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SEASONALITY IN EURODOLLAR INTEREST RATES

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SEASONALITY IN EURODOLLAR INTEREST RATES

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Abstract

Possible seasonal phenomena in capital markets are interesting both in themselves and because of the implications for the efficiency of the market. After the statement of a formal definition of seasonality, which allows for "weak" seasonal phenomena, the paper analyzes in detail the time series of interest rates in the Eurodollar market, for the period 1974-1980 (October). Given the controversial nature of the subject, several statistical tests are discussed, and the results examined: as a conclusion, a seasonal behaviour of interest rates is detected. In the last sections the proposition discussed is that such behaviour is an index of "market inefficiency"; to this purpose, a discussion of the definition of efficiency is developed, and the concept itself of efficiency in (financial) markets is discussed. Lastly, posssible explanations of the phenomenon are investigated.

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1. Introduction

The existence of seasonal phenomena in financial markets has been a controversial issue in the past years. The question is obviously relevant in itself, and has important practical consequences; but it has also been considered an important test of the degree of "efficiency" of capital markets.
According to the (by now standard) definition of weak efficiency as given by Fama (1970), a market is weakly efficient if the price "fully reflects" the information given by the past prices time series. As stated above, this is still a vague definition, and one could argue that the information set considered is unreasonably restrictive.
The implications of the definition in the case that will be examined here are more carefully discussed in the following; it must be noted, anyway, that the weak efficiency is a necessary condition for the stronger forms of efficiency: so that a market that is proved to be non weakly efficient is certainly not even semi-strongly or strongly efficient.

The recent and rich literature on seasonality in bond yields or shares prices is certainly interesting in the present case (see e.g. Praetz (1973), Officer (1976), Rozeff and Kinney (1976), Bertoneche (1979), Schneeweis and Woolridge (1979)); on the other hand, empirical studies on interest rates are, unfortunately, less frequent: and mostly concerned about national capital markets. In his seminal book

Morgestern (1959) provides a wide investigation of seasonal phenomena in interest rates in several countries, and over a long period. He detected seasonal behaviour in various cases; but another result is also noteworthy: "a phenomenon is definitely not random and of greater significance: it is the difference between pre-war (1914-'18) and post-war indexes for all countries..... We know what caused the shifts and - for Germany and the United States, even the entire disappearance of seasonal deviations " after the period 1928-'29: "it is the greater control over the money market exercised by central banks and treasuries". (p.83) A really complete disappearance of the phenomenon is anyway still doubtful: for the period 1947-'65 Diller (1969) using a moving average technique, found a "compelling evidence of the presence of repetitive seasonal movements in both long -and short-term interest rates in the years between 1955-1965."(p.104) An even stronger evidence is found - again in the USA interest rate - by Gibson (1970), using a regression estimate with monthly dummy variables; he also gives a description of the likely pattern:"seasonal coefficients showed a generally rising pattern from March through January; interest rates tend to be below February levels in the months preceding February." (p.442, fn.11) A spectral analysis of various United States interest rates is in Smith and Marcis (1972); the general conclusion is that "the twelve interest rates series analysed appear to have dissimilar cyclical and seasonal components are most pronounced for municipal bonds and least pronounced for corporate bonds." (p.605). More doubtful are the conclusions in the study by Barth and Bennet (1975) (the statistical technique in this case is the regression with dummy variables): "Our findings... indicate that there is no systematic month-to-month pattern in interest rates when monthly observations are employed. A seasonal model was also fitted to daily observations on the 90-day Treasury bill rate. All seasonal coefficients were significant and, though the coefficient of determination was quite small, the regression was significant." (p.53) Even for monthly data, anyway, the constant of the regression, where the dummy variable is set to zero, is significant, "indicating that the mean for the month of December is significantly different from zero" (p.81) and positive. A similar result will be found in the case of the Eurodollar market. The interesting point in the study by Barth and Bennet is that a seasonal phenomenon may disappear following the process of averaging the data. This implies that great care is needed both in the choice of the data and in their analysis; but this also implies that care is needed even at the first stage, of the definition of the phenomenon that is investigated.

2. A definition of seasonality.

In intuitive terms, a time series is seasonal (or, at least, has a seasonal component) if it behaves periodically; that is, if it repeats itself in some regular fashion. But there is no reason why this periodic component should be required to extend over the whole period. For example, a regular rise over the average interest rate in, say, December may be defined as a seasonal behaviour, even if restricted to a single month. The study of Barth and Bennet provides an example of a seasonal component restricted to December.

