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2005

Online at <https://mpra.ub.uni-muenchen.de/10822/>  
MPRA Paper No. 10822, posted 29 Sep 2008 09:19 UTC

## Forecasting International Bandwidth Capability

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### ABSTRACT

M-competition studies provide a set of stylized recommendations to enhance forecast reliability. However, no single method dominates across series, leading to consideration of the relationship between selected data characteristics and the reliability of alternative forecast methods. This study conducts an analysis of predictive accuracy in relation to Internet bandwidth loads. Extrapolation techniques that perform best in M-competitions perform relatively poorly in predicting Internet bandwidth loads. Such performance is attributed to Internet bandwidth data exhibiting considerably less structure than M-competition data. Copyright © 2005 John Wiley & Sons, Ltd.

KEY WORDS bandwidth; forecast comparisons

### INTRODUCTION

M-competition outcomes due to Makridakis and Hibon (1979, 2000), Makridakis *et al.* (1982, 1993) provide much information. These stylized outcomes, as summarized by Makridakis and Hibon (2000), are: statistically simpler models perform better than complex methods; ranking of competing methods varies across accuracy measures; combining forecasts perform best; and accuracy depends on the forecast horizon. Clements and Hendry (2001) contrast these conclusions with their theoretical research that demonstrates for weakly stationary processes, a congruent, encompassing model in-sample, based on causal variables, performs best for forecast horizons. Further, the practice of pooling forecasts does not enhance accuracy.

The conflicting results of forecast performance obtained from theoretical predictions and the stylized results of M-competitions are due to the non-stationary and evolving nature of data being modelled by M-competition participants (Clements and Hendry, 2001). Simple models, they argue, offer adaptability while complicated models are susceptible to structural breaks. Moreover, these data are not reducible to stationarity through differencing. More generally, Fildes and Ord (2002) indicate that prior knowledge of the data-generating process permits a link to be established between particular data characteristics and the forecast reliability of alternative methods.

The link between the underlying properties of the data and forecast performance is explored in Fildes (1992) and Fildes *et al.* (1998). In examining a set of 263 telecommunications time series,

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Fildes (1992) concludes that Robust Trend, developed specifically to forecast the telecommunications series, performs best. Additionally, Fildes *et al.* (1998) provide a framework to compare and contrast the respective properties of the telecommunications and M-competition data. The use of a common set of summary statistics allows Fildes *et al.* to observe the relative performance of methods in relation to data characteristics. For example, they attribute an increased random component of the M-competition data to the relative decline in Robust Trend performance.

Following Fildes *et al.*, this paper provides further information on the link between exhibited data characteristics and forecast reliability of methods. In doing so, a direct comparison with the earlier results is permitted. Moreover, like Fildes (1992) a single data type is examined—an index that measures Internet bandwidth loads.<sup>1</sup> The paper is organized as follows. The next section describes sample data. Discussion of the alternative forecast models is contained in the third section. Model results are presented in the fourth section, and concluding remarks are presented in the final section.

## DATA

The data set is comprised of 58 time series, each containing 232 observations. These data are sampled from a continuous data-generating process and obtained daily at 7 a.m. Australian Eastern Standard Time weekdays from 18 February 2000 to 3 March 2001. A representative specimen of these data is shown in Figure 1. These data oscillate between zero and 100 and appear to exhibit characteristics typical of stationary series. Another feature, common to many series in the data set, is the presence of occasional downward spikes. Spikes indicate high congestion and, depending on the

