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R. D. Snyder, C. Shah and C. Lehmer

Working Paper No. 1/89

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Multi-series Heuristics for Exponential Smoothing

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November 1988

Abstract

In this paper several heuristics are proposed for calculating the smoothing parameter in exponential smoothing when forecasts of many 'closely' related series are required on a regular basis. The methods are evaluated using both synthetic and real data. They not only compare favourably against several other known forecasting techniques but they are also simple and computationally efficient.
Keywords: Multi-series, time series, exponential smoothing.

1 Introduction

The performance of exponential smoothing as a forecasting technique depends critically on the choice of the smoothing parameter. Holt(1957) treated the parameter as a constant to be selected so as to minimize the sum of squared forecast errors. Brown(1963) recommended a more flexible approach in business applications, suggesting that the choice should be left to the discretion of management who would utilize market intelligence to anticipate above normal levels of structural change and temporarily increase the parameter in such circumstances. In a quest for greater automation Trigg and Leach(1967) introduced the concept of the adaptive response rate. Since then there have been many variations of these themes (e. g. see Dennis(1978), Ekern(1981), Gardner(1985), Snyder(1988), Taylor(1981) and Whybark(1973)) but no particular approach has achieved universal acceptance. The choice of the smoothing parameter still remains an issue warranting further attention.

In practice, the above methods are frequently applied in situations where many series are forecast in parallel on a regular basis. Often the series under consideration are influenced by the same external forces and exhibit common movements. For example, in the wool industry, wool is graded into classes according to several factors such as fibre diameter and colour. In this context it is reasonable to assume that factors such as floods, droughts, wars and exchange rate fluctuations which affect one class of wool generally have a similar effect on all other classes. This is reflected in the wool price data from Table 1, some of which after grouping have been plotted in Figure 1, where there is a clear visual evidence of common cyclical movements. Yet the above methods, with their univariate orientation, fail to exploit this cohesive behaviour.

The central theme of this paper is that information contained in closely related series can be utilized in forecasting. In this setting, multivariate methods may prove especially successful. Some progress towards this end has been made by Stevens(1964), Harrison and Stevens(1976), Enns et al. (1982) and Harvey(1986). However, little attention has been given to possibilities of adaptive response rates based on multivariate considerations. In the following such possibilities are proposed and evaluated against more traditional methods both on real data such as the wool series and synthetic data in a simulation study.

2 Multi-series heuristics

In this paper the one step ahead forecast $\hat{X}_{it+1}$ of the value X_{it+1} of a series i is generated by the recurrence relationship

$$\hat{X}_{it+1} = \hat{X}_{it} + \alpha_t e_{it} \tag{1}$$

where α_t is a common response rate at time t and e_{it} is the forecast error given by

$$e_{it} = X_{it} - \hat{X}_{it}. \tag{2}$$

In Table 2 a number of heuristics are outlined. These can be used to calculate the response rate where N denotes the number of series. The formula for heuristic A1 contains the sgn function which takes the values 1 or -1 according to whether e_{it} is positive or negative. The rationale for such a formula is that when there is an unanticipated upturn(downturn) across the whole set of series, most of the forecast errors will tend to be positive(negative) and α_t will be close to one. On the other hand during periods of relative stability neither the positive nor the negative errors predominate and α_t will be close to zero. Accordingly during periods of structural instability the heuristic yields a large value for the smoothing parameter, just when it is necessary for the forecasts to adapt to the change. However, when there is structural stability, the value of the smoothing parameter is small, thus ensuring that forecasts do not alter substantially in response to the changes which are essentially random in nature.

Heuristic B1 considers the relative size of the error terms in calculating α_t. This formula requires that X_{it} be non-zero for all i and t. It should also be noted that α_t in this case is not necessarily between 0 and 1 any more. In order to restrict the value of α_t to between 0 and 1 and also take account of the relative size of error terms, heuristic C1 is proposed.

Finally, in the formula for heuristic D1, the error terms are divided by $\hat{\sigma}_{it-1}$, the progressive estimate of the standard deviation of the error terms instead of X_{it}, where

$$\hat{\sigma}^2_{it} = \sum_{j=2}^{t} e^2_{ij}/(t-1). \tag{3}$$

Box and Jenkins(1976) when considering ARIMA(0,1,1) process, showed that exponential smoothing is stable for smoothing parameter values that are in the range 0 to 2. Therefore a second version of each of the above heuristics, where the formula in each case is multiplied by a factor of 2, is also considered. They are labelled A2, B2, C2 and D2 respectively.

For all heuristics the procedure is initialised by setting $\hat{X}_{i2} = X_{i1}$. In the case of D1 and D2 the initialisation also involves setting $\hat{X}_{i3} = (X_{i1} + X_{i2})/2$.

3 Evaluation

Although multi-series heuristics make intuitive sense it is necessary to check their performance on both simulated and real data. The statistical properties of the heuristics are too difficult to establish using analytical methods. Hence, in this study we examine their performance using naive forecasting, progressively optimized exponential smoothing (POES) and adaptive response rate smoothing (Trigg and Leach) methods, as described in appendix A, for comparison purposes.

The criteria used to evaluate the accuracy of the heuristics were:

1. the average of the mean absolute percentage errors taken over all the series according to the formula:
$$GMAPE = 100(\sum_{i=1}^{N}\sum_{t=2}^{T}|e_{it}/X_{it}|)/N(T-1) \qquad (4)$$
where T is the number of observations in each series;
2. the percentage PL of series that have a lower mean squared error than progressive optimised exponential smoothing (POES).

3.1 Simulation

The simulation study was undertaken to determine the effectiveness of the heuristics under a range of conditions involving business cycles, step and ramp changes. For each simulation, monthly data for 50 series of six years duration were generated. Five different amplitudes for the business cycle, ten different step sizes, and ramps with ten different gradients were considered. The algorithms used to generate synthetic data are described in detail in Appendix B.

The results of the simulation are shown in Table 3 where ρ is the factor which determines the amplitude of the business cycle, the size of step change, or the gradient of the ramp. It is evident that the heuristics perform reasonably well in comparison to their traditional counterparts, although no particular one is dominant throughout the entire study. Here B2, C2 and D1 have the lowest GMAPE values while A1 performs well in terms of the PL criterion.

3.2 Real data

The heuristics were also tested on the real data from Lehmer(1985) shown in Table 1. The results in Table 4 indicate that heuristics A2 and D2 are superior to progressively optimized exponential smoothing and the Trigg and Leach method on this data. The results in relation to the naive method are ambiguous, depending on whether GMAPE or PL is employed as the performance measure, but they confirm the common finding that this method generally performs well on price data.

4 Conclusion

In this paper heuristics have been presented for determining the response rate in applications of exponential smoothing. The distinguishing feature was the exploitation of common movements in series to detect and adapt to structural change. In terms of forecast accuracy, the performance of the heuristics was shown to depend on the structure of the series. However, in almost all circumstances, at least one of the heuristics produced results which were better than progressively optimized exponential smoothing or the adaptive response rate method of Trigg and Leach(1967).