It is now useful to recall a standard definition: a function $c': \mathbb{R} \to \mathbb{R}$ is called <u>periodic</u> if there is a value $T \in \mathbb{R}$ such that $c'(t+T)=c'(t)$ for every t. The least of such values T is called the <u>period</u> of the function.

Once the value T is given, the domain of the function c(.) can be restricted to the interval $I = \{0,T\}$, so that the function $c: \{0,T\} \to \mathbb{R}$ is defined, where

$c(t')=c'(nT+t')$ for n integer, $t' \in I$.

It is natural to assume c(.) to be non constant; but, for the reasons seen above, c(.) is allowed to be constant over a subset I', say, $I' \subset I$. The only reasonable requirement is now that the measure of the subset $I \setminus I'$ is positive. Note that periodic functions are defined except for a constant: a natural equivalence relation $\sim$ is given among periodic functions so that $c(.) \sim b(.)$ if and only if $c(.) = b(.) + k$, k constant. This is roughly equivalent to say that in mathematical terms and even in the statistical tests the distinction is meaningless between (for example) the statement that "the interest rates are higher than average in the first half of the year", and the other "interest rates are lower in the second half"; while, of course, it makes a big difference from the point of view of economic analysis.

The following definition can now be introduced: a function $f: \mathbb{R} \to \mathbb{R}$ is said to have <u>periodic components</u> if it can be expressed as:

$f(t) = s(a(t), c_1(t), c_2(t), \dots, c_n(t), u(t))$

for every $t \in \mathbb{R}$, where:

$a(.)$ is a non-periodic function (as it can be naturally defined once the definition of periodic function is given).

$c_1(.)$ $(i=1,\dots,n)$ are periodic functions, that satisfy the requirements seen above (they may differ both for the T period and for their structure).

$u(.)$ is a random variable.

$s: \mathbb{R}^{n+2} \to \mathbb{R}$ may be specified in different ways; the ones used below are the following:

i) $f(t) = a(t) + \sum_{i=1}^{n} \lambda_i c_i(t) + u(t), \lambda_i \in \mathbb{R} \; (i=1,\dots,n)$

(additive form)

ii) $f(t) = a(t) \left(\prod_{i=1}^{n} c_i(t)\right) u(t)$

(multiplicative form)

3. The empirical evidence

An examination of the literature, both relating to interest rates and to various other markets, shows that the answer of different statistical techniques about the existence of seasonal phenomena may not be unanimous; on the other hand the definition of seasonality given in section 2. requires an investigation of "short" forms of seasonality

also (i.e. of seasonal components that do not extend over the whole year), and so it requires the statistical techniques to adjust themselves accordingly. Some test may in fact be more suitable than another when different sorts of seasonality are examined; later the question will be discussed if the discrepancies of the answers are at least partly due to this "short" seasonality.
For this reason various statistical techniques will be tested in the following.[1]

3.2.

A first, rough, test can be provided by taking, for each week of the year, the "average" interest rate.[2]
This procedure should eliminate the effect of the non-periodic components (as indicated in the definition in sec.2.), as well as the ones which do not have a period of one year, or even shorter but such that one year is exactly a multiple of it . Of course the result of the test is not at all conclusive, for two main reasons. The first is that an apparent yearly period could be produced as a superposition of non yearly periodicities, or even produced from the non periodic component. The second reason is the small size (for this specific test) of the sample used. On the other hand, the test can provide an idea of the exact pattern of an yearly cycle, once its existence could be also proved by different methods.
The pattern of the average (as given in table 1. and 2.) shows, for both the three months and the six months rates, a clear

Tab. 1.

"Average" interest rate per week

(three months rates)

week	rate	week	rate
1	8.160	27	8.560
2	7.897	28	8.474
3	7.897	29	8.516
4	7.617	30	8.439
5	7.497	31	8.558
6	7.245	32	8.521
7	7.319	33	8.641
8	7.297	34	8.723
9	7.426	35	9.020
10	7.422	36	8.947
11	7.328	37	8.975
12	7.338	38	8.936
13	7.650	39	9.013
14	7.555	40	9.326
15	7.751	41	9.203
16	7.594	42	9.165
17	7.759	43	9.186
18	7.832	44	9.350
19	7.977	45	9.322
20	7.996	46	9.227
21	7.916	47	9.076
22	8.114	48	9.188
23	7.958	49	9.072
24	7.882	50	9.116
25	8.077	51	9.210
26	8.512	52	9.238

Tab. 2.