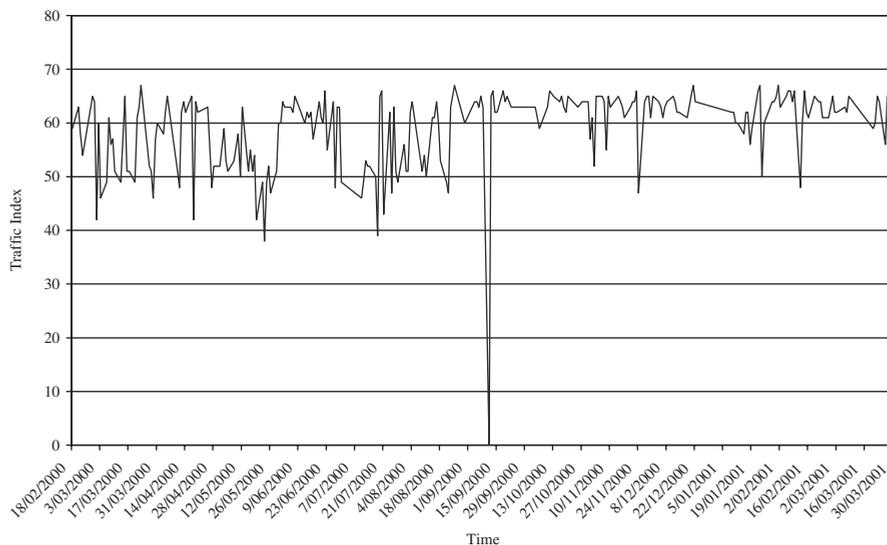


Figure 1. Japan dm-gw1.kddnet.ad.jp  
Source: Opinix (2001).

<sup>1</sup>The Internet Traffic Report URL is <http://www.internettrafficreport.com/index.html>.

motivation for generating forecasts, can be treated as outliers that are atypical or incorporated in the model as infrequent but important characteristics of the data-generating process.

Summary statistics indicate the frequency of the downward spikes with 27 of the 58 routers reporting at least one minimum value below the 25th percentile. Sampled regions include Australia, East Asia, Israel, North America, Russia, South America and Western Europe. Regions not included are Africa, Antarctica and most of the Middle East. The Denver denver-br2.bbnplanet.net router is recorded as providing the fastest response, while AOL1 pop1-dtc.atdn.net has the lowest response time. On average, the Perth1 opera.iinet.net.au router consistently provides the fastest response. Yahoo fe3-0.cr3.SNV.globalcenter.net typically records the slowest response.<sup>2</sup> The sample average coefficient of variation is 6.3 and the corresponding standard deviation is 1.8.

Following Fildes (1992), the frequency of outliers, strength of trend, degree of randomness and seasonality are analysed. The results are shown in Figures 2 to 5. An observation  $X_t$  is treated as an outlier when either  $X_t < L_x - 1.5(U_x - L_x)$  or  $X_t > L_x + 1.5(U_x - L_x)$ , where  $L_x$  denotes the lower quartile and  $U_x$  the upper quartile. The strength of trend is measured by the correlation between series (with outliers removed) and a time trend, with the absolute value of the trend indicating its strength. Randomness is measured by estimating the regression:

$$X'_t = \alpha + \beta t + \delta_1 X'_{t-1} + \delta_2 X'_{t-2} + \delta_3 X'_{t-3} \quad (1)$$

where  $X'_t$  denotes the series  $X_t$  with outliers removed.  $\bar{R}^2$  measures the variation explained by the model. High  $\bar{R}^2$  indicates low randomness, while low  $\bar{R}^2$  reveals high randomness. Deterministic seasonality is estimated by regressing the series on an intercept and dummy variables which equal one when  $t = s$ , where  $t$  denotes observation  $X_t$ 's position in time and  $s$  corresponds to the frequency of the seasonality. For example, to test the hypothesis that Mondays are statistically different to bandwidth capacity for the rest of the week,  $t = \{1, 2, 3, 4, 5, \dots, T\}$ ,  $s = \{1, 5, 10, 15, \dots, T\}$  and dummy variable  $D_{\text{Monday}} = 0$  for  $t = s$ , zero otherwise.

Figure 2 reveals half the series contain between 1% and 5% outliers. In percentage terms these data appear slightly more heterogeneous than Fildes' (1992) telecommunications data. Figure 3 shows that these data are generally uncorrelated with time. This contrasts with Fildes, where the data exhibit strong negative trends. Moreover, histograms contained in Figures 3 and 4 reveal that variation in these data presents a high degree of randomness with little serial correlation.

Finally, Figure 5 presents some evidence of regularity in weekly capacity variation aggregated by region. There appear regular dips occurring on different days across regions. Typically, Asia experiences lower traffic volumes from Wednesday through Friday, while most Australian routers have excess capacity from Monday through Tuesday. Conversely, Europe and North America experience a smoother traffic flow—perhaps due to more sophisticated capacity pricing and network management systems. Finally, South American Internet traffic variation is tied to particular routers.

