mean simply adds a series of numbers and divides that sum by the amount of numbers added together. This mean (or average) is the most commonly known and frequently referenced.

Typically, to determine a future growth rate, the FE calculates the historical percentage change on an annual basis, adds those annual percent changes, and subsequently divides by the number of years. The resulting

arithmetic mean rate is utilized to project future growth. We are not concerned with how many past years are used to estimate the growth rate. It is assumed the FE will be able to justify any period of time.

Using the arithmetic mean to project future growth overstates the growth rate by not accounting for the cumulative effect on the base, that is, the compounding effect from year to year. This problem can be corrected by determining the geometric mean. The geometric mean is established when various observations are multiplied together to produce a product to determine *if all the quantities had the same value, what would that value have to be in order to achieve the same product*. The difference between the means is that a series is added to determine the arithmetic and multiplied to establish the geometric with the geometric mean accounting for the compound effect. Thus, if the purpose of the growth rate is to account for compounding, then the geometric mean (not arithmetic) of historical data should be employed.

Why Utilize the Geometric Mean

The following example illustrates the difference between the arithmetic and geometric mean. Suppose a worker's wage increased 5.0% the first year, 16.0% the second year, and 3.0% the third year. The arithmetic mean is $(5.0 + 16.0 + 3.0) / 3 = 8.0\%$. The three numbers are added together to produce a sum and subsequently divided by 3.

The arithmetic mean can be illustrated by the following formula:

$$\bar{r} = \frac{1}{n} \sum_{i=1}^n r_i = \frac{1}{n} (r_1 + r_2 + \dots + r_n)$$

where r is the growth rate of wages (in this case, the annual percentage change).

When a worker receives a wage increase, we assume that each wage increase is a permanent addition to the base pay and not a onetime, lump sum amount. Thus, in the foregoing example, the 16% increase in the third year is based in part on the 5% increase from the prior year. Similarly, the 3% increase in the fourth year is based on the prior two years increases. In essence, we want to obtain the compounding growth rate of wages. To perform this calculation, the growth rates should not be added to each year (as in the arithmetic mean) but instead should be multiplied, or compounded by the cumulative growth rates from prior years. This method results in deter-

mining the geometric mean and is used any time several quantities are multiplied together.

When determining the geometric mean for the example above, we note that in order to establish the individual's earnings for the second year, the base earnings are multiplied by 1.05 (not added to the base). To establish earnings for the third year, to incorporate the second annual percentage change, the new base earnings are multiplied by 1.16; the fourth year base earnings are determined by multiplying the third year's base earnings by 1.03. To project earnings into the future for personal injury or wrongful death cases, the important quantity is the geometric mean of the actual historical earnings, or the three growth rates. The arithmetic mean of these three percentage changes is 8.0% while the geometric mean amounts to 7.85% or approximately 1.875% less than the arithmetic mean. When annual wage growth does not vary much from year to year, the difference between the arithmetic and geometric means is minimal. However, when the annual variation of growth is larger and as more years are used to determine the different means, the difference is more significant. Regardless of the magnitude of the difference in the geometric and arithmetic means utilizing the correct methodology is paramount in the calculation.

From a practical perspective, an otherwise flawless report can be sullied by employing the wrong mean. Doubt can be raised about the overall accuracy of the FE's calculation. For example, if testifying to growth rates when utilizing the arithmetic mean the FE may be asked, "Isn't it true, since you are essentially estimating the compound effect of wage increases, that the geometric mean should be utilized, and by using the arithmetic mean you are overestimating the loss?" The only answer that can be given is "yes." While the FE can explain how the difference is minor, ultimately the FE would be overestimating the damages. The obvious follow-up question from the cross-examining attorney is, "I wonder what other little overestimating errors you have made?"

Confusing the jury by elaborating on the difference between the two means can be avoided altogether by simply not using the words "geometric" or "arithmetic" in testimony and simply stating "mean." However, the actual calculation should incorporate the geometric mean and the report may note it. If, on cross examination, the FE is specifically asked about the two means, the explanation to the jury is fairly straightforward, illustrating the concept of compounding by using a simple savings account as an example.

The geometric mean can be illustrated by the following:

$$G_m = \left(\prod_{i=1}^n a_i \right)^{1/n} - 1 = \sqrt[n]{a_1 * a_2 * \dots * a_n} - 1$$

where $a_n = (1 + r)$ and r is the growth rate of wages.