Apart from the accuracy issue the heuristics have other advantages. They are elegantly simple and easily computerized; they access only current data; they avoid the time consuming grid searches for optimal parameter values or the excessive storage requirements of progressively optimized exponential smoothing. The heuristics therefore appear to hold considerable promise and could become a significant addition to the applied statistician's forecasting toolkit.

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A Appendix

An outline of the forecasting methods used for comparing the performance of multi-series heuristic methods is given in this appendix.

A.1 Naive

This is a special case of simple exponential smoothing where the smoothing parameter is set equal to a constant one. The forecast, $\hat{X}_{it+1}$, for series i in period $t+1$, is given by

$$\hat{X}_{it+1} = X_{it} \tag{5}$$

where X_{it} is the observed value of series i, in period t.

A.2 Progressively optimised exponential smoothing(POES)

Twenty versions of simple exponential smoothing with varying values of the smoothing parameter are applied in parallel to each of the series. The forecast, $\hat{X}_{ijt+1}$, for series i in period $t+1$, using smoothing parameter α_j, is given by

$$\hat{X}_{ijt+1} = \hat{X}_{ijt} + \alpha_j e_{ijt} \tag{6}$$

where α_j is the j^{th} smoothing parameter and

$$e_{ijt} = X_{it} - \hat{X}_{ijt} \tag{7}$$

is the one step ahead forecast error for series i when using the j^{th} smoothing parameter. The α_j are defined by

$$\alpha_j = j/10 \quad \text{for } j = 1 \text{ to } 20. \tag{8}$$

A progressive total of the squared forecast error for each smoothing parameter is kept. Therefore if S_{ijt} is the progressive total for series i using the j^{th} smoothing parameter, then after period t

$$S_{ijt} = \sum_{k=2}^{t} e_{ijk}^2. \tag{9}$$

If $j_{\min}$ is such that

$$S_{ij_{\min}t} = \min_{1 \leq j \leq 20} \{S_{ijt}\} \tag{10}$$

then the forecast for series i in period $t+1$ is

$$\hat{X}_{it+1} = \hat{X}_{ij_{min}t+1}. \tag{11}$$

The procedure is initialized by letting $\hat{X}_{ij2} = X_{i1}$ for every j.

A.3 Trigg and Leach's adaptive response rate smoothing

Using notation already defined,

$$\hat{X}_{it+1} = \hat{X}_{it} + \alpha_{it} e_{it} \tag{12}$$

where

$$\alpha_{it} = \begin{cases} |\bar{e}_{it}|/m_{it} & \text{if } m_{it} > 0 \\ 1 & \text{if } m_{it} = 0, \end{cases} \tag{13}$$

The smoothed error, $\bar{e}_{it}$, and the smoothed absolute error, m_{it}, are calculated using the following:

$$\bar{e}_{it} = (1-\gamma)\bar{e}_{it-1} + \gamma e_{it} \tag{14}$$

$$m_{it} = (1-\gamma)m_{it-1} + \gamma |e_{it}| \tag{15}$$

where γ is the smoothing constant for the errors. The procedure is initialized by setting $\hat{X}_{i2} = X_{i1}$. Three different values of γ, .05, .1 and .5, are considered.

B Appendix

This appendix describes the way the synthetic data was generated.

B.1 Time series with a business cycle

If it is assumed that the business cycle follows a simple sine curve and there are no seasonality or trend components, then the data generating function is given by

$$X_{it} = A_i + \rho A_i \sin(\pi(t-1)/18) + s_i N_{it} \tag{16}$$

where

$$
\begin{aligned}
A_i &= \text{mean level for the } i^{th} \text{ series} \\
N_{it} &= \text{normally distributed variate with mean zero and} \\
&\quad \text{standard deviation one} \\
s_i &= \text{standard deviation of the noise component} \\
&\quad \text{for the } i^{th} \text{ series} \\
\rho &= \text{constant}
\end{aligned}
$$

The s_i^2's are determined using the following formula:

$$s_i^2 = \sigma_i^2 - (\rho A_i)^2/2 \tag{17}$$

where σ_i^2 is the variance of the i^{th} series and the second term on the right hand side is the variance of the business cycle. Hausman and Kirby(1970) derived empirical relations between the mean level and the variance of a series. The one that has been used in this study is

$$\sigma_i^2 = .338 A_i^{.900}. \tag{18}$$

Figures 2 shows a typical series that was generated. It has a mean level of 145 and $\rho = .05$. In Figure 3 the same series is shown with $\rho = .22$. As can clearly been seen that the business cycle is more pronounced in this second case.

B.2 Time series with a step change

In this model a step change in the mean level of the series was assumed to occur at period 25. Using notation already defined, the data generating function is given by

$$X_{it} = \begin{cases} A_i + \sigma_{i1} N_{it} & \text{if } t \le 25 \\ \rho A_i + \sigma_{i2} N_{it} & \text{if } t > 25 \end{cases} \tag{19}$$

where

$$
\begin{aligned}
\sigma_{i1} &= \text{standard deviation of the noise component of the} \\
&\quad i^{th} \text{ series before period 25} \\
\sigma_{i2} &= \text{standard deviation of the noise component of the} \\
&\quad i^{th} \text{ series after period 25} \\
\rho &= \text{step size.}
\end{aligned}
$$

σ_{i1} and σ_{i2} are determined using the following formulae:

$$\sigma_{i1} = .338 A_i^{.900} \tag{20}$$

$$\sigma_{i2} = .338 (\rho A_i)^{.900}. \tag{21}$$

Figure 4 shows a typical series that was generated. It has an initial mean level of 145 and a jump in this level by 20% from period 25 on ($\rho = 1.2$). In Figure 5 a similar series with $\rho = 1.5$ is shown.

B.3 Time series with a ramp

A linear ramp for the mean level of the series was introduced between periods 24 and 36. The data generating function is defined as

$$X_{it} = \begin{cases} A_i + \sigma_{i1} N_{it} & \text{if } t \leq 24 \\ A_i(3 - 2\rho + (\rho - 1)t/12) + \sigma_{it} N_{it} & \text{if } 24 < t \leq 36 \\ \rho A_i + \sigma_{i2} N_{it} & \text{if } t > 36 \end{cases} \tag{22}$$

where

σ_{i1} = standard deviation of the noise component before period 24 for the i^{th} series

σ_{i2} = standard deviation of the noise component after period 36 for the i^{th} series

σ_{it} = standard deviation of the noise component for period t for the i^{th} series where $24 < t \leq 36$.