The regressions are also conducted to test for regularity of both weekly and monthly traffic patterns. Weekly variation is not apparent, with only six routers reporting regular spikes across weeks. Surprisingly, given the short time series, substantial monthly variation was found for 95% of sampled routers.<sup>3</sup> Although the sustained increase in traffic is too haphazard across routers to reveal a cycli-

<sup>2</sup>Time-of-day and scale-of-demand effects may impact on router performance. For example, the Perth router services a small market and is likely to have relatively low congestion early in the morning, while in real time, the Yahoo router may be at peak demand in the mid-to-late afternoon.

<sup>3</sup>Comparisons between consecutive months are considered here.

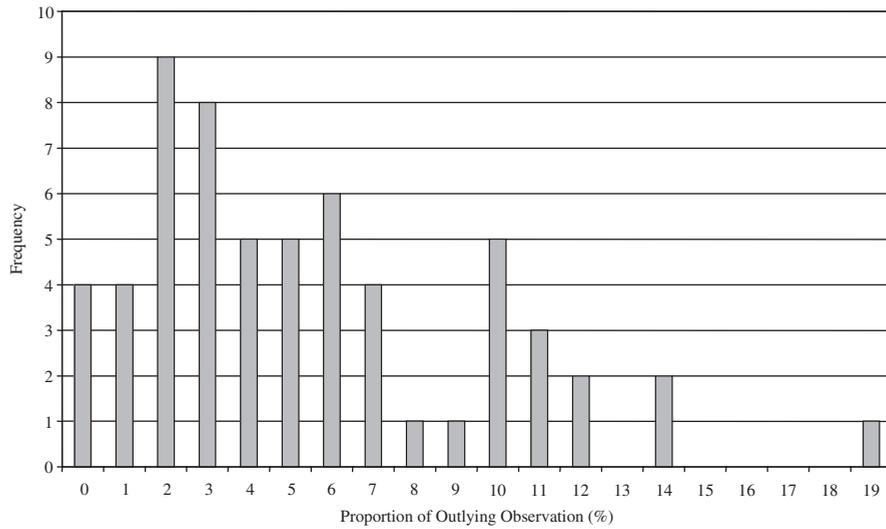


Figure 2. Outlier frequency

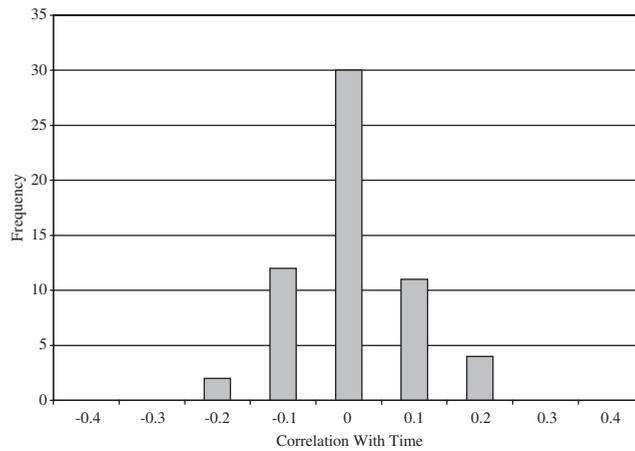


Figure 3. Strength of linear trend

cal pattern, most routers experience significant increases for an average of 2 months, with some routers showing surges of up to 3 months. This pattern may reflect the average lagged response time required before routers are expanded to cope with the increased traffic. Once expanded, the Internet traffic index for the router is likely to increase, reflecting a permanent increase in capacity. To sum, the data series exhibit a high degree of randomness with not infrequent spikes in index scores apparent. Compared to telecommunications data analysed in Fildes (1992) and Fildes *et al.* (1998), these data appear considerably more heterogeneous and so less predictable.