It is important to note that the compounding effect is shown in $a_n = (1 + r)$. This is known as the decimal multiplier equivalent. Additionally, the $(1 + r)$ decimal multiplier equivalent solves the problem of non-positive growth rates discussed below. When the FE employs the spreadsheet function for the geometric mean in Microsoft's Excel ("geomean"), it is crucial to change the annual percentage growth rate r to $(1 + r)$. Thus, with a series of annual data points exhibiting percentage changes (growth), it is essential to convert those to $(1 + r)$ and calculate the geometric mean on $(1 + r)$. The geometric mean $(1 + r) \neq$ geometric mean r . To obtain the geometric mean r , simply subtract 1 from the decimal multiplier equivalent.

How to Utilize the Geometric Mean

Three common applications of growth rates for the FE include projecting future losses of wages, projecting future costs of a Life Care Plan, and determining discount rates for present value calculations.

When estimating wage growth rates for an injured or deceased individual, the FE might have case-specific data showing actual year-by-year growth. These may be the most appropriate data to project future earnings, but industry-specific data or data for union workers or public sector workers may help as well.

In the absence of actual historical earnings data or industry-specific data, the FE may consult the following (not all inclusive) statistical data as a proxy for data on the growth of wages:

- The "All Items" component of the "Consumer Price Index" (CPI-U);
- The "Average Hourly earnings" in the total private, nonagricultural industries from the U.S. Department of Labor;
- The "Average Weekly Earnings" in the total private, nonagricultural industries from the U.S. Department of Labor;
- The "Wages and Salaries" Employment Cost Index for the total private industries; and
- The "Total Compensation" Employment Cost Index for the total private industries.

Regardless which index, statistic, or actual data the FE utilizes for estimating the future growth rates, the arithmetic mean will always overestimate the loss when growth in each year is a positive number. By mathematical proof (not provided here), for a list of nonnegative real numbers, the following relationship holds:

$$\text{Arithmetic Mean} \geq \text{Geometric Mean}$$

The second use of growth rates that FEs utilize are in Life Care Plans. When a Life Care Plan has different components of losses in current dollars, the FE must project those losses into the future. The CPI for different medical care components is often utilized to provide historical price changes in order to estimate future cost increases. The annual index as well as the annual percent change is presented in the CPI data. Again, if the arithmetic mean is employed instead of the geometric mean, the growth and total Life Care Plan costs will be overestimated.

The third example illustrated in this paper is the yield on various interest-bearing investments utilized to determine discount rates from the Economic Report of the President (2007). When discount rates are required, actual current or statistical data can be consulted to determine the appropriate rate.

In all three uses discussed above, for positive growth rates, the geometric mean will always be less than the arithmetic mean. Thus, if we want to demonstrate the cumulative compounding effect of wage or price increases or discount rates the geometric mean should be applied. The reader can see the mathematical proof of this differential by doing a simple Google search of “Arithmetic-Geometric Mean Inequality.”

The most common example illustrated in finance to demonstrate the difference in the means is the classic stock price example. Suppose a stock price was \$10 as of January 1, 2005 and increased to \$20 as of January 1, 2006. As of January 1, 2007, the stock price returned to the original \$10. What was the growth rate of the stock price during this period? We know the price grew by zero (0)% from January 1, 2005 until January 1, 2007 because it returned to \$10. To determine the arithmetic mean rate of growth, we must first calculate the year-by-year growth as follows:

$$[(\text{End period price} - \text{Beginning period price}) / \text{Beginning period price}]$$

$$1^{\text{st}} \text{ year growth (1/1/05 to 1/1/06): } [\$20 - \$10] / \$10 = 100\%$$

$$2^{\text{nd}} \text{ year growth (1/1/06 to 1/1/07): } [\$10 - \$20] / \$20 = -50\%$$

The arithmetic mean growth rate is determined by adding the two growth rates and dividing by two, as follows:

$$[100\% - 50\%] / 2 = 25\%$$

Obviously, this is not accurate as we know the stock price did not increase; it was \$10 at the beginning of the first year and \$10 at the beginning of the third year. Thus, this simple example illustrates why the arithmetic mean is not appropriate when averaging economic series involving growth rates of prices, costs, or rates.

