

**PARSIMONY AND OMITTED FACTORS: THE AIRLINE MODEL
AND THE CENSUS X-11 ASSUMPTIONS**

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El Banco de España al publicar esta serie pretende facilitar la difusión de estudios de interés que contribuyan al mejor conocimiento de la economía española.

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Abstract.

Box and Jenkins proposed the so called "airline" model (AL) as a prototype model for monthly time series. In addition, several authors have tried to identify the type of ARIMA model for which the Census X-11 method is suitable, and have found that it is: $\Delta\Delta_{12} X_t = \psi(L)a_t$. (CX), where $\psi(L)$ is a polynomial of order the 14, 25 or 26.

In this paper we study the significance of the difference between AL and CX by approximating CX by a more parsimonious model. The model obtained for the approximation of CX is an Arima (1,1,2)(0,1,1), which for the standard option of the Census X-11 program is estimated as: $(1-0.94L)\Delta\Delta_{12} X_t = (1-1.61L+0.89L^2)(1-0.47L^{12})a_t$. We denote the Arima (1,1,2)(0,1,1) models with similar characteristics by ALX.

The most notable difference between ALX and AL models can be seen in the corresponding autocorrelation function (acf). This difference consists of a decreasing sequence of positive values in lags two to ten ($\rho_2=0.2$) of the acf of ALX models. Thus we see that these models represent a prototype of Arima models, which incorporates a stability factor which is absent from the AL model.

Key Words: ARIMA model, Seasonal models, Seasonal adjustment.

I.- Introduction.

In the Box-Jenkins (1970) text the following ARIMA model

$$(1-L)(1-L^{12})X_t = (1-\theta_1 L)(1-\theta_{12} L^{12})a_t \quad (1)$$

is suggested as being one that can be useful for monthly seasonal series. This point is illustrated by fitting the model to a data series of airline passengers. Several authors have subsequently found that (1) is a convenient model to explain monthly series and it has come to be known as the airline model.

For monthly series the X-11 seasonal adjustment method is widely used and Cleveland and Tiao (1976) have investigated the type of ARIMA model for which the X-11 method is appropriate. This problem was faced earlier by Cleveland (1972) and has recently been studied by Burrige and Wallis (1984). These last authors study, not only the standard X-11 procedure, but also two others that imply

shorter and longer filters, respectively. We will denote these three alternatives by X-11(84), X-11(72) and X-11(108) (*).

The models that the above-mentioned studies propose as support for the X-11 method are of the following type:

$$\Delta\Delta_{12}X_t = \psi(L)a_t, \quad (2)$$

and the coefficients of the $\psi(L)$ are given in table 1(**). The autocorrelation functions corresponding to a type of process $\{W\}$ such that

$$W_t = \Delta\Delta_{12}X_t = \psi(L)a_t,$$

are given in table 2 and figure 1, for the different $\psi(L)$ polynomials of table 1.

Inspection of table 1 and figure 1 suggests that model (1) could be an approximation of the models expressed in (2), because the important ψ_j coefficients are ψ_1 and ψ_{12} . Nevertheless the models in table 1 are not exactly like model (1). In fact, looking at the autocorrelation functions (acf) of W_t ,

(*) These three alternatives refer to symmetric filters. Burrige and Wallis (1984) also considered the X-11 method with non-symmetric filters but in this paper we are only concerned with the case of symmetric filters.

(**) We are grateful to Prof. Wallis for supplying us with the models for X-11(72) and X-11(108).

Table 1.