The standard deviations are calculated using the following formulae:

$$\sigma_{i1} = .338 A_i^{.900} \quad \text{if } t \leq 24 \tag{23}$$

$$\sigma_{i2} = .338(\rho A_i)^{.900} \quad \text{if } t > 36 \tag{24}$$

$$\sigma_{it} = .338(A_i(3 - 2\rho + (\rho - 1)t/12))^{.900} \quad \text{if } 24 < t \leq 36 \tag{25}$$

Figure 6 shows a typical series with $\rho = 1.2$. The initial level of the series is 145 and the ramp operates between periods 24 and 36. From period 36 on the mean level of the series is 20% more than its initial value. In Figure 7 a similar series with $\rho = 1.4$ is illustrated. It is obvious that the ramp is steeper in this case.

Wool	Quarter																								
	1978		1979				1980				1981				1982				1983				1984		
Type	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3
44	376	373	400	491	513	555	589	619	585	575	545	572	564	564	578	***	593	603	657	751	670	685	872	926	907
60	371	369	398	478	501	550	584	602	579	558	539	558	542	540	569	614	604	596	634	695	677	667	806	872	914
60B	363	368	400	477	492	548	571	594	566	557	538	551	532	539	567	611	601	582	632	669	664	658	826	826	896
76	363	383	395	476	489	533	563	573	556	539	524	547	526	527	563	607	601	579	616	661	646	646	750	787	894
76B	362	364	392	462	478	534	548	572	551	543	516	533	523	527	560	603	595	565	600	627	633	631	739	833	838
157B	329	338	352	407	400	432	481	471	456	472	473	475	479	487	492	496	484	487	512	525	532	544	597	658	667
61	361	362	390	478	484	513	532	530	517	497	496	514	520	515	538	606	589	550	574	615	609	605	623	672	688
61B	360	360	395	468	482	519	529	527	514	496	494	511	518	514	540	602	581	546	573	600	601	600	628	655	694
77	357	358	388	465	473	499	522	522	503	487	489	504	507	506	533	595	573	542	565	596	597	597	609	675	683
77B	358	358	385	466	476	502	518	517	505	486	484	498	507	506	531	588	572	537	561	582	593	593	602	620	650
158C	307	318	329	346	359	381	409	418	402	417	432	436	443	445	457	479	459	447	457	478	484	481	507	512	508
78	349	349	377	438	442	460	480	490	468	468	477	488	493	491	521	576	541	523	546	565	567	563	576	588	592
78B	350	349	378	432	448	459	480	490	471	471	478	486	492	491	521	563	539	521	540	558	563	561	569	594	585
84B	349	348	373	424	439	453	468	483	466	468	471	479	487	482	509	546	525	511	530	548	554	548	564	573	575
159B	321	322	338	365	369	390	411	422	414	428	443	455	450	445	456	484	464	446	466	489	489	485	503	513	518
79	342	342	385	397	404	421	450	458	441	448	469	476	483	480	507	534	511	504	528	547	548	547	552	560	555
79B	342	343	384	394	402	418	448	456	444	453	470	474	481	479	505	525	508	503	522	543	545	544	545	552	548
85B	341	344	362	389	395	412	439	450	438	451	463	464	477	472	499	516	500	495	515	533	538	535	538	540	539
159AB	318	313	332	363	362	375	401	408	398	414	433	437	437	434	448	447	451	435	457	492	478	471	488	502	489
80	335	333	352	371	370	396	422	419	413	430	456	457	466	466	491	484	487	488	507	528	527	527	529	533	527
80B	336	336	354	367	368	397	422	418	412	432	457	454	466	466	484	480	484	486	502	524	527	525	524	526	533
80S	337	334	355	366	369	396	423	412	410	432	455	448	463	463	486	478	477	480	498	519	520	518	526	522	514
80C	337	333	354	357	363	391	403	395	403	432	454	445	462	469	468	459	475	476	495	513	518	518	511	509	505
164C	293	293	310	329	325	351	385	370	370	379	409	393	404	389	400	388	378	376	399	433	437	426	436	426	410
81	330	326	345	360	358	389	410	393	389	415	447	439	450	454	476	457	468	473	484	518	513	504	505	510	503
81B	333	330	348	358	360	393	414	393	393	421	448	437	455	459	474	450	464	469	478	512	514	504	501	501	499
81C	340	344	354	346	358	391	392	371	390	425	450	431	458	463	459	437	452	456	468	503	508	498	484	488	485
96B	332	329	347	348	363	393	409	382	387	423	452	429	454	458	469	441	447	454	471	506	510	494	491	481	475
160AC	299	303	322	328	315	347	366	345	357	369	405	380	397	383	394	387	380	377	403	433	421	418	420	407	408
432A	329	326	343	368	358	387	405	394	395	413	449	449	450	451	476	473	461	468	486	520	512	503	506	506	505
433	326	320	335	360	353	380	395	376	376	400	430	418	432	442	455	440	436	454	466	504	505	483	483	480	473
486B	295	297	309	330	329	355	367	345	331	343	364	371	381	371	375	363	368	371	373	415	409	398	408	428	413
653	322	316	331	349	352	379	391	367	369	397	427	416	430	439	451	433	435	451	456	502	499	479	476	474	464
434	311	305	321	347	343	372	374	353	351	369	384	371	399	415	403	391	369	394	401	436	452	435	430	417	399
444B	309	312	324	339	342	372	382	345	346	362	370	353	391	407	400	383	355	369	363	418	425	410	407	382	373
479	306	290	298	326	341	349	348	329	318	324	314	304	320	329	332	360	335	330	339	357	347	353	354	371	351
487B	289	285	293	322	315	341	344	322	313	315	303	301	324	317	318	320	322	318	325	341	339	344	343	334	349
654	302	304	317	339	339	369	371	345	343	362	376	364	392	407	398	377	361	387	392	430	443	428	421	413	394
435	284	289	296	322	327	357	352	328	322	324	306	307	317	320	318	326	313	311	319	346	347	339	341	348	338
435B	284	294	298	319	326	362	356	326	323	322	305	306	321	313	317	323	312	308	316	348	344	338	337	341	335
436	273	282	288	315	322	351	343	318	313	311	295	296	303	299	307	313	299	296	302	328	328	320	317	324	319
437	263	275	285	312	323	346	337	313	306	301	289	291	297	294	297	296	289	290	295	316	322	313	310	312	311
445B	287	294	297	317	323	359	355	323	323	319	300	300	317	302	312	321	304	297	309	341	343	327	328	338	330
480	277	280	283	315	318	342	329	312	295	307	286	286	295	346	288	299	290	279	291	319	325	310	318	336	342
655	283	290	296	320	325	355	350	324	319	322	302	303	314	312	315	322	309	306	314	341	342	334	337	343	332
283C	264	277	294	294	290	301	317	314	303	326	343	340	330	315	317	313	299	299	311	327	323	321	328	323	310
304C	264	276	296	299	290	306	339	321	314	344	365	351	333	335	319	311	297	301	323	337	341	370	384	356	323
587C	260	273	282	280	285	308	316	298	294	305	315	297	293	295	292	271	260	270	279	312	315	334	342	310	308

Table 1: Quarterly Wool Prices (Aust. cents per kg. of clean wool), 1978.3 to 1984.3. Source: AWC internal Sales Catalogue History Records.