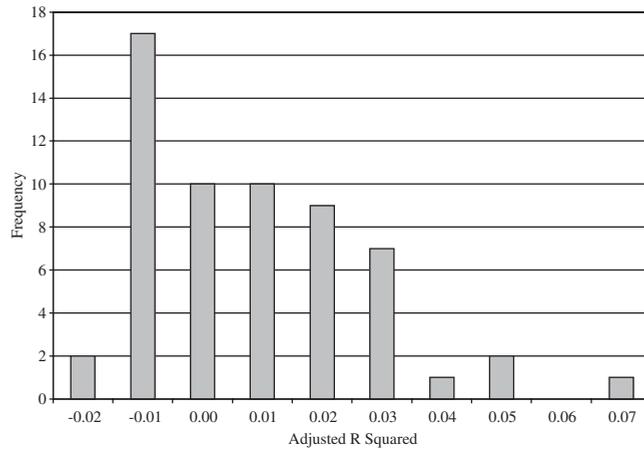


Figure 4. Variation explained by linear/AR

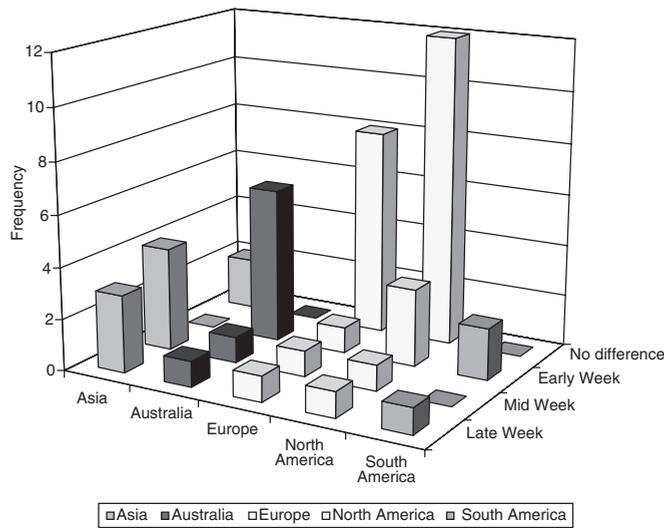


Figure 5. Daily variation in capacity utilization

### FORECAST MODELS AND ACCURACY MEASURES

Forecast models considered here are univariate ARARMA, ARMA, Filtered Trend, Holt, Holt-D exponential smoothing and Robust Trend against a benchmark Random Walk model. With the exception of Filtered Trend, these forecast methods have been shown to be reliable by Fildes (1992), Makridakis *et al.* (1993), Fildes *et al.* (1998) and Makridakis and Hibon (2000), and consistently perform well in the M-competition. Implicit in these analyses, however, is that the majority of data included in the M-competition are non-stationary, while data analysed here are stationary. Given this

fundamental difference in assumption, some of the forecast techniques are modified to avoid problems associated with over-differencing. For example, the ARMA method is applied rather than ARIMA. ARARMA explicitly questions the practice of differencing to achieve stationarity and has an advantage of utilizing information contained in these data, normally lost when differencing. Moreover, the approach outlined in Parzen (1982) contains a method of determining when it is appropriate to apply the AR filter, hence the method is adopted intact. Filtered Trend is simple extrapolation based on a regression of a series on a deterministic time trend after outliers have been removed. Holt and Holt-D methods provide adaptable alternatives to Filtered Trend while also retaining the advantage of simplicity and reliability. However, to ensure the opportunity for accuracy is maximized, the parameter is re-estimated for each new estimation period, as recommended in Fildes *et al.* (1998), rather than being held fixed. Robust Trend differences the data before calculating the stochastic trend. The perceived advantage in adopting this method is the outlier filter and its use of the median rather than mean in estimation, which may provide some advantage over the simple Random Walk extrapolation. Accordingly, for comparison, Random Walk is employed as the benchmark. When outliers do not bias estimation, Random Walk forecasts are difficult to improve on, given the reported properties of these data.

The choice of accuracy measures is guided by the recommendations of Armstrong and Collopy (1992). They argue that the Mean Absolute Percentage Error (MAPE), Median Absolute Percentage Error (MdAPE), % Better, Geometric Mean Relative Absolute Error (GMRAE) and Median Relative Absolute Error (MdRAE) best assess forecast performance. Both GMRAE and MdRAE are Winsorized as recommended by Armstrong and Collopy. Mean square error measures are avoided since these statistics are scale-dependent and sensitive to outliers.

