On Comparison of Temporal Disaggregation Methods in Flow Variables of Economic Data.

Isaac O. Ajao¹; Femi J. Ayoola²; and Joseph O. Iyaniwura²

²Department of Statistics, University of Ibadan, Ibadan, Nigeria.

E-mail: isaacoluwaeyeiajao@gmail.com
            ayoolafemi@yahoo.com
            jo_iyaniwura@yahoo.com

ABSTRACT

In this paper, annual Gross Domestic Products (GDP) were converted into quarterly series for Nigeria using observed annual time-series data for the period 1981-2012. Five different econometric disaggregation techniques, namely the Denton, Denton-Cholette, Chow-Lin-maxlog, Fernandez, and Litterman-maxlog, are used for quarterization. We made use of quarterly export and import as the indicator variables while disaggregating annual into quarterly data. The time series properties of estimated quarterly series were examined using various methods for measuring the accuracy of prediction such as, Theil's Inequality Coefficient, Root Mean Squared Error (RMSE), Absolute Mean Difference (MAD), and Correlation Coefficients. Results obtained showed that export and import are not good indicators for predicting GDP as far as Nigeria is concerned for the period covered. Denton method is the worst using the metrics such as Mean Absolute Difference (MAD) and Theil's Inequality Coefficient. However, RSME% and Pearson's correlation coefficient gave robust values for Litterman-maxlog, thereby making it the best method of temporal disaggregation of Nigeria GDP.

(Keywords: Chow-Lin-maxlog, Fernandez, GDP, Temporal disaggregation, Litterman-maxlog)

INTRODUCTION

A traditional problem often faced generally by economic researchers is the interpolation or distribution of economic time series observed at low frequency into compatible higher frequency data. While interpolation refers to estimation of missing observations of stock variables, a distribution (or temporal disaggregation) problem occurs for flow aggregates and time averages of stock variables. Temporal disaggregation is the process of deriving high frequency data from low frequency data, and is closely related to benchmarking and interpolation.

Temporal disaggregation has been extensively considered by previous econometric and statistical literature and many different solutions have been proposed. Broadly speaking, two alternative approaches have been followed: methods which do not involve the use of related series but rely upon purely mathematical criteria or time series models to derive a smooth path for the unobserved series; methods which make use of the information obtained from related indicators observed at the desired higher frequency.

All disaggregation methods ensure that the sum, the average, the first or the last value of the resulting high frequency series is consistent with the low frequency series. They can deal with situations where the high frequency is an integer multiple of the low frequency (e.g. years to quarters, weeks to days), but not with irregular frequencies (e.g. weeks to months). Temporal disaggregation methods are widely used in official statistics. For example, in France, Italy and other European countries, quarterly figures of Gross Domestic Product (GDP) are computed using disaggregation methods. Outside of R, there are several software packages to perform temporal disaggregation: Ecotrim by Barcellan et al. (2003); a Matlab extension by Quilis (2012); and a RATS extension by Doan (2008).

Temporal disaggregation is used to disaggregate or interpolate a low frequency to a higher frequency time series, while the sum, the

The Pacific Journal of Science and Technology
http://www.akamaiuniversity.us/PJST.htm

Volume 16. Number 2. November 2015 (Fall)
average, the first or the last value of the resulting high-frequency series is consistent with the low frequency series. Disaggregation can be performed with or without the help of one or more indicator series. It can deal with all situations where the high frequency is an integer multiple of the low frequency (e.g. weeks to days), but not with irregular frequencies (e.g. weeks to months).

The selection of a temporal disaggregation model is similar to the selection of a linear regression model. Despite the number of empirical studies conducted to evaluate the merits of various methods of temporal disaggregation, there is no consensus that one method is consistently superior in all situations. Rather, a common conclusion is that the choice of method depends on the desired application. However, few empirical results have attempted to establish the conditions under which some of these methods may have an advantage over competing models. Most empirical studies have focused on applying these methods to relatively well-behaved series; for example, constructing quarterly estimates of GDP (Abeysinghe and Lee, 1998; Di Fonzo and Marini, 2005a; Trabelsi and Hedhili, 2005) manufacturing (Brown, 2012), or retail and wholesale trade data (Brown, 2012; Dagum and Cholette, 2006; Di Fonzo and Marini, 2005b) from observed annual levels.