"Average" interest rate per week

(six months rates)

week	rate	week	rate
1	8.503	27	8.904
2	8.159	28	9.009
3	8.171	29	8.929
4	7.872	30	8.831
5	7.862	31	8.991
6	7.653	32	9.065
7	7.727	33	9.227
8	7.747	34	9.226
9	7.749	35	9.418
10	7.801	36	9.317
11	7.737	37	9.416
12	7.863	38	9.442
13	7.966	39	9.472
14	7.950	40	9.900
15	8.064	41	9.597
16	8.033	42	9.681
17	8.273	43	9.758
18	8.351	44	9.631
19	8.451	45	9.518
20	8.472	46	9.386
21	8.632	47	9.337
22	8.524	48	9.403
23	8.357	49	9.486
24	8.443	50	9.412
25	8.520	51	9.607
26	8.806	52	9.468

deereasing tendence starting from the last weeks of December, extending over January and reaching the last weeks of February. The overall decrease is fairly high: two points, over an average interest rate of nearly nine per cent at the end of November. The "average" interest rate then steadily rises through the whole year; such increase is regular, but less sharp than the preceding fall.

The result is what one expect, once the effect of the demand for funds of firms and other borrowers in the United States, at the end of the year, is taken into account; the demand for capital in December and the following "release" in January-February should give as a consequence the up and down movement in interest rates.

A more natural way (than the averaging procedure) to re move non-yearly periodic components is a polynomial interpolation, with a "time" variable (i.e. any variable linearly increasing over time) as the only independent variable. The technique used follows the lines, with some modification, of the one presented by Henshaw (1966). The components that will be removed depend in a strong way on the degree of the polynomial used to interpolate. An approximate idea of the dependence can be deduced by the fact that for $p^n(x)$, n^{th} degree polynomial in the x variable, $\frac{dp^n(x)}{dx} = q^{n-1}(x)$, i.e. the first derivative, has at most an n-1 degree, and so, at most, n-1 real roots. As a consequence the $p^n(x)$ polynomial will have <u>at most</u> n-1 maxima, or minima[(3)] and its graph, at most, n-1 "bends". In the present case: the trend component, over a period of almost seven years, and any other component of a period longer than one year can be removed by a polynomial with a degree not less than eight. On the other hand, the higher is the degree of the polynomial, the higher is also the risk that the polynomial regression also interpolates (and therefore removes) an yearly periodic component. This possibility becomes relevant as the degree of the polynomial increases, over twice the number of the years in the period. An intermediate degree should then work properly.

Tab. 3.

Polynomial regression

$$r = K + \sum_{i=1}^{7} a_i t^i$$

where:

r interest rate

k constant

t "time" variable (from 1.001 to 1.314)

<u>three months rates</u>

multiple R	0.8666
R^2	0.7510
adjusted R^2	0.7422
Standard Error	1.6535
F	85.711
Durbin Watson test	0.5536
Estimated AR process	$u_t = u_{t-1}\ 0.723 + e_t$

Tab. 4.

Polynomial regression (as above)

six months rates

multiple R	0.8874
R^2	0.7875
adjusted R^2	0.7801
Standard Error	1.4072
F	105.358
Durbin Watson test	0.1726
estimated AR process	$u_t = u_{t-1}\ 0.913 + e_t$

In table 3. and 4. the results are presented of a twelfth degree regression.(4) The stastics describe a reasonably good interpolation. The Durbin Watson statistic shows evidence, beyond any doubt, of a strong autocorrelation of residuals; but this may be due to both to a simple autoregressive process, or to a regular seasonal component; or both. To decide between these alternatives a direct inspection of the residuals is necessary. In general, in fact, a simple autoregressive process can produce a "wave" around the average; but there is no reason why it should have a regular, cyclical, one-year period. On the contrary, visual inspection of the residuals suggests a regular yearly cycle of the residuals around the estimated data. A synthetic index of this behaviour is provided in tables 5. and 6; for each week the following index is computed:

$$B_i = \sum_{j=1}^{6} e_{i+j.52} \Big/ \sum_{j=1}^{6} | e_{i+j.52} | \qquad i=1,\dots,52$$

where:

$$e_k = r_k - \hat{r}_k \qquad (k=1,\dots,312)^{(5)}$$

r_k actual interest rate

$\hat{r}_k$ estimated interest rate

(In this index the sum of the absolute values gives the overall dimension of the divergencies for each week; in the summation at the numerator, changes in the opposite direction cancel out; the ratio between the two gives a measure of the direction of the divergencies, and their overall sign).