$$\psi(L) = 1 + \psi_1 L + \psi_2 L^2 + \dots + \psi_{26} L^{26}$$

ψ_j	BURRIDGE- WALLIS X-11(72)	BURRIDGE- WALLIS X-11(108)	BURRIDGE- WALLIS X-11(84)	CLEVELAND X-11	CLEVELAND- TIAO X-11
ψ_0	1.000	1.000	1.000	1.000	1.000
ψ_1	-0.681	-0.663	-0.67	-0.23	-0.337
ψ_2	0.317	0.272	0.29	0.25	0.144
ψ_3	0.220	0.232	0.23	0.22	0.141
ψ_4	0.205	0.226	0.22	0.22	0.139
ψ_5	0.195	0.222	0.21	0.22	0.136
ψ_6	0.185	0.218	0.20	0.22	0.131
ψ_7	0.175	0.215	0.20	0.22	0.125
ψ_8	0.165	0.212	0.19	0.22	0.117
ψ_9	0.156	0.210	0.19	0.21	0.106
ψ_{10}	0.112	0.206	0.18	0.20	0.093
ψ_{11}	0.070	0.173	0.12	0.14	0.077
ψ_{12}	-0.106	-0.530	-0.33	-0.55	-0.417
ψ_{13}	0.213	0.656	0.45	0.29	0.232
ψ_{14}	0.044	0.003	0.02	-0.01	-
ψ_{15}	0.002	-	-	-	-
ψ_{16}	0.001	-	-	-	-
ψ_{17}	-	-	-	-	-
ψ_{18}	-	-	-	-	-
ψ_{19}	-0.001	-	-	-	-
ψ_{20}	-0.002	-	-	-	-0.001
ψ_{21}	-0.002	-	-	-	-0.003
ψ_{22}	-0.003	-	-	-	-0.004
ψ_{23}	-0.021	-0.007	-0.01	-	-0.006
ψ_{24}	0.087	0.025	0.04	-	0.035
ψ_{25}	-0.085	-0.024	-0.04	-	-0.021
ψ_{26}	0.026	0.007	0.01	-	-

Table 2.

AUTOCORRELATION FUNCTIONS

LAG	BURRIDGE- WALLIS X-11(72)	BURRIDGE- WALLIS X-11(108)	BURRIDGE- WALLIS X-11(84)	CLEVELAND X-11	CLEVELAND- TIAO X-11
0	1.000	1.000	1.000	1.000	1.000
1	-0.326	-0.323	-0.306	-0.061	-0.250
2	0.234	0.189	0.208	0.266	0.130
3	0.168	0.166	0.178	0.226	0.120
4	0.153	0.150	0.160	0.201	0.110
5	0.134	0.129	0.139	0.175	0.090
6	0.117	0.112	0.117	0.150	0.080
7	0.089	0.093	0.100	0.125	0.070
8	0.072	0.072	0.077	0.100	0.050
9	0.071	0.056	0.060	0.075	0.040
10	0.043	0.040	0.049	0.045	0.030
11	0.125	0.272	0.227	0.178	0.180
12	-0.141	-0.378	-0.300	-0.326	-0.350
13	0.106	0.257	0.209	0.153	0.160
14	0.019	0.001	0.008	-0.004	-
15	0.002	0.001	-	-	-
16	-	0.001	-	-	-
17	0.001	0.001	-	-	-
18	0.002	0.001	-	-	-
19	0.001	0.001	-	-	-
20	0.001	0.001	-	-	-
21	-	0.001	-	-	-
22	0.015	0.001	0.005	-	-
23	-0.054	-0.010	-0.021	-	-0.010
24	0.084	0.016	0.032	-	0.030
25	-0.058	-0.008	-0.021	-	-0.010
26	0.016	-	0.005	-	-

Figure 1.