**Denton Process**

The first method used for interpolation is the proportional Denton procedure. This method also computes the interpolation of a time series observed at low frequency by using a related high-frequency indicator time series. The Denton process imposes the condition that the sum of the interpolated series within each year equals the annual sum of the underlying series for that particular year. As recommended in International Monetary Fund (IMF) publications, this method is “relatively simple, robust, and well-suited for large-scaled applications.” In particular, the Denton process may useful in cases where the higher frequency indicators do not considerably associated with the low-frequency time series of the interest. Specifically, this method minimizes the distance between the two time series as much as possible using quadratic minimization framework.


However, we have changed the notations. Let \( G \) be an integer, and assume that our concern is \( G \) per year intra-annual time periods (in our case quarters). Let \( T \) be a number of years and the time series of interest spans over \( T \) years, consisting \( n = G \times T \) observations. The original figures are given in column-vector form as follows:

\[
t = \begin{bmatrix} t_1, t_2, \ldots, t_n \end{bmatrix}
\]

(1)

Further, assume that a column-vector of \( T \) annual sums is available from another data source, which is represented by:

\[
b = \begin{bmatrix} b_1, b_2, \ldots, b_n \end{bmatrix}
\]

(2)

Denton (1970, 1971) proposed a method in order to make adjustment in the preliminary vector \( t \) to derive a new column vector:

\[
\lambda = \begin{bmatrix} \lambda_1, \lambda_2, \ldots, \lambda_n \end{bmatrix}
\]

(3)

The Denton method satisfies the two conditions: (i) minimization of the distortion of the primary series (ii) equalization of the sum of the \( G \) observations of the derived series in a specific year to the given annual sum for that year. A penalty function given by \( p(\lambda, b) \), and select the \( \lambda \) so as to minimize the penalty function given the following constraint:

\[
\sum_{k=1}^{G} \lambda_k = b_n \quad \text{for} \quad N = 1, 2, \ldots, T
\]

(4)

**Chow-Lin Method**

This procedure is known as the best linear unbiased estimator (BLUE) approach, which was developed by Chow and Lin (1971, 1976). In this method, a regression model relates the unknown disaggregated series and a set of known high frequency indicators. Suppose that annual series of \( N \) years are available which is to be disaggregated into quarterly series, which is related to the \( k \) indicator (related) series and then relationship between the disaggregated series (to be estimated) and indicators series is:

\[
y = X\beta + e
\]

(5)
where \( y \) is \((n \times 1)\) vector \((n = 4N)\) of the quarterly series to be estimated, \( X \) is the matrix \((n \times k)\) of the \( k \) indicator variables which are observed quarterly, \( \beta \) is a \((k \times 1)\) vector of coefficients, and \( e \) is the \((n \times 1)\) vector of stochastic disturbances with mean, \( E(e) = 0 \) and variance, \( E(ee') = V \), where \( V \) is a \((n \times n)\) matrix.

It has to be mentioned that the disaggregated model at the high frequency level (here quarterly) is subject to the usual aggregation constraints:

\[
Y = B'y \tag{6}
\]

Substituting (5) into (6) gives a regression equation for the observed annual series in relation to the quarterly indicator series:

\[
Y = B'x\beta + B'e \tag{7}
\]

The regression coefficients \( \beta \) then can be calculated by using the Generalized Least Squares (GLS) estimator as:

\[
\hat{\beta} = \left[ X' B (B'VB)^{-1} B' X \right]^{-1} X' B (B'VB)^{-1} Y \tag{8}
\]

The estimated sub-period of the quarterly time series data is derived as:

\[
\hat{Y} = X\hat{\beta} + VB(B'VB)^{-1} [Y - B' X\hat{\beta}] \tag{9}
\]

**Fernandez Random Walk Process**

Fernandez (1981) proposed the usual regression model of Chow-Lin; and estimates \( \hat{\beta} \) and \( \hat{y} \) but assuming that the disturbances (residuals) in the disaggregated model follow a random walk process as:

\[
u_t = u_{t-1} + \varepsilon_t,
\]