Heuristic	Formula
A1	$\alpha_t = \lvert \sum_{i=1}^{N} \mathrm{sgn}(e_{it}) \rvert / N$
B1	$\alpha_t = \lvert \sum_{i=1}^{N} e_{it}/X_{it} \rvert / N$
C1	$\alpha_t = \lvert \sum_{i=1}^{N} e_{it}/X_{it} \rvert / \sum_{i=1}^{N} \lvert e_{it}/X_{it} \rvert$
D1	$\alpha_t = \lvert \sum_{i=1}^{N} e_{it}/\sigma_{it-1} \rvert / \sum_{i=1}^{N} \lvert e_{it}/\hat{\sigma}_{it-1} \rvert$

Table 2: Multi-series heuristics

Data characteristic	ρ	Method A1	A2	B1	B2	C1	C2	D1	D2	Naive	POES	Trigg .05	Trigg .1	Trigg .5
Business Cycle	.05	19.53(56)	20.15(26)	19.58(44)	19.41(42)	20.40(42)	18.98(76)	19.52(46)	20.37(16)	25.07(0)	19.72	19.99(44)	20.20(34)	22.98(2)
	.10	19.11(46)	19.58(40)	19.22(56)	18.98(48)	19.92(38)	18.97(66)	18.93(52)	19.91(18)	23.90(0)	19.32	19.69(40)	19.45(40)	21.89(2)
	.15	17.85(70)	18.34(46)	18.40(38)	17.87(62)	19.23(22)	18.65(38)	17.73(68)	18.72(28)	21.84(0)	18.24	18.90(24)	18.23(40)	19.99(2)
	.20	15.09(80)	16.16(52)	17.12(20)	16.10(46)	18.74(2)	18.07(6)	15.59(80)	16.37(34)	18.64(0)	16.09	17.29(4)	16.31(36)	17.05(10)
	.22	14.49(80)	14.95(42)	16.46(8)	15.18(38)	18.56(2)	17.74(2)	14.36(86)	15.15(40)	16.91(0)	14.86	16.34(2)	15.23(28)	15.48(12)
Step change	1.1	20.13(58)	20.85(22)	19.81(60)	19.68(70)	20.40(48)	20.34(68)	20.09(46)	21.20(12)	25.63(0)	20.18	20.73(36)	21.06(22)	23.62(0)
	1.2	20.06(60)	20.69(34)	19.72(54)	19.63(70)	20.58(32)	19.17(54)	20.03(50)	21.16(14)	25.45(0)	20.18	20.70(38)	21.00(26)	23.49(0)
	1.3	20.09(58)	20.82(30)	19.70(52)	19.59(72)	21.07(16)	19.43(28)	19.96(52)	21.24(16)	25.31(0)	20.23	20.71(38)	20.97(28)	23.38(0)
	1.4	20.01(76)	20.62(42)	19.70(62)	19.55(74)	21.65(10)	19.68(26)	19.90(58)	21.14(24)	25.20(0)	20.36	20.72(40)	20.96(44)	23.28(0)
	1.5	19.95(82)	20.53(44)	19.70(64)	19.51(70)	22.20(2)	19.90(20)	19.85(70)	21.11(34)	25.11(0)	20.45	20.74(48)	20.95(44)	23.21(0)
	1.6	19.90(84)	20.56(42)	19.69(68)	19.49(80)	22.73(0)	20.10(18)	19.80(80)	21.12(40)	25.03(0)	20.54	20.74(52)	20.94(52)	23.15(0)
	1.7	19.87(84)	20.46(50)	19.68(68)	19.46(74)	23.22(0)	20.27(16)	19.75(78)	21.15(44)	24.96(0)	20.59	20.74(62)	20.92(56)	23.09(0)
	1.8	19.82(84)	20.47(58)	19.66(76)	19.48(76)	23.67(0)	20.42(12)	19.70(82)	21.19(46)	24.90(0)	20.64	20.73(68)	20.90(64)	23.03(2)
	1.9	19.82(86)	20.48(60)	19.64(76)	19.52(80)	24.09(0)	20.56(12)	19.66(86)	21.24(44)	24.83(0)	20.69	20.71(74)	20.87(70)	22.98(0)
	2.0	19.76(88)	20.45(60)	19.62(80)	19.60(82)	24.47(0)	20.67(6)	19.62(38)	21.30(46)	24.77(2)	20.76	20.69(76)	20.84(74)	22.92(2)
Ramps	1.1	20.79(56)	21.18(30)	20.25(66)	20.12(64)	20.65(44)	19.74(62)	20.56(36)	21.40(12)	26.47(0)	20.68	21.13(40)	21.48(22)	24.40(2)
	1.2	20.60(68)	21.06(32)	20.22(60)	20.03(76)	21.08(28)	20.01(42)	20.49(52)	21.38(8)	26.27(0)	20.63	21.05(46)	21.36(24)	24.21(2)
	1.3	20.45(82)	20.96(34)	20.23(56)	19.98(78)	21.73(2)	20.37(16)	20.41(60)	21.37(14)	26.10(0)	20.66	21.01(48)	21.27(28)	24.04(2)
	1.4	20.44(84)	20.95(44)	20.26(54)	19.95(82)	22.43(2)	20.72(6)	20.33(72)	21.37(16)	25.94(0)	20.71	20.99(52)	21.21(40)	23.89(2)
	1.5	20.41(78)	20.89(48)	20.30(54)	19.91(84)	23.15(0)	21.06(0)	20.26(74)	21.33(18)	25.79(0)	20.73	20.97(54)	21.17(36)	23.76(2)
	1.6	20.37(82)	20.74(62)	20.33(52)	19.88(88)	23.83(0)	21.37(0)	20.19(84)	21.29(22)	25.66(0)	20.76	20.95(66)	21.12(42)	23.63(2)
	1.7	20.31(88)	20.79(60)	20.36(52)	19.86(88)	24.46(0)	21.67(0)	20.13(86)	21.24(24)	25.54(0)	20.80	20.93(68)	21.08(48)	23.52(2)
	1.8	20.28(86)	21.01(56)	20.39(52)	19.84(90)	25.05(0)	21.95(0)	20.07(86)	21.20(32)	25.43(0)	20.82	20.92(72)	21.05(48)	23.42(2)
	1.9	20.24(80)	20.76(64)	20.42(48)	19.82(90)	25.61(0)	22.22(0)	20.02(88)	21.17(32)	25.33(0)	20.84	20.90(74)	21.02(56)	23.33(2)
	2.0	20.17(88)	20.94(64)	20.44(48)	19.80(92)	26.14(0)	22.47(0)	19.98(94)	21.14(32)	25.23(0)	20.88	20.89(78)	20.99(56)	23.24(2)

Table 3: GMAPE and PL values (in brackets) from simulation study

Accuracy measure	Method												
												Trigg	
	A1	A2	B1	B2	C1	C2	D1	D2	Naive	POES	.05	.1	.5
GMAPE	4.34	3.36	10.65	8.24	8.85	6.72	3.70	3.40	3.55	3.78	3.97	4.05	3.89
PL	18	76	0	0	2	2	52	74	80		38	40	40