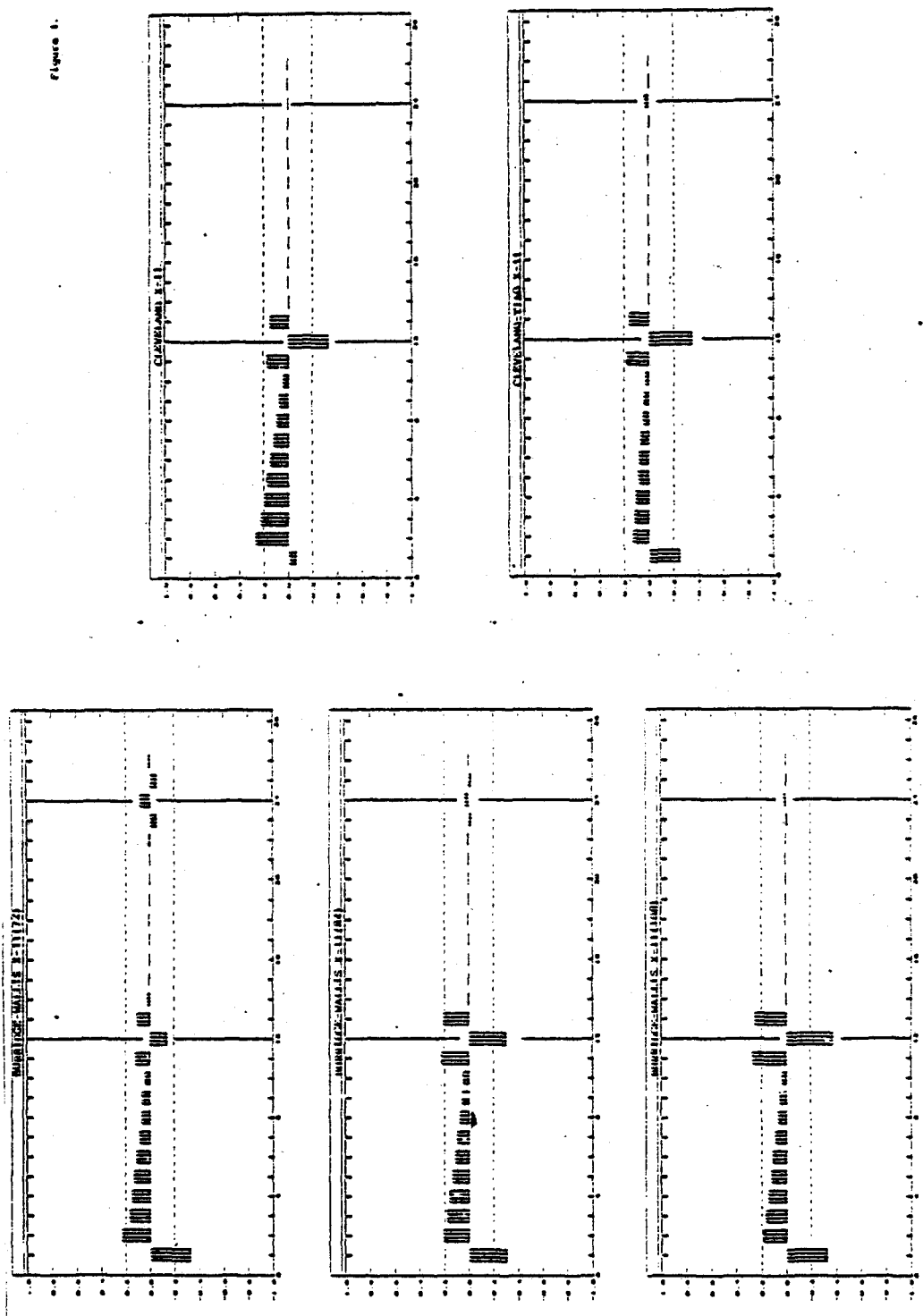


table 2 and figure 1, we observe that they differ in two aspects with respect to the acf of model (1). Firstly, the acf of (2) has values different from zero at lags 2 to 10 and, secondly, although it may be symmetric around lag 12, the constraint.

$$\rho_{11} = \rho_{13} = \rho_1 \cdot \rho_{12}.$$

is not fulfilled.

What we aim to do here is to look at the importance of the difference between the two models and then, if the difference is not trivial, to determine which model could be taken as a better prototype to explain monthly seasonal series. To study these differences in section II of the paper we approximate model (2) by a more parsimonious model such as (6). Then the properties of (6) and (1) are compared and important differences are detected in the regular factors; (6) is thus proposed as a better prototype model. In section III we point out some implications of the results.

II.- A parsimonious model supporting the X-11 method.-

It is worthy of note that with simple models for the trend and seasonal components the above-mentioned studies obtain the overall complex model (2)(*). This makes one suspect that model (2) could be approximated quite well by an ARIMA model with only a few parameters.