## FORECASTS

To identify the most accurate forecasting methods, six sets of forecasts are created by dividing these data into estimation and forecast segments. The estimation period is shifted forward 10 observations post-estimation. The model is re-estimated on this sample, and so on. Each forecast method uses 117 observations to forecast over the next 60 observations.<sup>4</sup> That is, the approach uses a rolling window beginning at the first observation and steps forward 10 days, re-estimating the forecasts over the next 117 observations. The approach provides 348 forecasts with an equal lead time of 60 periods per method to judge forecast performance. In evaluating the reliability of the alternative methods, forecasts are compared to post-sample data values. The number of forecast windows is maximized to offset the distortions created by outlying observations at the end of each estimation window.<sup>5</sup>

All forecast methods are estimated in SHAZAM utilizing automatic procedures. For example, ARMA is implemented by conducting a grid search of autoregressive moving average parameters with maximum lag length set to 10. The best performing model is deemed to be the one that scores the lowest Akaike Information Criterion statistic. The test for the long-memory filter in ARARMA (Parzen's  $\text{Err}(\tau)$  statistic) is used to determine the filter's lag length. The long-memory procedure is

<sup>4</sup>60-day forecasts are necessary due to the existence of standard capacity contracts.

<sup>5</sup>The effects of distortions created by these data are complex. To simplify the analysis, a total of 24 zero observations are replaced with variable medians after estimation. This is done to separate the anomalies observed in the forecast error measures. An attempt to predict the zero observations is being conducted in a separate forecast study.

verified using the results from the illustrative example provided in Parzen (1982).<sup>6</sup> In most cases, the model is determined to be short memory and is estimated as an unfiltered ARMA. In a portion of the cases deemed to be long memory the  $\text{Err}(\tau)$  statistic is less than zero. Analysis of the international airline data used by Parzen along with simulated data shows that data with exponential trends always yield positive  $\text{Err}(\tau)$  statistics. By contrast, the Internet bandwidth data does not exhibit any trend. The explanation for negative  $\text{Err}(\tau)$  statistics is provided by examining the calculations for  $\text{Err}(\tau)$  and the long-memory coefficient  $\hat{\phi}(\tau)$ , which are defined as:

$$\hat{\phi}(\tau) = \hat{\rho}(\tau) \frac{SSQ(T)}{SSQ(T-\tau)} \quad \text{and} \quad \text{Err}(\tau) = 1 - |\hat{\phi}(\tau)|^2 \frac{SSQ(T-\tau)}{SSQ(T) - SSQ(\tau)} \quad (2)$$

$\hat{\rho}(\tau)$  is the sample correlation coefficient between the current observation and its counterpart lagged  $\tau$  periods.  $SSQ(T)$  is the sum of squares for all observations in the estimation window and  $SSQ(T-\tau)$  is the sum of squares for observations between one and the observation corresponding to  $T-\tau$ . In the Internet bandwidth data, the calculated sum of squares increases linearly as  $T$  increases. Thus, the rate of increase in the ratio  $SSQ(T)/SSQ(T-\tau)$  is greater than the rate of decline in  $\hat{\rho}(\tau)$  (as lag  $\tau$  increases), resulting in a calculated coefficient  $\hat{\phi}(\tau)$  that can at times be substantially greater than one. The magnitude of the coefficient dominates the calculated  $\text{Err}(\tau)$ , resulting in a negative statistic. Rejection of negative  $\text{Err}(\tau)$  statistics results in estimation of short-memory ARMA models. This problem is indicative of the need to consider the underlying properties of the data prior to selecting specific forecast methods.

In general, selected models for both ARMA and ARARMA exhibit short lags (on average between one and four lags) and are, therefore, highly adaptive. Seventeen percent of ARARMA models calculated positive  $\text{Err}(\tau)$  statistics that are less than the critical value, resulting in estimates of  $\hat{\phi}(\tau)$  that range between 0.94 and 1.02. Holt, Holt-D and Robust Trend parameters are optimized for each estimation window and series.

Table I presents forecast accuracy results through average absolute error calculations. In general, Filtered Trend performed better than the other methods with Robust Trend the next best. ARARMA and Holt-D consistently performed worst. The ARARMA statistic is biased by 23% of forecast models with substantial forecast errors. In general, it appears that the poor performance of ARARMA is closely related to outliers near the end of some estimation windows in a number of series. Of these, 30% correspond to use of the long-memory filter. The poor performance of Holt-D is likely due to over-differencing. Although Robust Trend also differences these data, parameter estimates are often small in magnitude. Thus, forecast errors deteriorate gradually. The short-term good performance of ARMA provides some assurance that automatic procedures can model time series reasonably well. In the longer term, ARMA overtakes Robust Trend, indicating that flexible estimation of adaptive methods may be better for longer horizons.