Table 4: GMAPE and PL values for wool price data

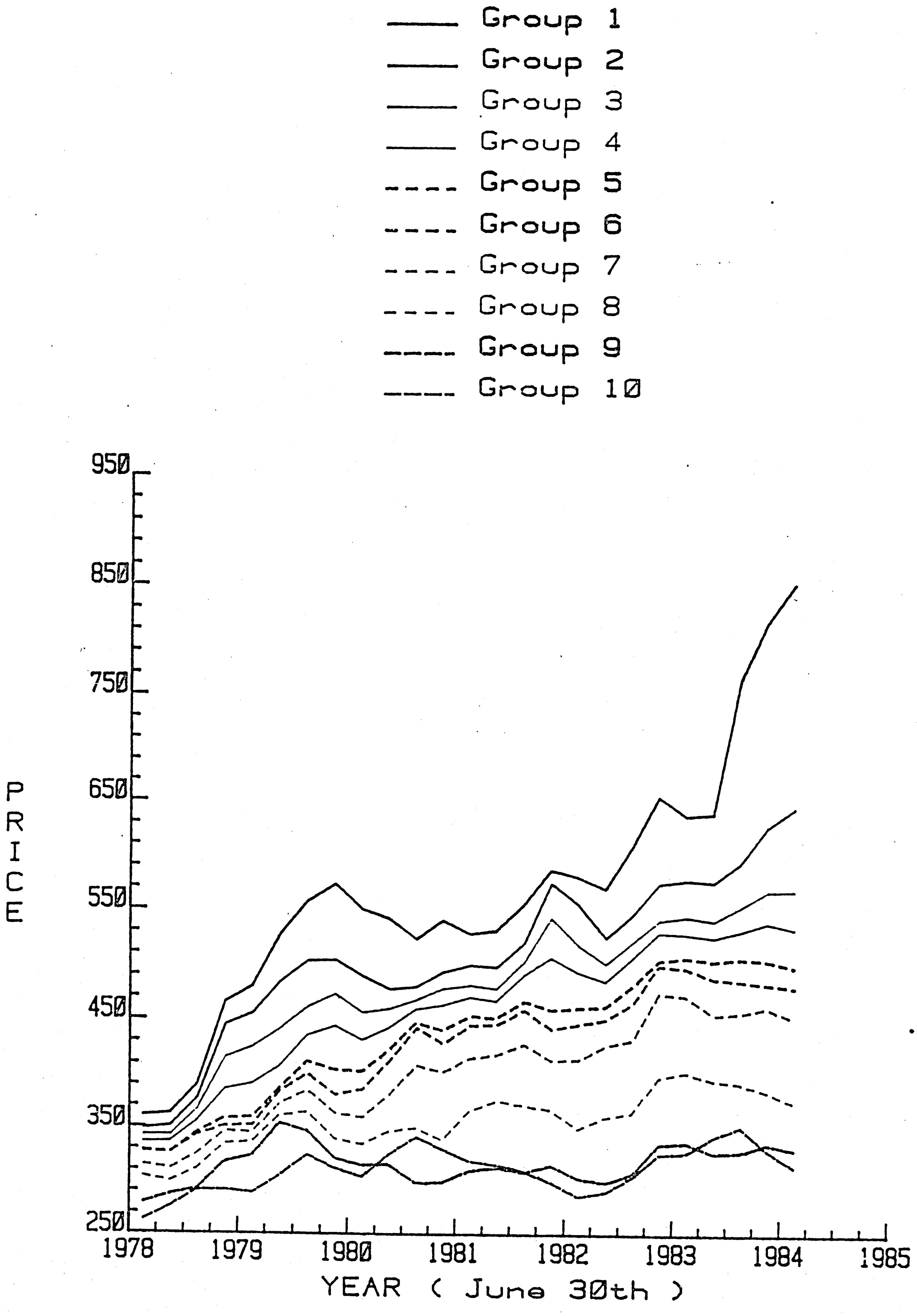

Figure 1: Quarterly prices (c/kg clean)