For models of type (2) with polynomials $\Psi(L)$, as given in Table 2, we try to approximate them by model (1) and by the following other models:

$$\Delta\Delta_{12}x_t = \frac{(1-\theta_1L - \theta_2L^2 - \theta_{12}L^{12} - \theta_{13}L^{13})}{(1-\phi L_1)} a_t \quad (3)$$

$$\Delta\Delta_{12}x_t = \frac{(1-\theta_1L - \theta_2L^2 - \theta_{12}L^{12} - \theta_{13}L^{13} - \theta_{14}L^{14})}{(1-\phi L_1)} a_t \quad (4)$$

$$\Delta\Delta_{12}x_t = \frac{(1-\theta_1L - \theta_2L^2)(1-\theta_{12}L^{12})}{(1-\phi_1L)(1-\phi_{12}L^{12})} a_t \quad \text{and} \quad (5)$$

$$\Delta\Delta_{12}x_t = \frac{(1-\theta_1L - \theta_2L^2)(1-\theta_{12}L^{12})}{(1-\phi_1L)} a_t \quad (6)$$

(*) All these authors search for an overall model fixing the autoregressive part at $\Delta\Delta_{12}$ and to what extent this restriction is responsible for the complexity of (2) still remains to be studied.

Models (3) to (6) have been chosen because they contain sufficient factors to capture the essential aspects of the autocorrelation function of model (2).

In the approximation process we expand the stationary ARMA filter of models, (1) and (3)-(6), in a moving average form, $\Psi^*(L) = 1 + \Psi^*_1 L + \Psi^*_2 L^2 + \dots + \Psi^*_n L^n$, and we estimate the parameters of the given ARMA filter that minimize the sum of squares,

$$\sum_{j=1}^n (\Psi_j - \Psi_j^*)^2, \quad (7)$$

where Ψ_j are the coefficients of the corresponding $\Psi(L)$ polynomial of Table 1. In the minimization process we have tried $n = 15$ and 40 .

The root mean squared errors of these estimations are given in Table 3. The results can be summarized as follows:

1. The worst approximating filter is MA(1)(12), followed by the incomplete additive filter AR(1) MA(1, 2, 12, 13) (*). Nevertheless for the Cleveland-Tiao X-11 model, the MA(1)(12) approximation is better than for the other models.

(*) We denote the ARMA filters by AR() () MA() (), putting in the first brackets after AR and MA the non-zero powers of L for which the polynomials in L has a coefficient different from zero. In the second brackets we put the corresponding powers of L in the polynomials in L¹².

Table 3.

Approximating ARMA factors for the $\psi(L)$ polynomials corresponding to the X-11 ARIMA models:

Root mean squared errors

3.A. $\psi(L)$, Burr ridge-Wallis X-11 (84)

	MA(1)(12)	AR(1) MA(1,2,12, 13)	AR(1) MA(1,2,12, 13,14)	AR(1)(12) MA(1,2)(12) (12)	AR(1) MA(1,2)(12)
n=40	0.108	0.066	0.013	0.010	0.013
n=15	0.175	0.090	0.015		0.015

3.B. $\psi(L)$, Burr ridge-Wallis X-11(72)

n=40	0.099	0.037	0.024	0.017	0.024
n=15	0.159	0.042	0.020		0.020

3.C. $\psi(L)$, Burr ridge-Wallis X-11(108)

n=40	0.116	0.100	0.008	0.006	0.008
n=15	0.189	0.162	0.009		0.009

3.D. $\psi(L)$, Cleveland X-11

n=40	0.109	0.045	0.009	0.011	0.011
n=15	0.178	0.063	0.014		0.017

3.E. $\psi(L)$, Cleveland-Tiao

n=40	0.063	0.035	0.008	0.005	0.008
n=15	0.120	0.048	0.006		0.008

2. In all cases but Cleveland X-11 the best approximation is obtained by the multiplicative AR(1)(12) MA(1, 2)(12) filter. But the ϕ_{12} parameter has a value close to zero, around -0.08 (*), indicating that we can take the AR(1) MA(1,2)(12) to approximate the $\Psi(L)$ filters.
3. In the aforementioned four cases the AR(1) MA(1,2)(12) filter provides an approximation as good as that obtained with the AR(1) MA(1, 2, 12, 13, 14) filter. This latter filter fulfils the multiplicative restriction of the former.
4. For the $\Psi(L)$ polynomial put forward by Cleveland the best approximation is obtained with the additive filter AR(1) MA (1, 2, 12, 13, 14), but this approximation is not substantially better than that given by the multiplicative AR(1) MA(1,2)(12) filter (**); and we can say that this filter can be used to approximate this $\Psi(L)$ polynomial.

We will denote model (6) as the airline-X11 (ALX) model and we will use it to approximate models (2) of Table 1. The ALX models which correspond to those of Table

(*) For the Cleveland X-11(84) the value of the ϕ_{12} parameter is -0.34.