Applying the geometric mean in the example above, we first calculate the growth relative for each period as follows:

$$[\text{End of period price} / \text{Beginning of year price}]$$

$$1^{\text{st}} \text{ year growth relative (1/1/05 to 1/1/06): } [\$20 / \$10] = 2$$

$$2^{\text{nd}} \text{ year growth relative (1/1/06 to 1/1/07): } [\$10 / \$20] = .5$$

Applying the geometric mean formula above which multiplies the two computed growth relatives ($2 * .5 = 1.0$) and subsequently extracting the root equal to the number of relative observations [$(1.0)^{1/2} = 1.0$], then 1.0 results in $1.0 - 1.0 = 0$. Thus, the geometric mean demonstrates that the price did not increase. Accordingly, this simple example illustrates why the geometric mean should be utilized when averaging economic series involving growth rates of prices, costs, or rates.

It should be recognized that the geometric mean only works for positive growth rates as you are multiplying each year by the period growth rates. If growth is zero, then multiplying by zero is not possible. If the growth rate is negative, the geometric mean also presents a problem when attempting to obtain the compound annual growth rate for a series of numbers that contains a negative number. Intuitively, there is no compound annual growth rate for a series of numbers that include negative growth (or loss).

The decimal multiplier equivalent method is utilized in this paper, whereas $a_n = (I + r)$ solves the problem of negative growth rates (or loss). For example, if the growth rate of wages for an individual is 1% the first year with a decline of 2% the second year (as illustrated in our stock price example above), there will be an issue obtaining the geometric mean when $a_n = r$. However, employing $(a_n = I + r)$, the FE can account for no growth and negative growth.

By way of further explanation suppose that when the first year is complete, the plaintiff has 1.01 times more earnings than at the start of the year. If he has the original amount, such as \$30,000, and 1% more (or \$300) at the end of the first year, he has \$30,300. At the end of the second year, the plaintiff has 98% times what he started the second year with (\$30,300). That is, the original \$30,300 less 2%, or \$29,694. Thus, the numbers utilized to obtain the geometric mean are 1.01 and .98 ($a_n = I + r$), resulting in the mean of approximately 0.994887.

On average, earnings for the plaintiff are being multiplied by 0.994887 each year, or a loss of earnings of approximately 0.5113% ($1 - 0.994887$), not an average decline of -0.5% which is the arithmetic mean. By applying the decimal multiplier equivalent “growth relatives” of 1.01 and 0.98 (two positive numbers), the problem of determining the geometric mean inclusive of negative growth is resolved. Therefore, in the foregoing example, the compound annual growth rate is (approximately) negative 0.5113%.

Examples

Table 1: Percent change of hourly and weekly earnings, illustrates the five, ten, twenty and thirty-year arithmetic and geometric means of the average hourly earnings for Total Private, Goods-Producing, and Private Service-Producing production workers. The table also includes average weekly earnings from the Total Private production workers. Note that the data exhibited are not the decimal multiplier equivalents. Thus, the geometric mean is not calculated utilizing the data illustrated in the tables but instead is determined utilizing the aforementioned decimal multiplier equivalents. The FE has to make the adjustment of $(I + r)$ and then calculate the geometric mean on that series of numbers. Albeit a small difference, the geometric mean is always less than the arithmetic mean.

Table 2: Percent Change of Medical Care Costs illustrates the five, ten, twenty and thirty-year geometric and arithmetic means for the “All Items” component of the CPI, Medical Care CPI, Medical Care Services CPI, and Medical Care Commodities CPI. The general medical care sub-categories of the Consumer Price Index (M-CPI) could be correlated to the Life Care Plan. Although the FE may have to defend matching the M-CPI category to the appropriate category within the Life Care Plan, that is not at issue within this note. What is important is that if the FE utilizes the historical arithmetic average of the appropriate M-CPI category instead of the geometric mean, then the total Life Care Plan loss will be overestimated.

Given the potentially large values of Life Care Plans, especially for younger individuals, a small increase in the growth rate can raise future costs significantly.

Table 3: Percent Yield of Interest Rates exhibits the five, ten, twenty and thirty-year geometric and arithmetic means for three-year and ten-year U.S. Treasury Securities, Moody's Corporate AAA Bonds and Standard and Poor's High Grade Municipal Bonds. As with the CPI, the FE may have to defend which instrument is selected for discounting; however, if the FE utilizes the historical arithmetic average of the appropriate instrument instead of the geometric mean, then the discount rate will be overestimated, thus lowering the present value.