Further evaluation is reported in Table II, which presents the GMRAE and MdRAE forecast error measures. Both GMRAE and MdRAE compare each method to a 'no-change' benchmark forecast. A score of less than one indicates the forecast method is at least more reliable than the Random Walk benchmark. By these criteria Filtered Trend is the only method to consistently outperform the benchmark.

An important factor is accuracy variation over forecast horizons. M-competition results indicate some methods are better for short-term forecasts, while others perform better over longer horizon.

<sup>6</sup>The  $\text{Err}(\tau)$  statistic is calculated for lags 1 to 100, correctly selecting lag 12. The calculated  $\hat{\phi}(\tau)$  is 1.021468.

Table I. Mean absolute percentage error

Method	Forecasting horizon							
	1	20	40	60	1–5	1–25	1–45	1–60
ARARMA	356	180	151	137	328	237	198	180
ARMA	15	53	<b>13</b>	14	151	159	116	94
Filtered Trend	8	<b>10</b>	15	<b>5</b>	<b>13</b>	<b>18</b>	<b>8</b>	<b>8</b>
Holt	17	67	36	50	100	110	116	122
Holt-D	136	134	132	132	133	134	134	134
Robust Trend	<b>0</b>	29	36	48	14	22	25	28

Note: Bold minimum MAPE statistic indicates the best performed method.

Table II. Geometric mean RAE and median RAE

Method	Geometric mean RAE					
	1	12	24	36	48	60
ARARMA	2.97	2.51	2.36	1.95	2.08	2.12
ARMA	1.92	1.74	1.56	1.33	1.32	1.31
Filtered Trend	0.98	<b>0.57</b>	<b>0.75</b>	<b>0.70</b>	<b>0.63</b>	<b>0.77</b>
Holt	1.07	1.59	1.93	2.22	2.71	3.51
Holt-D	1.34	1.40	1.08	1.12	1.15	1.30
Robust Trend	<b>0.84</b>	1.07	1.14	1.58	1.83	1.77

Method	Median RAE					
	1	12	24	36	48	60
ARARMA	5.33	3.19	3.12	2.43	2.55	2.97
ARMA	2.19	1.95	1.58	1.43	1.65	1.59
Filtered Trend	<b>0.97</b>	<b>0.65</b>	<b>0.87</b>	<b>0.91</b>	<b>0.77</b>	<b>0.83</b>
Holt	1.15	1.95	2.57	2.78	4.11	5.01
Holt-D	1.69	1.58	1.17	1.06	1.20	1.43
Robust Trend	1.00	1.06	1.09	1.45	1.72	1.93

Note: Statistic in bold indicates the best performed method.

Figure 6 reports the cumulative forecast errors for the initial estimation window. As Figure 6 clearly shows, ARARMA is consistently worst. Interestingly, ARMA cumulative forecast accuracy improves as the forecast horizon lengthens, overtaking Holt and Holt-D. However, in terms of cumulative errors, none of the adaptive forecasts are particularly reliable.

Finally, Table III presents the proportion of better than Random Walk extrapolation forecasts. Results suggest that the best forecast method, Filtered Trend, has only a one in two chance of performing better than the naïve forecast. For relatively short horizons, Robust Trend outperforms the naïve benchmark. Robust Trend's gradual deterioration in forecasts corresponds to its fixed trend direction, whereas ARMA and Holt are able to accommodate trend changes. Further, the results reaffirm the relatively poor performance of ARARMA.

To sum, the results show that Internet bandwidth is most reliably forecast in the short run by deterministic trend methods. MAPE statistics show that Robust Trend tracks index values with an average