(**) In the additive filter, $\theta_{13}=-0.822$ and $\theta_{14}=0.281$
and $\theta_1\theta_{12}=-0.870$ and $\theta_2\theta_{12}=0.339$.
therefore the multiplicative restriction is not too strong.

1 are given in Table 4 (*). It is important to observe that for all models of Table 4, the MA (1,2) factor has complex roots and so there cannot be any cancellation with the AR (1) factor (**). This shows that the ALX model is a parsimonious representation of the models (2) which have been suggested to support the X-11 procedure.

The goodness of the approximation can be seen in figure 2 which represents the spectral transformations of the $\Psi(L)$ and AR(1) MA(1,2)(12) filters. The figure also includes the spectral transformation of the MA(1)(12) filters of Table 4 showing that with models of type (1) we get an unsatisfactory approximation of models (2), at frequencies less than $\pi/2$.

The big differences between the models of type (6) and of type (1) in Table 4 are not in the seasonal MA(12) factor but in the rest of the stationary ARMA component. We will denote this by the regular factor. The spectral transformations of the regular factors of Table 4 are given in figure 3. We see in this figure that the spectra of the AR(1) MA(1, 2) and MA(1) factors only differ substantially at frequencies less than $\pi/2$. The regular factor of the ALX model is characterized by having

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- (*) In Table 4 we also include the estimates of model (1) that approximate the models of Table 2. The approximation procedure has also consisted of minimizing the sum of squares of the deviations in the Ψ_j coefficients.
- (**) For the ALX corresponding to Burridge-Wallis X-11 (84) the roots of the MA(1, 2) factor are: $0.805 \pm 0.496i$.

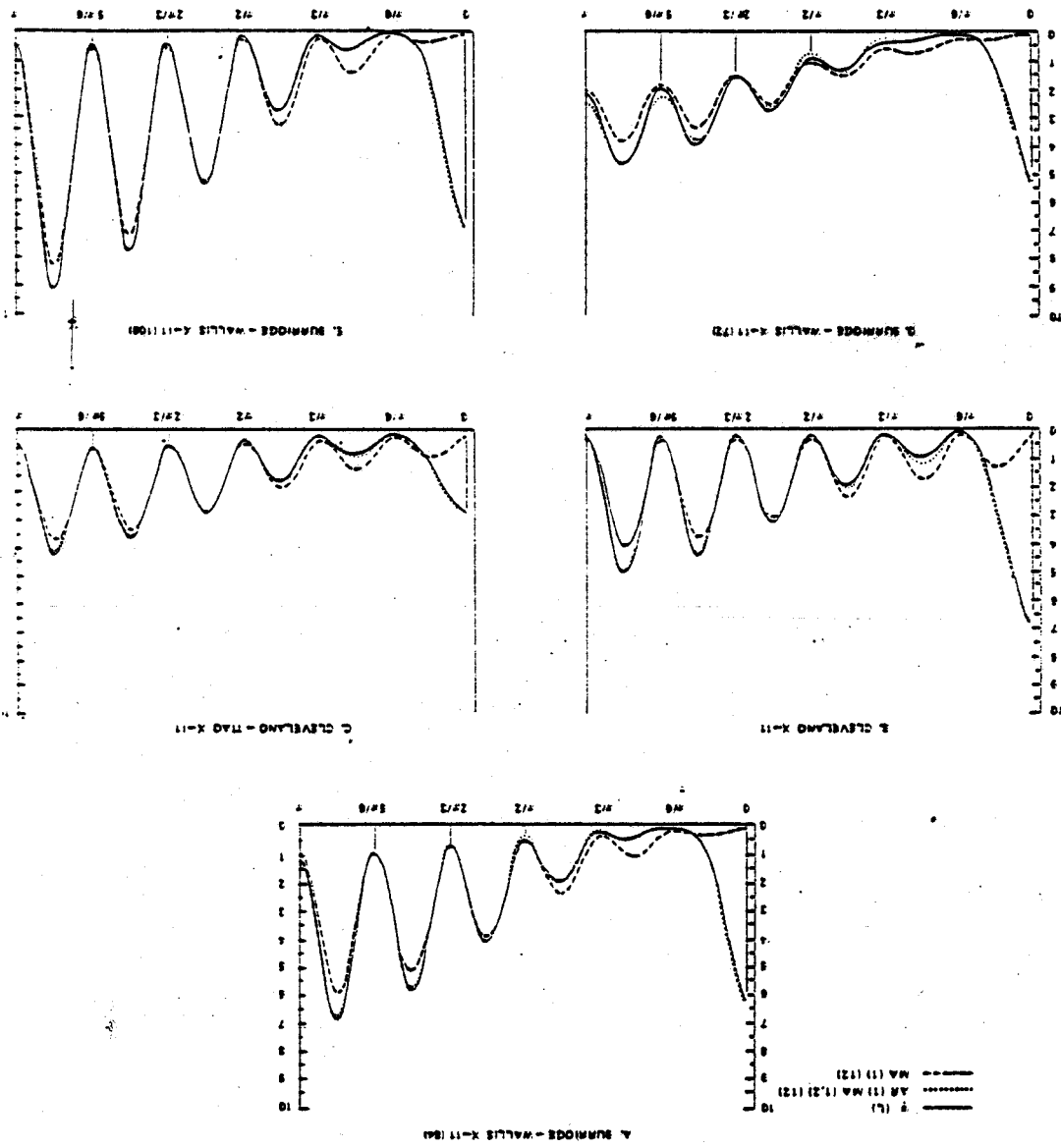
Table 4.