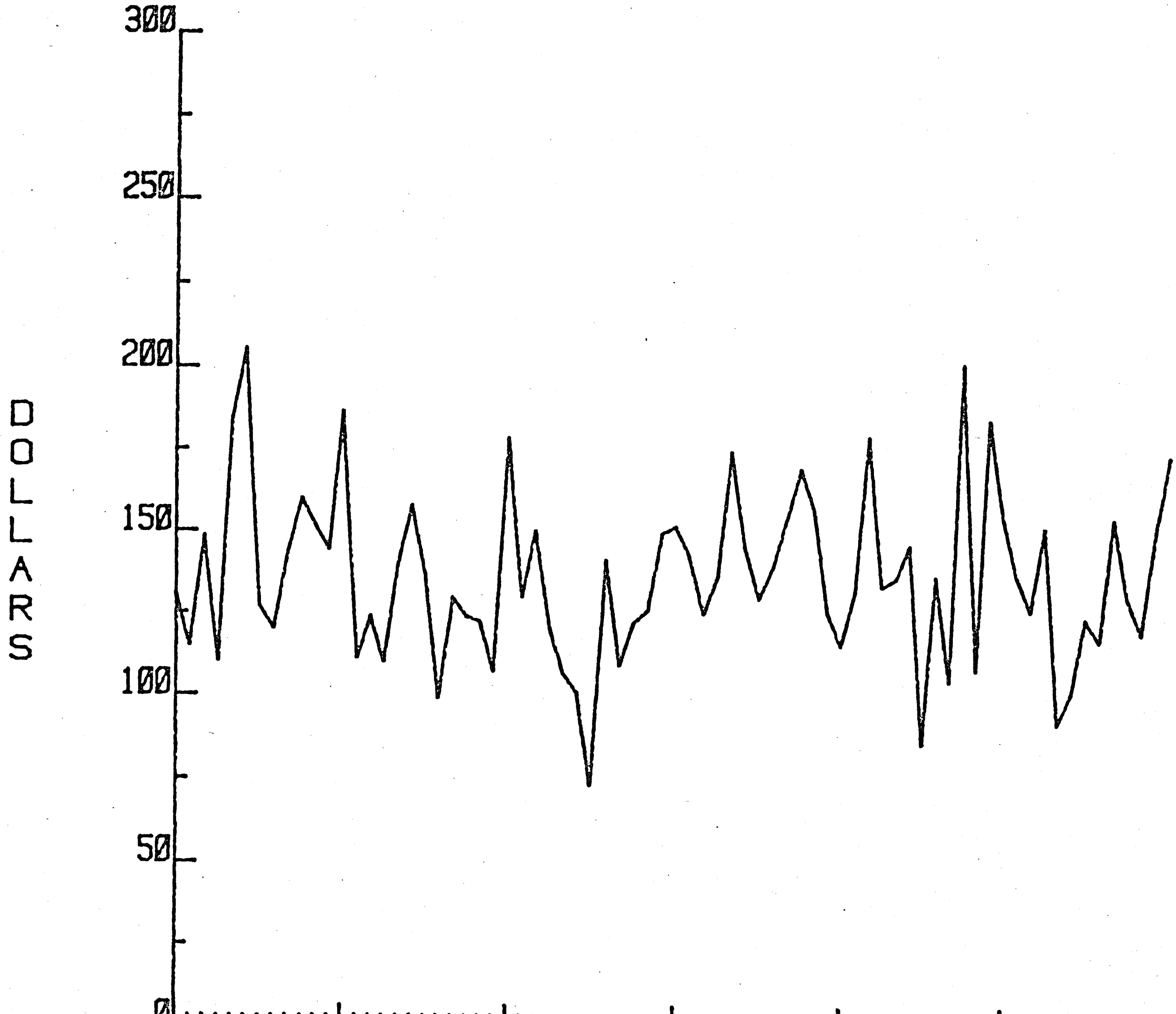

Figure 2: Time series with business cycle ($\rho = .05$)

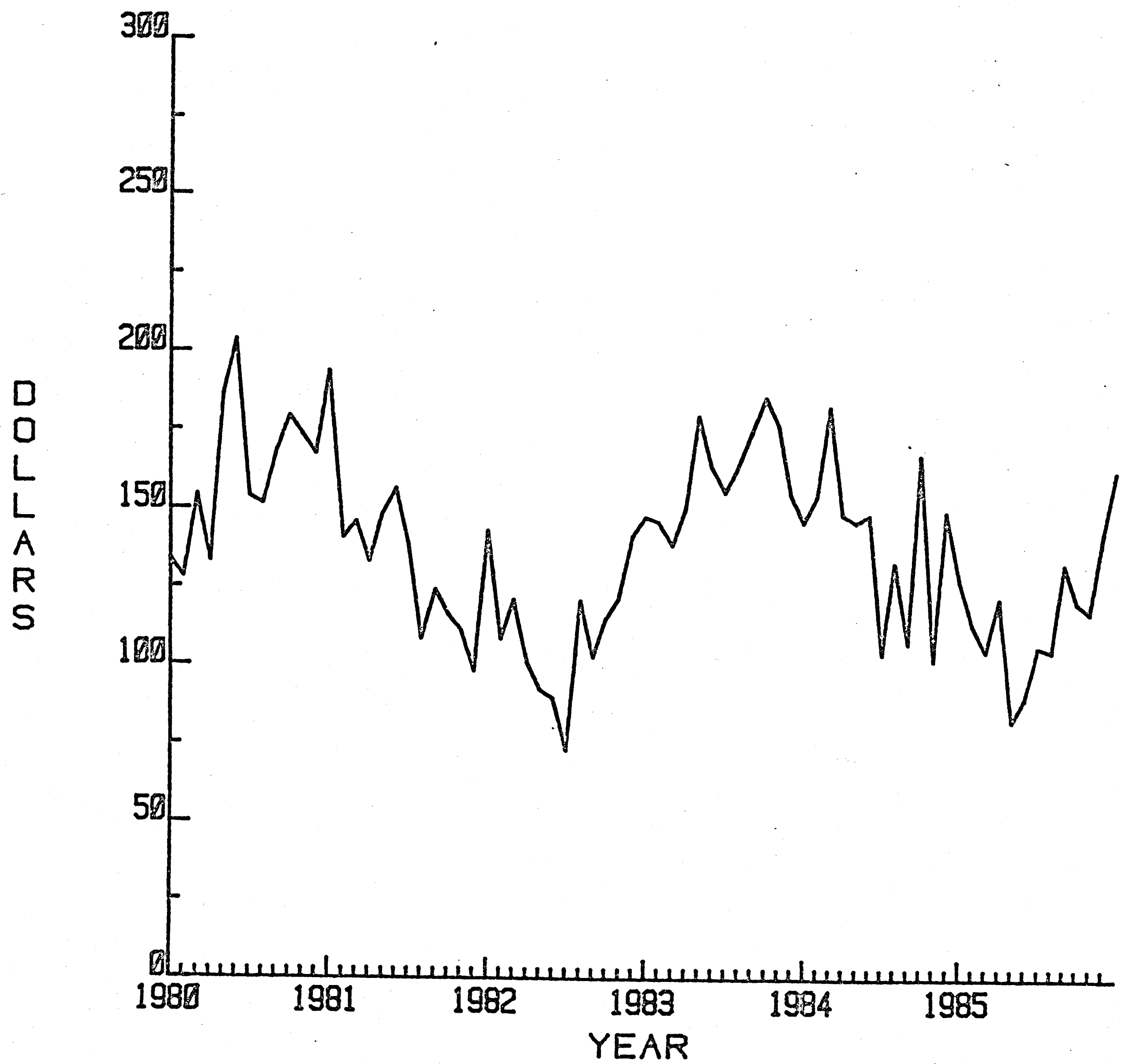

Figure 3: Time series with business cycle ($\rho = .22$)