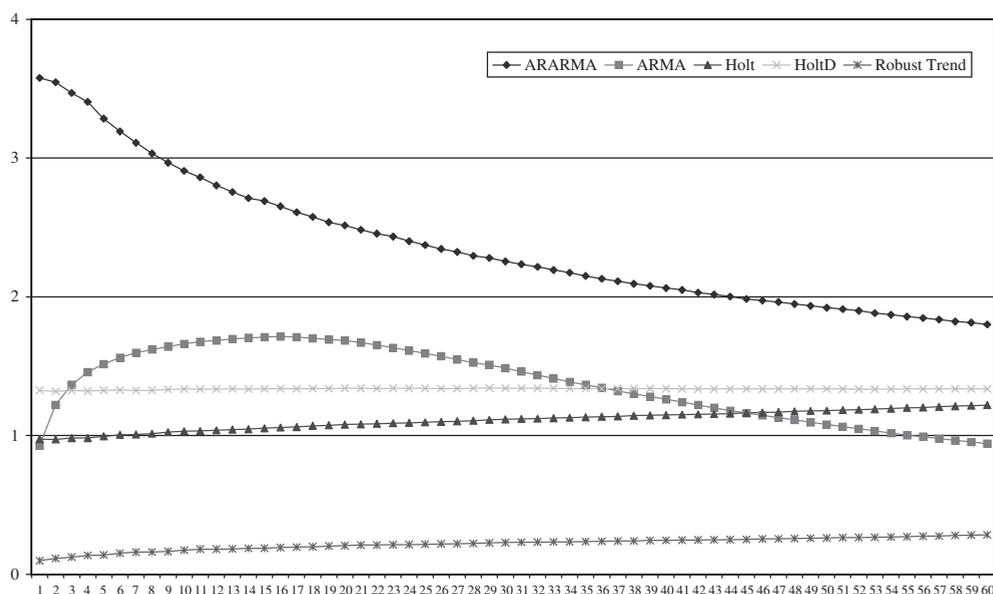


Figure 6. Cumulative mean absolute percentage error

Table III. Percent better

Method	Forecast horizon										
	1	6	12	18	24	30	36	42	48	54	60
ARARMA	19	20	19	16	18	17	20	18	19	21	21
ARMA	32	44	39	35	46	41	44	38	35	41	48
Filtered Trend	47	53	<b>62</b>	<b>53</b>	51	41	<b>53</b>	<b>55</b>	<b>59</b>	47	<b>56</b>
Holt	49	40	32	29	27	23	24	20	18	14	14
Holt-D	44	49	40	47	<b>52</b>	<b>47</b>	53	44	53	<b>48</b>	46
Robust Trend	<b>51</b>	<b>53</b>	44	40	42	34	34	31	30	27	29

Note: Bold indicates best performed method.

variation of 28%, while ARMA’s average forecast provides a slight improvement for longer time horizons. The convergence in accuracy between ARMA and Filtered Trend suggests that ARMA may be useful in confirming the long forecasts generated by Filtered Trend. Finally, the inherent stationarity of these data may explain the failure of ARARMA and Holt-D forecast methods.

### CONCLUSIONS

The study provides further evidence as to the link between data characteristics and forecast accuracy for specific univariate extrapolation methods. Forecast techniques employed here are extrapo-

lation methods that perform well in the M-competition and are easily implemented. In evaluating methods, a single data series is utilized to facilitate the analysis of forecast performance, conditional on the properties of these data. Analysis of summary statistics reveals that bandwidth data exhibit considerably less structure than telecommunications data as reported by Fildes (1992) and M-competition data (Fildes *et al.*, 1998). As a result, the univariate extrapolation methods perform poorly when compared to previous studies. This outcome is not surprising as univariate extrapolation methods are intended to exploit data regularities, such as autocorrelation and trend direction, generally not present in bandwidth data. Study findings highlight the need to better understand the data characteristics, prior to forecasting. In particular, the high degree of randomness and the presence of outliers are responsible for the performance of Filtered Trend and Robust Trend in relation to the other forecast methods. Finally, future research directed at developing a consistent approach to data classification may provide further useful insights into the optimal selection of forecast method.

#### ACKNOWLEDGEMENTS

We thank Jim Alleman, Robert Fildes and two anonymous referees for helpful comments. Coble-Neal benefited greatly from a presentation by J. Scott Armstrong delivered at the ICFC 2000 Conference in Seattle, Washington, September 2000. The usual disclaimer applies.

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**Grant Coble-Neal** was Research Associate at the Communication Economics and Electronic Markets Research Centre (CEEM), Curtin University of Technology, Australia from 1999 to 2003. During that time Grant co-authored several articles with Gary Madden analyzing various aspects of the telecommunications industry. Prior to joining CEEM, Grant worked for several government agencies. He is currently attempting to complete his doctoral studies.

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