Estimates of models (6) proposed to approximate the $\psi(L)$ polynomials of table 2

	BURRIDGE-WALLIS			CLEVELAND X-11	CLEVELAND- TIAO X-11
	X-11(84)	X-11(72)	X-11(108)		
ϕ_1	0.940	0.888	0.972	0.971	0.943
θ_1	1.610	1.569	1.636	1.179	1.273
θ_2	-0.894	-0.893	-0.892	-0.440	-0.466
θ_{12}	0.472	0.198	0.715	0.713	0.497
Modulus of the complex roots of MA(1,2)	0.945	0.945	0.945	0.663	0.682

Estimates of model (1) that approximate the $\psi(L)$ polynomials of table 2

θ_1	0.73	0.697	0.766	0.298	0.368
θ_{12}	0.43	0.17	0.651	0.584	0.442

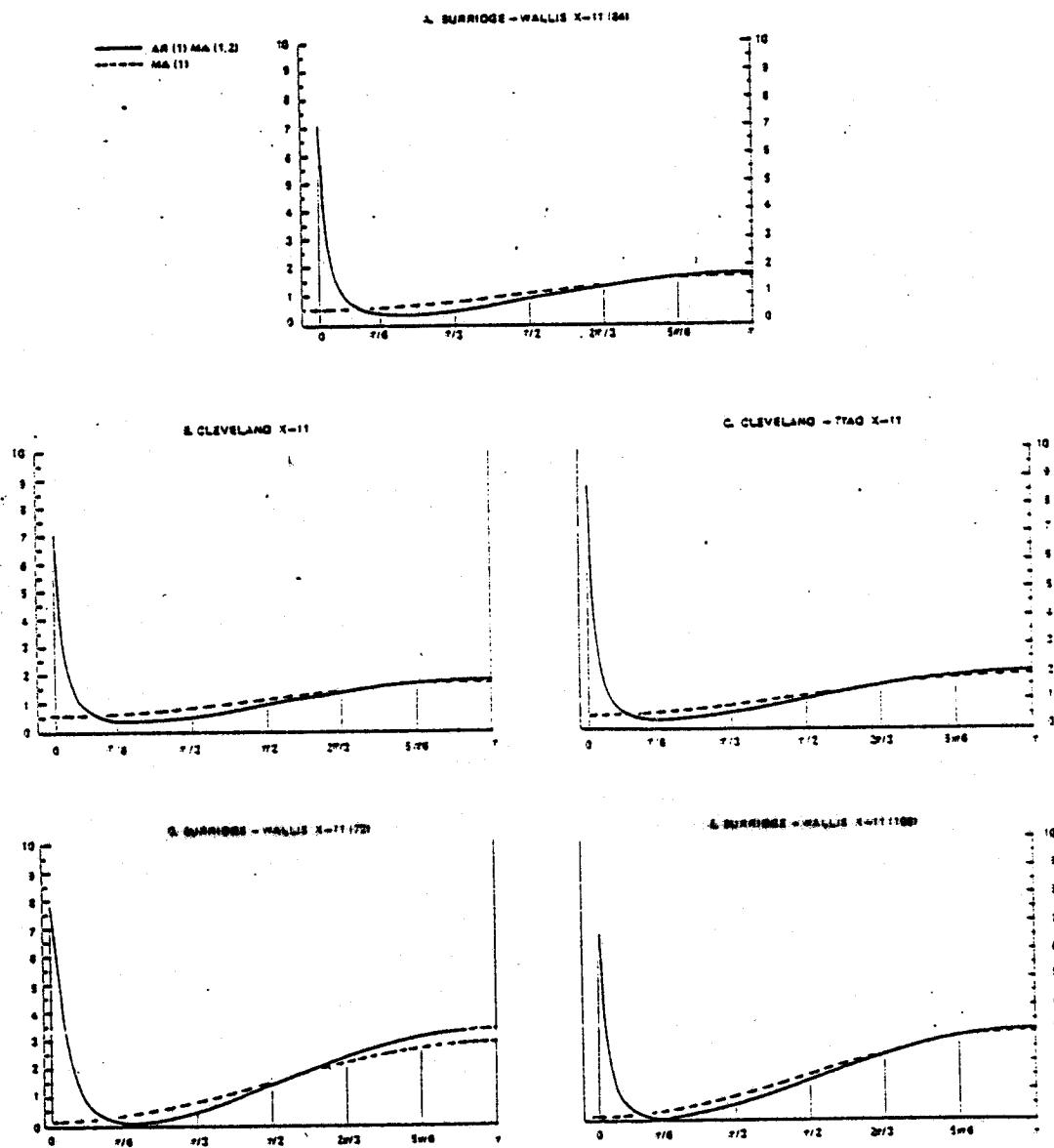


SPECTRAL TRANSFORMATION OF THE STATIONARY FILTERS OF THE X-11 MODELS

Figure 2

Figure 3

SPECTRAL TRANSFORMATION OF THE REGULAR FACTORS OF THE X-11 MODELS



maximum power at frequency zero and a dip around the seasonal frequency $\pi/6$; and the regular factor of the airline model has a power that increases with the frequency. Comparing the airline and the ALX models we can say that the multiplicative structure of the model proposed by Box-Jenkins is not in question. Possible improvements to this model to explain a large number of series must be made on the regular factor of the model.

The regular factor in (1) is an MA(1) that is usually estimated with a positive coefficient. This is useful for explaining a negative first order autocorrelation. In practice, after taking monthly and annual differences in a given series to obtain stationarity, we observed that the transformed series shows oscillations and that one of the main aspects of its correlogram is a negative value in the first lag. Therefore the regular factor of (1) captures one of the main aspects of the dynamics present in many time series, but the MA(1) factor alone could imply excessive oscillation and it would be useful to add to it another factor which induced some stability. This can be done by adding an ARMA(1,1), and in so doing we end up with an ARMA(1,2) for the regular factor, as in model (6).