Conclusion

Tables 1, 2, and 3 demonstrate that the geometric mean will always be less than the arithmetic mean: this relationship is a mathematical certainty. While the difference between the two can be small, the gap is more significant when the rates are widely dispersed and spread over a longer time frame. Nevertheless, it is incumbent upon the FE to be mathematically accurate and employ the geometric mean. Current electronic technology allows almost instantaneous access to government data. Spreadsheets make any additional time necessary to calculate the geometric mean trivial given the more accurate measurement. A Forensic Economist would be hard-pressed not to have access to any of these data sources and spreadsheet programs. Additionally, the red flag of doubt may be raised if the incorrect mean was used which may discredit a FE's testimony under cross-examination. This can be avoided by utilizing the mathematically accurate geometric mean. Therefore, when cumulative compounding of rates is required, few limitations prevent the FE from making the correct geometric mean calculation.

TABLE 1- PERCENT CHANGE OF HOURLY AND WEEKLY EARNINGS

EARNINGS PRODUCTION WORKERS

Year	AVG HOURLY			AVG WEEKLY
	Total Private	Goods- Producing	Private Service Providing	Total Private
<i>r = percentage change from year to year</i>				
1977	7.5099	8.1967	6.8182	6.9141
1978	8.0882	9.0909	7.5435	7.7829
1979	7.8231	8.6420	7.1942	7.2209
1980	8.0442	8.8068	7.8859	6.8321
1981	8.6131	9.7911	8.0871	8.6140
1982	5.7796	7.0155	5.8993	4.2766
1983	4.1931	3.5556	4.7554	4.7933
1984	3.5366	3.7554	3.2425	4.1303
1985	2.9446	3.5160	2.7638	2.3591
1986	2.1739	1.8981	2.5672	1.5867
1987	2.3516	1.8627	2.8605	2.3526
1988	3.2823	2.8874	3.4762	2.9827
1989	3.8136	3.2741	4.4793	3.5148
1990	4.0816	3.8043	4.1801	3.4457
1991	3.1373	2.6178	3.6008	2.5046
1992	2.3764	1.9558	2.7805	2.7168
1993	2.5998	2.4187	2.6087	2.8893
1994	2.6244	2.8502	2.5424	3.2542
1995	2.7337	2.6128	2.9385	2.2622
1996	3.3476	3.2407	3.3898	3.3019
1997	3.9037	3.2885	4.1415	4.4957
1998	3.9968	2.9667	4.4739	3.8670
1999	3.6895	3.3732	3.8065	3.2526
2000	3.9288	3.8069	4.0489	3.8562
2001	3.7090	3.3399	4.1116	2.6569
2002	2.9574	3.4854	2.8914	2.6185
2003	2.6720	2.8781	2.7416	2.2379
2004	2.0820	2.3214	2.0013	2.1291
2005	2.8043	2.3851	2.9431	2.8804
2006	3.9058	2.3864	4.3202	4.3246
Arithmetic Mean:				
5-year (2002-06)	2.8843	2.6913	2.9795	2.8381
10-year (1997-06)	3.3649	3.0232	3.5480	3.2319
20-year (1987-06)	3.1999	2.8878	3.4168	3.0772
30-year (1977-06)	4.0901	4.0675	4.1698	3.8685
Geometric Mean:				
5-year (2002-06)	2.8826	2.6903	2.9768	2.8351
10-year (1997-06)	3.3629	3.0220	3.5450	3.2287
20-year (1987-06)	3.1980	2.8863	3.4143	3.0750
30-year (1977-06)	4.0729	4.0414	4.1560	3.8531