\( t = 1, 2, \ldots, n \)

\[
\varepsilon_t \sim N(0, \sigma^2),
\]

\[
u_0 = 0
\]

**Litterman Random Walk Markov Process**

The other variant of Chow-Lin is the random walk Markov model derived by Litterman (1983 and also Di Fonzo, 1987) as:

\[
u_t = u_{t-1} + \varepsilon_t,
\]

\[
\varepsilon_t = \alpha \varepsilon_{t-1} + \varepsilon_t
\]

**Estimating the Autoregressive Parameter**

There are several ways to estimate the autoregressive parameter \( r \) in the Chow-Lin and Litterman methods. An iterative procedure has been proposed by Chow and Lin (1971). It infers the parameter from the observed autocorrelation of the low frequency residuals, \( u \). In a different approach, Bournay and Laroque (1979) suggest the maximization of the likelihood of the GLS-regression:

\[
L(\rho, \sigma^2) = \frac{\exp \left[ -\frac{1}{2} u' (C \Sigma C')^{-1} u \right]}{(2\pi)^{n/2} \left[ \det(C \Sigma C') \right]^{1/2}} \tag{10}
\]

Where,

\[
C = \begin{bmatrix} 1 & 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 \end{bmatrix}
\]

is the conversion matrix and,

\[
\rho = \hat{\beta} X
\]

The maximum likelihood estimator of the autoregressive parameter, \( \hat{\rho} \), is a consistent estimator of the true value, thus it has been chosen as the working estimator. However, in some cases, \( \hat{\rho} \) turns out to be negative even if the true \( \rho \) is positive.

A final approach is the minimization of the weighted residual sum of squares (RSS), as it has been suggested by Barbone et al. (1981):

\[
RSS(\rho, \sigma^2, \beta) = u' (C \Sigma C')^{-1} u \tag{11}
\]
Contrary to the maximum likelihood approach, \( \sigma^2 \) does not cancel out. The results are thus sensitive to the specification of \( \Sigma \), with different implementations leading to different but inconsistent estimations of \( \rho \).

**DATA AND METHODS**

All analyses were carried out using R version 3.1.3 (R Development Core Team, 2015).

**Temporal Disaggregation without Indicator Denton Method**

Call:
```r
td(formula = GDPannual ~ 1, conversion = "sum", to = "quarterly", method = "denton")
```

Residuals:
- Min: 227251
- 1Q: 290166
- Median: 372520
- 3Q: 536161
- Max: 888889

No Coefficients

'denton' disaggregation with 'sum' conversion
32 low-freq. obs. converted to 128 high-freq. obs.
criterion: proportional order of differencing 'h': 1

**Chow-Lin-maxlog**

Call:
```r
td(formula = GDPannual ~ 1, conversion = "sum", to = "quarterly", method = "chow-lin-maxlog")
```

Residuals:
- Min: 338794
- 1Q: 275878
- Median: 193524
- 3Q: 29884
- Max: 322845

Coefficients:
- Estimate: 141512
- Std. Error: 77133
- t value: 1.835
- Pr(>|t|): 0.0762

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

'chow-lin-maxlog' disaggregation with 'sum' conversion
32 low-freq. obs. converted to 128 high-freq. obs.
Adjusted R-squared: -3.775e-15 AR1 Parameter: 0.9989

**Fernandez**

Call:
```r
td(formula = GDPannual ~ 1, conversion = "sum", to = "quarterly", method = "fernandez")
```

Residuals:
- Min: -24017
- 1Q: 38898
- Median: 121252
- 3Q: 284893
- Max: 637621

Coefficients:
- Estimate: 62818
- Std. Error: 4805
- t value: 13.07
- Pr(>|t|): 3.73e-14

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

'fernandez' disaggregation with 'sum' conversion
32 low-freq. obs. converted to 128 high-freq. obs.
Adjusted R-squared: 3.331e-16 AR1 Parameter: 0
Litterman-maxlog

Call:
  `td(formula = GDPannual ~ 1, conversion = "sum", to = "quarterly",
    method = "litterman-maxlog")`