Tab. 5

Index of persistence of divergence of residuals from polynomial regression

(three months rates)

week	B_i.10	week	B_i.10
1	3.023	27	3.061
2	-0.769	28	1.200
3	-0.000	29	2.174
4	-6.875	30	1.282
5	-9.394	31	3.023
6	-9.000	32	1.628
7	-9.608	33	3.500
8	-10.000	34	5.556
9	-9.130	35	8.182
10	-10.000	36	8.857
11	-9.000	37	9.459
12	-10.000	38	9.394
13	-8.919	39	8.636
14	-10.000	40	10.000
15	-10.000	41	8.333
16	-10.000	42	10.000
17	-8.462	43	10.000
18	-7.647	44	10.000
19	-3.636	45	8.400
20	-3.077	46	10.000
21	-3.134	47	8.065
22	-1.212	48	8.095
23	-3.559	49	3.770
24	-4.118	50	6.970
25	-3.103	51	7.368
26	2.542	52	6.500

Tab. 6

Index of persistency of divergence

of residuals from polynomial regression

(six months rates)

week	B_i.10	week	B_i.10
1	1.064	28	3.659
2	-3.636	29	2.444
3	-4.074	30	1.500
4	-10.000	31	2.889
5	-8.500	32	3.778
6	-9.630	33	7.143
7	-10.000	34	6.216
8	-9.583	35	7.021
9	-8.846	36	6.842
10	-9.167	37	9.444
11	-8.644	38	9.487
12	-9.545	39	10.000
13	-9.474	40	10.000
14	-10.000	41	7.551
15	-7.459	42	8.222
16	-10.000	43	10.000
17	-7.778	44	8.140
18	-5.714	45	6.923
19	-2.903	46	7.037
20	-1.200	47	4.211
21	1.064	48	5.000
22	-0.667	49	4.500
23	-3.000	50	4.286
24	-2.453	51	5.500
25	-1.864	52	4.286
26	1.273		
27	1.923		

The index clearly shows a regular, cyclical tendency in the residuals: generally below the estimated data in the first half of the year, and generally above the estimated data in the second half.

The same index can be computed once the residuals from a polynomial regression have been substituted with the first differences. It must be recalled, anyway, that first differences remove the trend component, but do not discriminate among various seasonal components. The results are shown in tables 7. and 8.[(5)] : as one could expect, regular behaviour of the first differences is not as evident as it was in the case of residuals. In both cases, anyway, (i. e. for three and six months rates) the index is generally high (and negative in sign) in the first weeks of the year showing a regular tendency of the rates to fall in January. This "short" periodic component seems therefore strong enough to show itself even in this test.

3.3.

Two seasonal patterns seem, therefore, to be present: a short, but deep decrease of the interest rates in the first months; and a flatter (and more doubtful) increase in the following part of the year. In the following a specific test for these two components, based on a proper adaption of a polynominal regression is discussed, and results presented. Suppose that a periodic component exists in the time series, non costant over a subset $I' \subset I = [0,T]$ where T corresponds, in

Tab. 7

First differences:

Index of persistency of changes per week

(B_i , i=1,...,52, defined as above)

(three months rates)

week	B_i.10	week	B_i.10
1	-10.000	27	1.758
2	-6.183	28	-6.757
3	-0.080	29	1.935
4	-10.000	30	-3.623
5	-10.000	31	3.521
6	-6.016	32	-2.791
7	3.333	33	7.400
8	-1.494	34	5.000
9	6.160	35	10.000
10	-0.200	36	-3.435
11	-3.333	37	0.695
12	0.588	38	-1.656
13	10.000	39	2.444
14	-10.000	40	6.088
15	8.333	41	-1.299
16	-10.000	42	-1.739
17	7.246	43	0.776
18	10.000	44	5.657
19	4.652	45	-2.195
20	1.200	46	-3.986
21	-3.245	47	-6.528
22	10.000	48	2.832
23	-7.815	49	-3.043
24	-4.894	50	0.724
25	7.041	51	4.308
26	10.000	52	-1.887

Tab. 8

First differences:

Index of persistency of changes

(six months rates)

week	B_i.10	week	B_i.10
1	-5.912	28	5.652
2	-10.000	29	-6.579
3	0.185	30	-3.298
4	-10.000	31	5.294
5	-0.420	32	4.151
6	-6.238	33	6.757
7	5.500	34	-0.000
8	3.333	35	8.322
9	-0.000	36	-3.600
10	5.714	37	2.780
11	-3.393	38	0.578
12	6.032	39	1.364
13	4.493	40	10.000
14	-0.678	41	-6.441
15	4.487	42	2.511
16	-2.128	43	1.475
17	8.580	44	-7.600
18	4.340	45	-7.419
19	6.289	46	-7.570
20	0.553	47	-1.498
21	7.252	48	2.754
22	-4.599	49	2.535
23	-5.747	50	-4.286
24	3.723	51	7.059
25	3.984	52	-8.395
26	8.700		
27	3.697		

the suitable unit measure, to one year. Each $t \in \mathbb{R}$ can be reduced to a value in I, according to the function: $\rho : \mathbb{R} \to I$, defined as $\rho(t) = t'$, with t' such that $t' \in I$, $t = nT + t'$; t' may then be defined as the periodic variable. Now the interest rate (assuming, for simplicity) the additive form of the s(.) function in section 2., can be expressed as:

$$r(t) = a(t) + c(t) + u(t)$$

where c(.) is the (unique) periodic component, non constant over a subset $I' \subset I$; and it can be estimated in the form:

$$r(t) = \alpha_0 + \alpha_1 t + \alpha_2 t^2 + \dots \alpha_n t^n + \beta_1 \chi(t') t' + \beta_2 \chi(t') t'^2 + \dots$$

$$\dots \beta_m \chi(t') t'^m ;$$

where (.) is the indicator function of the interval I', defined as:

$$\chi(t') = \begin{cases} 0 \text{ if } t' \notin I' \\ 1 \quad \text{othw.} \end{cases}$$

t is any increasing ("time") variable.

The equation for r(t) is therefore the sum of two polynomials of degree n and m respectively, and in the two variables t and t'. The n degree is chosen according to the criteria discussed in section 3.1.; for the m degree the choice is suggested by the pattern the seasonal component to be tested is assumed to have. In the estimates below m has a maximum value of 7, but only the significant variables are chosen in a stepwise regression. The structure of the equation is fairly flexible: when I'=I, the existence of a seasonal component is tested that extends over the whole year; when I' is a proper subset of I, "shorter" components (i.e. components with one year as period, but non constant over a shorter interval of time) are tested. In tables 9. and 10. results are presented for the regression estimate when I"=I; i.e. when the hypothesis of a periodic component, extending over the whole year, is tested. The periodic variable is M in table 9. and M7 in table 10. In both cases the relevant coefficients are highly significant, even at the significance level of 99%.

The same test is then used to test the hypothesis of a "short" periodic component, extending nearly over the December of one year and January of the following one. The periodic variable is therefore restricted over an interval of ten weeks (the last five of one year and the first five of the following). The results are given in tables 11. and 12. The relevant variables are, in both cases, M and M7. The significancy of their coefficient may appear doubtful in the case of the three months interest rates, but is fairly high in the other case. It is also noteworthy that the signs of the coefficients are, in both cases, as expected. If the other variables are, in fact, kept fixed, the periodic variables give an increase in the first part of this sub-period that is followed by a decrease.

3.4.

One last test is worth considering. A spectral analysis exam has been performed on the interest rates time series.

Tab. 9

Polynomial regression

$$\ln r_t = k + \sum_{i=1}^{12} N(t)_i + \sum_{j=1}^{n} M(t)_j$$

where:

$\ln r_t$ (natural) logarithm of interest rate

$N(t)_i = t^i$ t: trend variable, t = 1.001,...,1.354

$M(t)_j = s^j$ s: yearly periodic variable, s = 1.001,...,1.052

(three months rates)

MULTIPLE R	0.493
R SQUARE	0.243
ADJUSTED R SQUARE	0.234
STANDARD ERROR	0.504

------------------- VARIABLES IN THE EQUATION -------------

VARIABLE	B	BETA	STD ERROR B	F
N7	-12.766	-46.322	2.397	28.367
N	-59.266	-10.520	9.298	40.621
N6	22.160	56.852	4.013	30.482
M	6.441	0.165	1.839	12.259
(CONSTANT)	46.000			

F 28.099

With all the time variables, the D.W. test has been for the unchanged variable (interest rate) case:

DURBIN-WATSON TEST 0.55111

for the log regression:

DURBIN-WATSON TEST 1.99859

Tab. 10.