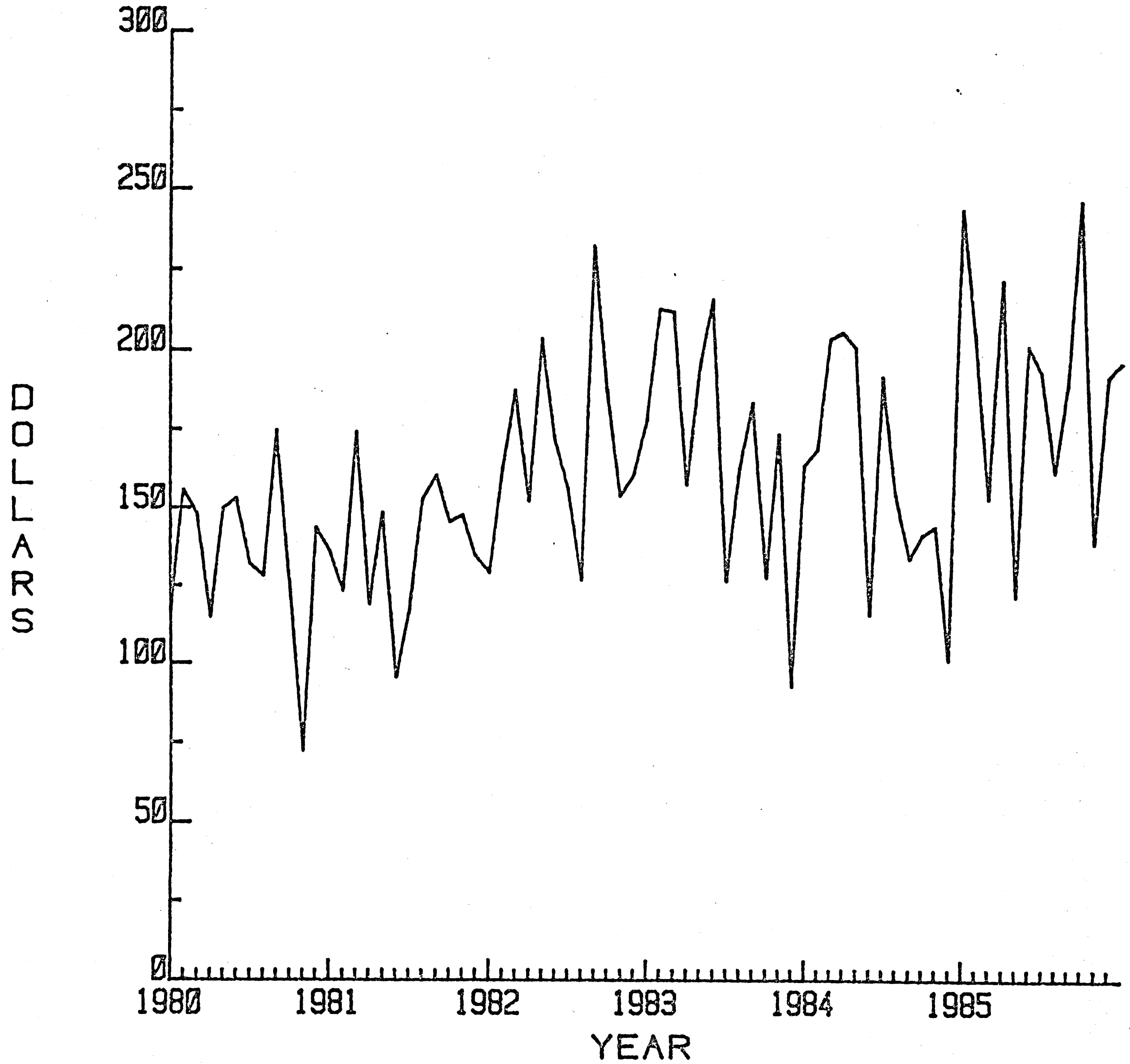

Figure 4: Time series with a step change ($\rho = 1.2$)

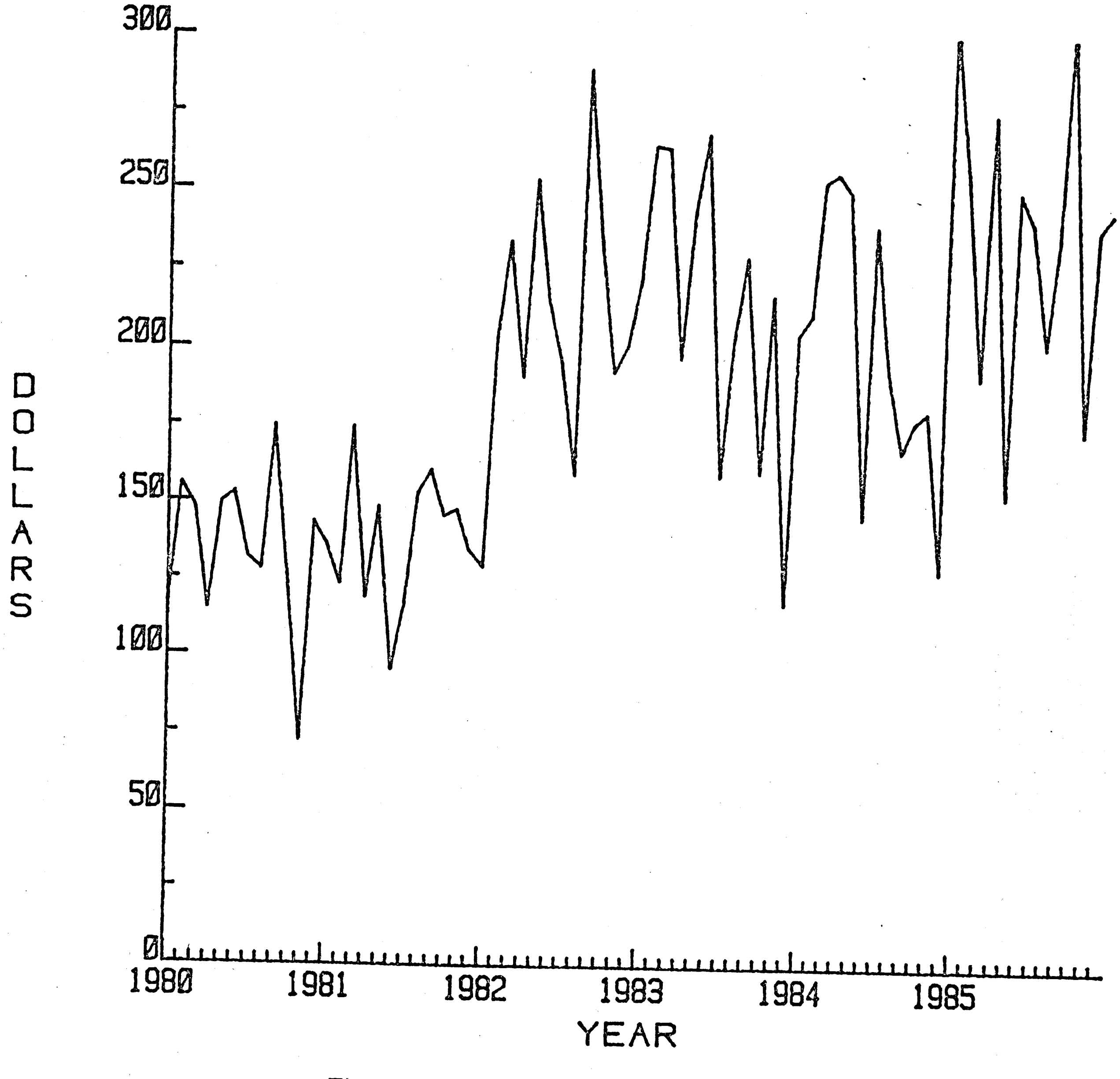

Figure 5: Time series with a step change ($\rho = 1.5$)