Residuals:
  Min     1Q Median     3Q    Max
  -23640  39276 121629 285270 637998

Coefficients:
  Estimate Std. Error   t value
  (Intercept)     62724       1208  51.93   ***
  ---
  Signif. codes:  0 '***' 0.001 '**' 0.01 '

'GDPannual' disaggregation with 'sum' conversion
32 low-freq. obs. converted to 128 high-freq. obs.
Adjusted R-squared: 7.108e-11  AR1-Parameter: 0.9391

Metrics for Measuring the Accuracy of Prediction

We begin by examining the performance of each method based on statistics that measure the accuracy of each method with respect to the levels of the original series. Theil’s (1961) inequality coefficient, U, which is a measure of accuracy used in forecasting (Leuthold, 1975) used by Trabelsi and Hedhili (2005), is given by equation:

\[ U = \frac{1}{N} \frac{1}{\sqrt{\frac{1}{N} \sum_{n=1}^{N} p_n^2 + \frac{1}{N} \sum_{n=1}^{N} a_n^2}} \sum_{n=1}^{N} (p_n - a_n)^2 \]

where \( p_n \) is the predicted value and \( a_n \) is the actual value in quarter \( n \). The U statistic takes on a value between 0 and 1, where \( U = 0 \) indicates that the method used is a perfect predictor of the actual series (Leuthold, 1975; Trabelsi and Hedhili, 2005). Consistent with Trabelsi and Hedhili (2005), we also calculate the mean of the absolute differences between actual, \( a \), and predicted values, \( p \).

Abeyesinghe and Lee (1998) employed a different criterion, the Root Mean Squared Error as a percent of the mean (RMSE%) of the observed series, in which a lower value implies a more accurate prediction.

The Root Mean Square Error (also called the root mean square deviation, RMSD) is a frequently used measure of the difference between values predicted by a model and the values actually observed from the environment that is being modelled. These individual differences are also called residuals, and the RMSE serves to aggregate them into a single measure of predictive power.

The RMSE of a model prediction with respect to the estimated variable \( X_{model} \) is defined as the square root of the mean squared error:

\[ \text{RMSE} = \sqrt{\frac{1}{N} \sum_{i=1}^{n} (X_{obsi} - X_{model,i})^2} \]

It can be observed from Table 1 that all the five methods used have the same mean of 108244 as the true GDP values. Denton-Chollette and Fernandez share the similar properties. Denton, Denton-Chollette, Chow-Lin and Fernandez have a uniform median of 93206, while Litterman has a different value.

Table 2 indicates that the three methods Denton-Chollette, Chow-Lin, and Fernandez perform similarly with Mean Absolute Difference (MAD) of 6117.3, this means that any of the three methods is better that either Denton or Litterman methods as far as the data used is concerned.

Considering the Inequality coefficient (U), the minimum value 0.0197 is common with the Denton-Chollette, Chow-Lin, and Fernandez, the worst method is Denton with coefficient 0.02. Using the RSME% as a metric, Litterman method is the best method with the least value 10.09%, while Denton is the least accurate with the highest percentage of 10.56%.
Table 1: Summary Statistics of the True Quarterly GDP and Estimated.