TABLE 2- PERCENT CHANGE OF MEDICAL CARE COSTS				
Year	CPI - ALL URBAN CONSUMERS			
	All Items	Medical Care	Medical Care Services	Medical Care Commodities
<i>r = percentage change from year to year</i>				
1977	6.5026	9.6154	9.9415	6.5487
1978	7.5908	8.4211	8.5106	6.9767
1979	11.3497	9.2233	9.8039	7.1429
1980	13.4986	10.9630	11.3095	9.2754
1981	10.3155	10.6809	10.6952	11.0080
1982	6.1606	11.5802	11.8357	10.2748
1983	3.2124	8.7568	8.7473	8.5590
1984	4.3173	6.1630	5.9583	7.2854
1985	3.5611	6.2734	6.0918	7.1628
1986	1.8587	7.4890	7.6855	6.5972
1987	3.6496	6.6393	6.6448	6.6775
1988	4.1373	6.5334	6.3846	6.7939
1989	4.8183	7.7201	7.6645	7.7913
1990	5.4032	9.0422	9.2680	8.3554
1991	4.2081	8.7224	8.8506	8.2007
1992	3.0103	7.4011	7.5663	6.3914
1993	2.9936	5.9442	6.5092	3.6683
1994	2.5606	4.7666	5.1750	2.9231
1995	2.8340	4.5024	5.0609	1.8934
1996	2.9528	3.4921	3.6574	2.8851
1997	2.2945	2.8046	2.8830	2.3289
1998	1.5576	3.1969	3.2204	3.0190
1999	2.2086	3.5109	3.3630	4.0126
2000	3.3613	4.0702	4.2728	3.2076
2001	2.8455	4.6012	4.8120	3.9899
2002	1.5810	4.6921	5.0574	3.5541
2003	2.2790	4.0266	4.4725	2.4961
2004	2.6630	4.3756	5.0000	2.4734
2005	3.3880	4.2244	4.7930	2.4879
2006	3.2258	4.0223	4.1283	3.5870
Arithmetic Mean:				
5-year (2002-06)	2.6274	4.2682	4.6902	2.9197
10-year (1997-06)	2.5405	3.9525	4.2003	3.1157
20-year (1987-06)	3.0986	5.2144	5.4392	4.3368
30-year (1977-06)	4.3447	6.4485	6.6454	5.5856
Geometric Mean:				
5-year (2002-06)	2.6253	4.2679	4.6897	2.9183
10-year (1997-06)	2.5385	3.9509	4.1976	3.1138
20-year (1987-06)	3.0941	5.1991	5.4242	4.3160
30-year (1977-06)	4.3068	6.4192	6.6162	5.5534

TABLE 3- PERCENT YIELD OF INTEREST RATES				
Year	U.S. TREASURY SECURITIES		MOODY'S	S & P's
	3-Year	10-Year	Corporate Aaa	High-Grade Muni Bonds
<i>r = percentage change from year to year</i>				
1977	6.6900	7.4200	8.0200	5.5600
1978	8.2900	8.4100	8.7300	5.9000
1979	9.7100	9.4400	9.6300	6.3900
1980	11.5500	11.4600	11.9400	8.5100
1981	14.4400	13.9100	14.1700	11.2300
1982	12.9200	13.0000	13.7900	11.5700
1983	10.4500	11.1000	12.0400	9.4700
1984	11.8900	12.4400	12.7100	10.1500
1985	9.6400	10.6200	11.3700	9.1800
1986	7.0600	7.6800	9.0200	7.3800
1987	7.6800	8.3900	9.3800	7.7300
1988	8.2600	8.8500	9.7100	7.7600
1989	8.5500	8.4900	9.2600	7.2400
1990	8.2600	8.5500	9.3200	7.2500
1991	6.8200	7.8600	8.7700	6.8900
1992	5.3000	7.0100	8.1400	6.4100
1993	4.4400	5.8700	7.2200	5.6300
1994	6.2700	7.0900	7.9600	6.1900
1995	6.2500	6.5700	7.5900	5.9500
1996	5.9900	6.4400	7.3700	5.7500
1997	6.1000	6.3500	7.2600	5.5500
1998	5.1400	5.2600	6.5300	5.1200
1999	5.4900	5.6500	7.0400	5.4300
2000	6.2200	6.0300	7.6200	5.7700
2001	4.0900	5.0200	7.0800	5.1900
2002	3.1000	4.6100	6.4900	5.0500
2003	2.1000	4.0100	5.6700	4.7300
2004	2.7800	4.2700	5.6300	4.6300
2005	3.9300	4.2900	5.2400	4.2900
2006	4.7700	4.8000	5.5900	4.4200
Arithmetic Mean:				
5-year (2002-06)	3.3360	4.3960	5.7240	4.6240
10-year (1997-06)	4.3720	5.0290	6.4150	5.0180
20-year (1987-06)	5.5770	6.2705	7.4435	5.8490
30-year (1977-06)	7.1393	7.6963	8.6763	6.7440
Geometric Mean:				
5-year (2002-06)	3.3318	4.3956	5.7232	4.6237
10-year (1997-06)	4.3634	5.0264	6.4121	5.0170
20-year (1987-06)	5.5618	6.2596	7.4353	5.8439
30-year (1977-06)	7.0982	7.6635	8.6507	6.7267

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