Polynominal regression

defined as above

(six months rates)

MULTIPLE R	0.92180
R SQUARE	0.84972
ADJUSTED R SQUARE	0.84756
STANDARD ERROR	0.12127

------------- VARIABLES IN THE EQUATION ------------------

VARIABLE	B	BETA	STD ERROR B	F
N7	-95.021	-639.975	6.058	245.974
N	1546.166	509.440	114.298	182.992
N6	194.25	925.029	12.595	237.833
N2	-1022.865	-794.279	73.188	195.320
M7	0.362	0.141	0.054	44.778
(COSTANT)	-620.553			

F 357.131

With all the time variables in the equation, the D.W. test has been for the unchanged variable case:

DURBIN-WATSON TEST 0.17376

for the log regression:

DURBIN-WATSON TEST 0.18976

Tab. 11

Polynomial regression

$$\ln r_t = k + \sum_{i=1}^{12} a_i N(t)_i + \sum_{j=1}^{7} b_j M(t)_j$$

where:

$\ln r_t$, $N(t)_i$ as above;

$$M(t)_j = \begin{cases} (1+\{(t-(n.52-5)/100)\})^j & \text{if } n52-5 \leq t \leq n52+5 \text{ (n int.n>0)} \\ 0 & \text{otherwise} \end{cases}$$

(three months rates)

MULTIPLE R	0.50825
R SQUARE	0.25832
ADJUSTED R SQUARE	0.24327
STANDARD ERROR	0.50202

--------------- VARIABLES IN THE EQUATION ------------------

VARIABLE	B	STD ERROR B	F
N7	1935.161	807.263	5.747
N	19612.38	7462.548	6.907
N6	-8164.497	3340.457	5.974
N2	-16594.80	6383.133	6.759
N5	9806.051	3940.683	6.192
M7	-6.024	3.642	2.736
M	5.934	3.658	2.631
(CONSTANT)	-6591.999		

F 7.166

DURBIN-WATSON TEST 1.98269

Tab. 12

Polynomial regression

as defined above

(six months rates)

MULTIPLE R	0.92128
R SQUARE	0.84877
ADJUSTED R SQUARE	0.84570
STANDARD ERROR	0.12205

------------------ VARIABLES IN THE EQUATION ----------------

VARIABLE	B	STD ERROR B	F
N7	701.934	132.085	28.241
N	16399.96	2443.031	45.064
N6	-2283.860	409.960	31.035
N2	-15305.36	2350.756	42.391
N4	5753.104	948.898	36.759
M	2.00	0.889	5.057
M7	-1.981	0.885	5.006
(CONSTANT)	-5263.532		

F 276.603

DURBIN-WATSON TEST 0.16991

The graph of estimated spectral density function (for the three months rates) is presented in graph 1. The result does not support the hypothesis of an yearly cycle: the estimated amplitude for a 52 weeks period is nearly zero. The conflict between the answer of this test with that of the other ones has three possible explanations:

1. The yearly cycle described above is too weak (in a time series that is strongly non stationary) for a spectral analysis exam.

2. The phenomenon of beats may occur (see Bloomfield, (1976) p.99-101); small perturbations in the frequency of a periodic function, as in

$$x(t) = R\cos((\omega \pm \delta\omega)t + \phi)$$

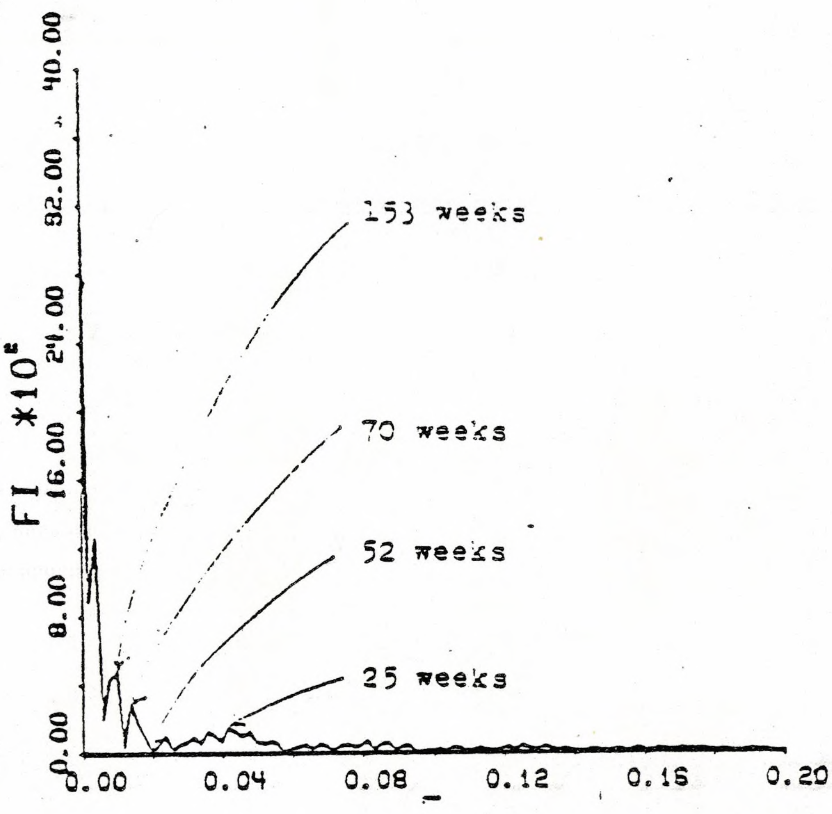
implies that the "real" frequency ω splits into $\omega + \delta\omega, \omega - \delta\omega$; so that the transform has in fact value zero at ω.
This may happen in the present case, where in fact two peaks can be found on the right and on the left of the yearly period.