<table>
<thead>
<tr>
<th>Factor</th>
<th>True values</th>
<th>Denton</th>
<th>Denton-Cholette</th>
<th>Chow-Lin</th>
<th>Fernandez</th>
<th>Litterman</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>56260</td>
<td>36422</td>
<td>55745</td>
<td>55744</td>
<td>55745</td>
<td>55591</td>
</tr>
<tr>
<td>1st Qtr</td>
<td>72522</td>
<td>73946</td>
<td>71059</td>
<td>71059</td>
<td>71059</td>
<td>70925</td>
</tr>
<tr>
<td>Median</td>
<td>93173</td>
<td>93206</td>
<td>93206</td>
<td>93206</td>
<td>93206</td>
<td>93180</td>
</tr>
<tr>
<td>Mean</td>
<td>108244</td>
<td>108244</td>
<td>108244</td>
<td>108244</td>
<td>108244</td>
<td>108244</td>
</tr>
<tr>
<td>3rd Qtr</td>
<td>128624</td>
<td>135518</td>
<td>135518</td>
<td>135518</td>
<td>135518</td>
<td>135427</td>
</tr>
<tr>
<td>Maximum</td>
<td>263679</td>
<td>224855</td>
<td>224855</td>
<td>224790</td>
<td>224855</td>
<td>226958</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>47713.61</td>
<td>46172.42</td>
<td>46073.53</td>
<td>46073.50</td>
<td>46073.53</td>
<td>46076.39</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>0.96</td>
<td>-0.01</td>
<td>-0.02</td>
<td>-0.02</td>
<td>-0.02</td>
<td>-0.01</td>
</tr>
<tr>
<td>Skewness</td>
<td>1.25</td>
<td>0.98</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Table 2: Absolute Mean Difference (MAD), Inequality Coefficient (√), and Root Mean Squared Error % (RMSE).

<table>
<thead>
<tr>
<th>Factor</th>
<th>Denton</th>
<th>Denton-Cholette</th>
<th>Chow-Lin</th>
<th>Fernandez</th>
<th>Litterman</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAD</td>
<td>6618.22</td>
<td>6117.15</td>
<td>6117.54</td>
<td>6117.15</td>
<td>6128.83</td>
</tr>
<tr>
<td>Theil's U</td>
<td>0.0241</td>
<td>0.0197</td>
<td>0.0197</td>
<td>0.0197</td>
<td>0.0199</td>
</tr>
<tr>
<td>RMSE%</td>
<td>10.56</td>
<td>10.17</td>
<td>10.17</td>
<td>10.17</td>
<td>10.09</td>
</tr>
</tbody>
</table>

Table 3: Correlation Matrix of the Various Methods.

<table>
<thead>
<tr>
<th>Method</th>
<th>GDPreal</th>
<th>Denton</th>
<th>DentonCH</th>
<th>Chow-Lin</th>
<th>Fernandez</th>
<th>Litterman</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDPreal</td>
<td>1.0000</td>
<td>0.97067</td>
<td>0.97283</td>
<td>0.97282</td>
<td>0.97283</td>
<td>0.97324</td>
</tr>
<tr>
<td>Denton</td>
<td>0.97067</td>
<td>1.0000</td>
<td>0.99787</td>
<td>0.99786</td>
<td>0.99787</td>
<td>0.99787</td>
</tr>
<tr>
<td>DentonCH</td>
<td>0.97283</td>
<td>0.99787</td>
<td>1.0000</td>
<td>1.0000</td>
<td>1.0000</td>
<td>0.99998</td>
</tr>
<tr>
<td>Chow-Lin</td>
<td>0.97282</td>
<td>0.99786</td>
<td>1.0000</td>
<td>1.0000</td>
<td>1.0000</td>
<td>0.99998</td>
</tr>
<tr>
<td>Fernandez</td>
<td>0.97283</td>
<td>0.99787</td>
<td>1.0000</td>
<td>1.0000</td>
<td>1.0000</td>
<td>0.99998</td>
</tr>
<tr>
<td>Litterman</td>
<td>0.97324</td>
<td>0.99787</td>
<td>0.99998</td>
<td>0.99998</td>
<td>0.99998</td>
<td>1.0000</td>
</tr>
</tbody>
</table>

Disaggregated values from Denton, Denton-Cholette, Chow-Lin, and Fernandez methods related favorably with the real GDP, but the series produced using Litterman method was better with a correlation coefficient of 0.97324.

From Figure 1, it can be seen that all other four methods of disaggregation are similar in shape with the real GDP annual series (frame 1) expect Denton (frame 2) having departures at the beginning of the series.
Figure 1: Temporal Disaggregation using Various Methods.
Comparing the true values with the disaggregated using the five methods, it is discovered that the it is only the Denton method that is having a slight change at the beginning of the series.

**Using some indicator series**

```r
new <- td(GDPannual ~ exports + imports)
summary(new)
```

Call:
```
td(formula = GDPannual ~ exports + imports)
```
The result from using exports and imports as indicator series indicates that Nigeria GDP is not significantly influenced by her exports and imports, that is, they are not good indicators for predicting the GDP. The $R^2$ of 0.08 is too low when talking about accuracy and reliability of any model.