It is important to observe that for differenced series the oscillatory pattern dominates any possible underlying stability. Consequently the correlogram, in its regular part, is dominated by a negative value in the first lag, even when small positive values are possible after it. Therefore, when we try to model a series with these characteristics, what seems more relevant is to capture the aforementioned negative autocorrelation and this is done with an MA(1) factor. Having included an

MA(1), if we want to capture a minor sort of stability in the series reflected by small positive values in the correlogram after lag one, we will need a factor that could induce some structure in the correlogram, i.e., we will need an AR(1) factor with a positive root (*). But this AR factor must act in the correlogram from a positive value and not from a negative one and therefore we need another MA(1) to change the value of the correlogram from negative, in the first lag, to positive, in the second. In this way we end up with an ARMA(1,2):

$$\frac{(1 - \theta_1 L - \theta_2 L^2)}{(1 - \phi_1 L)} \quad (7)$$

If, as we have mentioned, the possible regularity in a differenced series is of small order compared with the marked oscillation that such a series usually shows, it will be difficult, in practice, to estimate the ARMA(1,2) factor and very often we will detect only the MA(1) component. But at this point it is important to consider what factor could be more suitable for real series. In this respect we can say that the ARMA(1,2) incorporates a stability that seems reasonable, and so we can conclude that model (6) is more robust than model (1). It captures the main features of (1) and in addition, has a factor of second order importance. This could explain the robustness of the X-11 method.