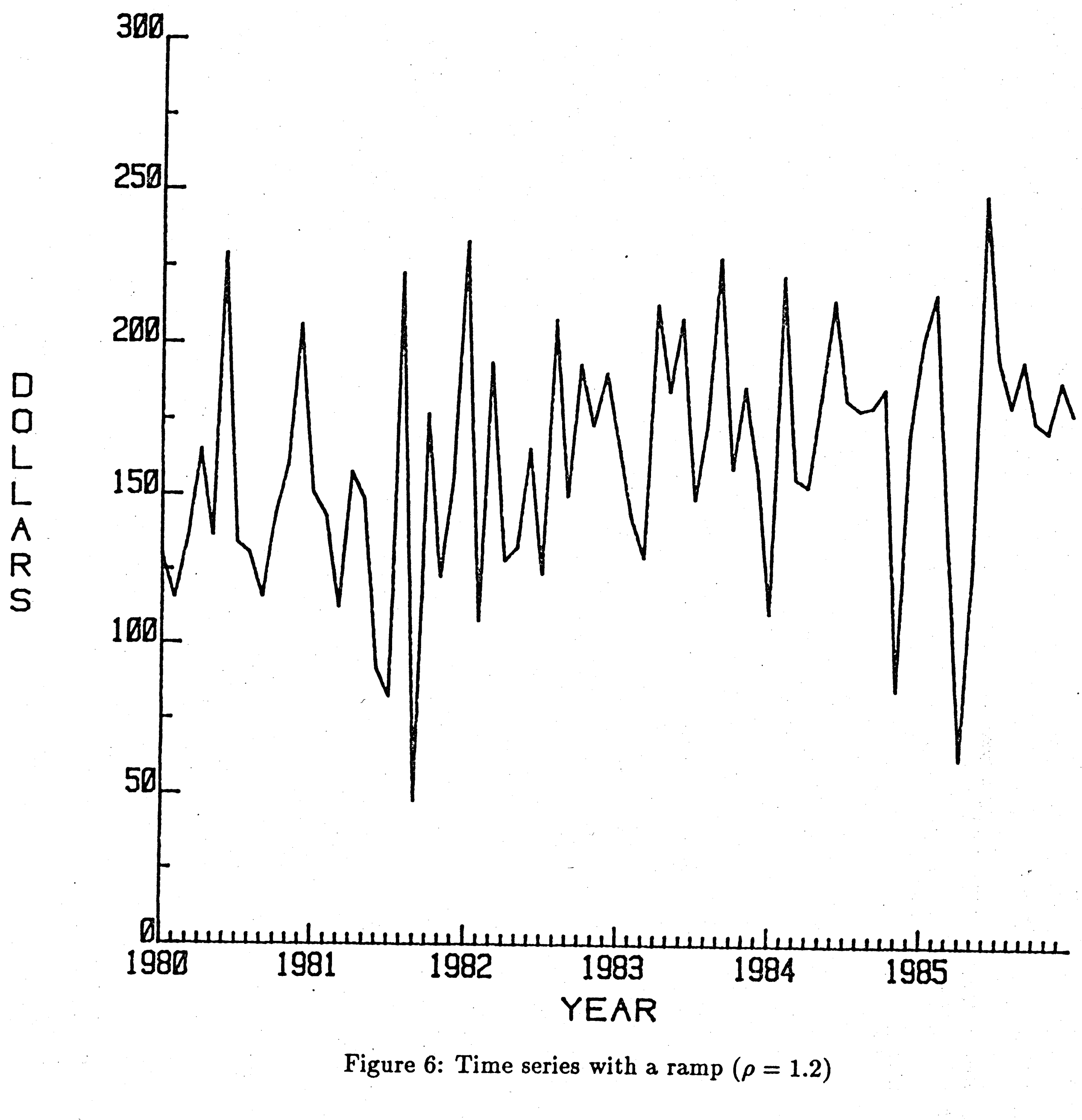

Figure 6: Time series with a ramp ($\rho = 1.2$)

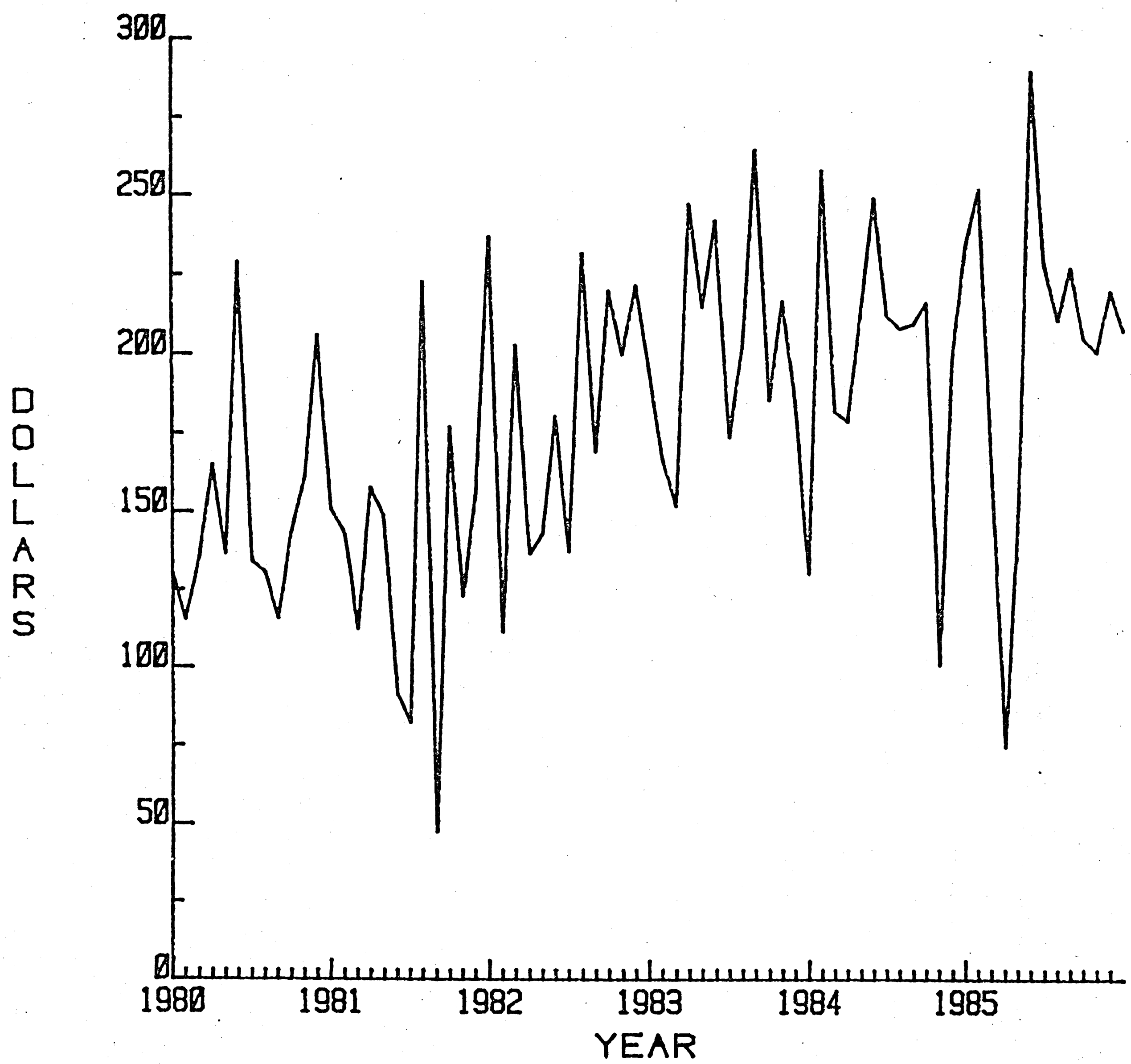

Figure 7: Time series with a ramp ($\rho = 1.4$)

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