**CONCLUSION AND RECOMMENDATION**

In this paper, we disaggregated annual Gross Domestic Product (GDP) of Nigeria to quarterly series using Denton, Denton-Cholette, Chow-Lin, Fernandez, and Litterman methods. Further test was carried out to verify the possibility of using a related indicator series (export) to make forecast of GDP, but the result obtained showed that export is not a good indicator for predicting GDP as far as Nigeria is concerned for the period covered. Later, comparison is made among the quarterly GDP series obtained by these methods (Appendix).

It was found out that Denton method is the worst using the metrics such as Mean Absolute Difference (MAD) and Theil’s Inequality coefficient. However, RSME% and Pearson’s correlation coefficient gave robust values for Litterman, thereby making it the best method of temporal disaggregation of Nigeria GDP. It can be recommended that Litterman method of temporal disaggregation could be used by users in need of higher frequency data, such as the GDP, import, export and so on. Future researchers who wish to do comparison of methods should explore the Cubic Spline Interpolation method.

**REFERENCES**


Techniques and Their Application to Official Statistics.


**APPENDIX:** Disaggregated Quarterly GDP using the Five Methods.

<table>
<thead>
<tr>
<th>QTRS</th>
<th>GDPReal</th>
<th>Denton</th>
<th>Denton-Choielle</th>
<th>Chow-Linmaxlog</th>
<th>Fernandez</th>
<th>Littermanmaxlog</th>
</tr>
</thead>
<tbody>
<tr>
<td>1981Q1</td>
<td>63433.0800</td>
<td>36422.0424</td>
<td>62818.0061</td>
<td>62880.1077</td>
<td>62818.0061</td>
<td>62739.1053</td>
</tr>
<tr>
<td>Q2</td>
<td>62446.9700</td>
<td>61526.8704</td>
<td>62796.0317</td>
<td>62799.0177</td>
<td>62796.0317</td>
<td>62769.8860</td>
</tr>
<tr>
<td>Q3</td>
<td>61818.9800</td>
<td>75315.4840</td>
<td>62752.0828</td>
<td>62722.0520</td>
<td>62752.0828</td>
<td>62791.0293</td>
</tr>
<tr>
<td>Q4</td>
<td>63353.2500</td>
<td>77787.8832</td>
<td>62666.1594</td>
<td>62650.6296</td>
<td>62666.1594</td>
<td>62752.2595</td>
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<tr>
<td>1982Q1</td>
<td>61555.1700</td>
<td>68944.0679</td>
<td>62598.2616</td>
<td>62583.3131</td>
<td>62598.2616</td>
<td>62577.8853</td>
</tr>
<tr>
<td>Q2</td>
<td>61338.7900</td>
<td>62501.5716</td>
<td>62196.4549</td>
<td>62195.7368</td>
<td>62196.4549</td>
<td>62166.5007</td>
</tr>
<tr>
<td>Q3</td>
<td>60930.5000</td>
<td>58460.3944</td>
<td>61480.7391</td>
<td>61487.8454</td>
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<td>61473.1307</td>
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<tr>
<td>Q4</td>
<td>62857.1000</td>
<td>56820.5361</td>
<td>60451.1144</td>
<td>60459.6565</td>
<td>60451.1144</td>
<td>60509.0534</td>
</tr>
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<td>1983Q1</td>
<td>58056.4900</td>
<td>57581.9968</td>
<td>59107.5807</td>
<td>59111.1687</td>
<td>59107.5807</td>
<td>59341.8448</td>
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<td>57965.2150</td>
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<td>Q3</td>
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<td>57024.0171</td>
<td>57023.0930</td>
<td>57024.0171</td>
<td>56925.4734</td>
</tr>
<tr>
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http://www.akamaiuniversity.us/PJST.htm
Volume 16. Number 2. November 2015 (Fall)
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Note: The table contains data for the years 2000 to 2015, with each year having four quarters and each quarter showing the total revenue for that period.
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