(*) The negative autocorrelation is reflected in the spectrum by the important contribution of frequencies between $\pi/2$, and π , and the positive correlation by the contribution of frequencies around zero.

III.- Implications for modelling and seasonal adjustment.-

The above discussion has some implications for modelling monthly series and for estimating their seasonal factors. A first principle in modelling implies that one must capture the important aspects, in our discussion "dynamic aspects", of a series and for each aspect we must employ appropriate instruments. We denote this principle as the principle of adequacy. If, and only if, it is fulfilled a second one must be considered: the principle of parsimony. In this context one should specify first the essential characteristics that a model should have and then try to be as parsimonious as possible. Trying to be parsimonious without having specified the essential aspects that cannot be omitted, could be dangerous. Thus, with an MA (1) factor we can only approximate the dynamic behaviour reflected in the first value of the autocorrelation function and if the regular part of the autocorrelation function is essentially more complex, as is the case in table 2, with model (1) we will violate the adequacy principle. On the other hand, (2) with $\Psi(L)$ of the order 14 or more is by no means a parsimonious model. The adequacy and parsimony, apparently, can be obtained with model (6).

It should be observed that the type of positiveness in the correlogram after lag two cannot be captured by a MA (2) factor nor by an ARMA (1,1) factor

if the first lag in the acf has a negative value. We will need an ARMA (1,2). To what extent the negative value at lag one can be due to the application of a $(1-L)^2$ operator instead of a $(1-L)^d$ with a fraction d less than 2 is an open question that we have not considered in this paper.

In seasonal adjustment the theoretical advantages of the model based methods are well established. The problem with them is that we do not know the model and we need to estimate it, and if the sample is not informative enough it will be difficult to capture factors like the mentioned ARMA (1,2), due to the high correlation between the AR and MA coefficients.

One proposition for this case is to estimate model (6) fixing the value of ϕ_1 and searching the value of ϕ_1 for which we get the best fit. The fixing of ϕ_1 does not need to be worse than the fixing of $\Delta\Delta_{12}$ in models (1) to (6). Once we have estimated model (6) we can examine the roots of the MA(1,2) factor and observe if they are real or complex. If they are real with a dominant positive root, this root will tend to cancel out with the autoregressive root and we will end up with model (1). In this case if the coefficient ρ_2 of the acf corresponding to the stationary filter of model (6) is also negative, we shall have that the contribution of the stationary filter of model (1) at low frequencies will be higher than the corresponding contribution of model (6)(*). But if the

(*) For the airline series of the Box-Jenkins text the estimated model (6), without fixing any coefficient, is $\phi_1=0.81(0.09)$, $\theta_1=1.23(0.11)$, $\theta_2=-0.29(0.10)$ and $\hat{\sigma}_{12}^2=0.56(0.08)$. The residual variance, 0.001316, is a 3.3% lower than the residual variance of the airline model. The Whittle statistic, $x^2(2)=4.11$, does not reject (1) in favour of (6), showing that the 0.92 MA root cancels with the 0.81 AR root.

the MA roots are complex it will be useful to calculate the value of the coefficient of the imaginary part and take it as a measure against cancellation. The higher of this coefficient in absolute value, the better the use of model (6) for factor decomposition.

When for a specific time series we have evidence of no cancellation between the roots of model (6) it would be better to obtain the seasonal and trend components using a method based on model (6) or the X-11 procedure than a method based on model (1).

On the other hand in the a priori design of models for the components of a series our results show that the characterization of the trend by ARMA models with an autoregressive factor $(1-L)^2$ might not be enough.

We can conclude by saying that we advocate the use of model based adjustment methods but in applying them the research worker must be very conscious that the model employed must be adequate, in the sense that it does not omit factors of interest for a proper characterization of the dynamics of the process. For short-term forecasting some of these factors could be of second order importance and in practice very difficult to estimate. But if the research worker suspects that the estimated model might not fulfil the principle of adequacy, then ad-hoc methods, based on models that have been proved robust, like X-11, could be used.

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