3. The last possible explanation refers to the particular type of seasonality of the data under exam, and seems to suggest that spectral analysis (as well as Box-Jenkins approach) could not be the best in this and analogous cases. (For an analogous point of view, see Bertoneche (1979): "Spectral analysis should not be considered as a powerful test of market efficiency". p.204) Suppose in fact (for simplicity) that the seasonal component is non zero only over a fraction T' of the entire period T. In the discrete case, it is non zero for i: $1 \leq i \leq p$, and constant for i: $p < i \leq q$ (say), where $i=1,\ldots,q$ over the whole period.

Graph 1.

Spectral density function

Time series of interest rates in the
Eurodollar market, three months interest rates.



Consider now the expected value of the estimate of the autovariance function for a lag k:

$$E(\gamma_k) = (1/N) \sum_{i=1}^{N} E\{(z_i - \bar{z})(z_{i-k} - \bar{z})\} \ ;$$

of course:

$$E\{(z_i - \bar{z})(z_{i-k} - \bar{z})\} = \begin{cases} \tau & \text{(say) if } n \leqq i \leqq np, \ n \text{ integer} \\ 0 & \text{if } np < i \leqq nq, \quad " \end{cases}$$

when k is the "right" lag; so that (assuming for simplicity N=mq, m integer) $E(\gamma_k) = \frac{m}{N}\frac{p}{q}\tau$, and this value is obviously smaller, the smaller is p/q (i.e., the shorter is the period where the periodic component is not zero). So the estimate of the autocovariance function (and of its Fourier transform) can be very small in the case of a periodic component that is constant over a relevant fraction of the period (as it seems to be the case for the Eurodollar interest rates).

4. Seasonality and efficiency in Eurodollar capital market

The empirical evidence that has been discussed so far seems to suggest the existence of a seasonal component in the interest rates time series. In particular, a sharp decrease of the rate itself (both in the three and six months rates) in January and February appears reasonably certain; while a slow increase over the year is equally detected, but is less sharp.

It is well know, anyway, that a seasonal phenomenon in the time series of prices is not enough, <u>in itself,</u> to imply the non-efficiency of the market. The point is made clear in Samuelson (1965), and is extensively discussed in Fama (1970), p.384-388. The same point, also, has been carefully examined in the recent discussion on seasonality and efficiency in the bond market: while for Praetz (1973) seasonality does imply market inefficiency ("market imperfection", in his own terms), Officer (1976) maintains that "a seasonal may be well known and still exist in an efficient capital market simply because the opportunity cost of capital may be different at different times of the year". (p.31); or Schneeweis and Woolridge (1979) "the presence of seasonal returns, however, does not necessitate market inefficiency". (p.939). Care is needed, therefore.

The general concept of efficient market ("a market in which prices always 'fully reflect' available information') is more precisely defined by Fama along the following lines of reasoning. Let Φ_t be the set of information available at time t to the market (different sets may be considered, and the degree of efficiency will change accordingly: weak, semi-strong, strong; see Fama (1970), p.383). According to the theory of expected returns that is adopted, the expected value of the random variable $\tilde{r}_{j,t+1}$, the return of the security j at time t+1, will be determined. Then the market will be efficient if the expected value of the price of the same security at time t+1 will be set in equilibrium with such expected return; i.e., in formal terms:

1) $$E(\tilde{p}_{j,t+1}|\Phi_t) = E(1+\tilde{r}_{j,t+1}|\Phi_t)\ p_{j,t}$$

where E is the expectations operator, tildes indicate random variables. Unfortunately (see LeRoy (1976)), since the return is defined as:

2) $$r_{j,t+1} = \frac{p_{j,t+1} - p_{j,t}}{p_{j,t}}$$

the equation 1) holds as an identity (as a simple substitution can show). Hence, in order to make the definition of efficiency a meaningful one, the two sides of the equation have to be determined in some autonomous way. According to Fama's reply (Fama (1976)) to LeRoy, the definition of market efficiency can be formulated as follows:

1*) $$E_m(\tilde{p}_{j,t}|\Phi^m) = E(\tilde{p}_{j,t}|\Phi_t)$$

where the left-hand side is the expected value as assessed by the market, according to the set of information Φ_t^m it uses, while the right-hand side is the "true" expected value (p.143). Again, for the definition to be meaningful, the "true" value of the RHS must be determined according to a theory of equilibrium in financial markets. Furthermore, equation 1*) only describes how the market expectations are produced. Fama further assumes that the market in fact acts setting the "prices of securities at t-1 so that it perceives expected returns to be equal to their equilibrium value". (p.143); formally:

3) $$p_{j,t-1} = \frac{E_m\ (\tilde{p}_{j,t}\ |\Phi_{t-1}^m)}{1+E_m\ (\tilde{r}_{j,t}\ |\Phi_{t-1}^m)}$$

Finally, in order to "rule out the possibility of trading systems based only on information in Φ_t that have expected profits or returns in excess of equilibrium expected profits or returns", (as required in Fama (1970), p.385), it is also necessary that the equilibrium theory implicit in 1) is the "good" one, i.e. that the value expected is an "unbiased estimator" of the real price.

The efficient Market Hypothesis is therefore the result of the combination of the sort of perfect competition assump tion implicit in 3), of the assumption about the market ability in information processing (implicit in 1*)), and of the exacteness of the chosen equilibrium theory.
This fact has obvious consequences for the empirical analysis: "Tests must be based on a model of equilibrium, and any test is a joint test of efficiency and of the model of equilibrium". (Fama (1976), p.143). Hence, once one is confronted with nega tive answers from the empirical tests, it is impossible to decide which of the hypotheses jointly assumed has been refuted. Once these difficulties are kept into account, a more direct way of testing the efficiency of the market may be found in the classical article by Samuelson (Samuelson (1965)).
Under the assumption of the "Axiom of Mathematically Expected Price Formation":

4) $$fp^{t}_{j,t+1} = E_t(\tilde{p}_{j,t+T} \mid \Phi_t)$$

where fp^{t}_{t+T} is the future price at time t for "delivery" at time t+T, and E_t is the expectations operator at time t, (in words: "a future price is to be set by competitive bidding at the now expected level of the terminal spot price"; that is equivalent, in the present different framework, to the assumption expressed in 3)); Samuelson proved the martingale property for future prices:

5) $$E(fp^{t+1}_{j,t+T} - fp^{t}_{j,t+T}) = 0$$

By the use of future prices it is possible not to introduce the additional hypothesis implicit in a model of market equilibrium. The obvious difficulty is now given by the fact that there is no future market (so far) in the Eurodollar market. But the time structure of the interest rates provides a sort of "implicit future interest rates". In fact, if no transactions costs are assumed, and the differences between borrowing and lending rates are assumed to be small, then, if $\hat{fr}(3)^{t}_{t+3}$ indicates this "implicit future interest rate" for a three months loan at time t+3 stipulated at time t, it may be defined as:

6) $$\hat{fr}(3)^{t}_{t+3} = (1+\tilde{r}_t(6) \;/\; 1+r_t(3)) - 1$$

since an operator in the market can guarantee himself at time t a loan at time t+3 for three months, at rate $fr(3)^{t}_{t+3}$ by borrowing at time t for six months and lending at the same time for three months. Now if seasonal behaviour of the interest rate was well known and taken into account, so that $E(\tilde{r}(3)_{t+3} \mid \Phi_t)$ would behave seasonally, then 4) and 5) above imply that also the rate $1+r(6)_t/1+r(3)_t$ should behave seasonally; or, in terms of the 1*), that in the present case can be expressed as

1*) $$E(1+r(3)_{t+3} - E(1+\tilde{r}(3)^{(t)}_{t+3})) = 0$$

the following equation should hold (over the time series data):

7) $$E((1+r(3)_{t+3})(1+r(3)_t) - (1+r(6)_t)) = 0$$

An analogous argument can give an idea of how high the seasonal change may be in an efficient market. Suppose an operator in the market knows, at time 0, that he will need a given amount of capital at time t for a period T, and he knows and keeps into account a seasonal phenomenon, then the cost of borrowing at time t for the period T:

8) $$\tilde{C}(t) = E(\tilde{r}(T)_t).T$$

must be equal to the cost of borrowing at time 0 for a period t+T and lending at time 0 for a period t:

9) $$C(0) = r(t+T)_{t=0}\ (t+T - r(t)_{t=0}\ t$$

so that the (expected) seasonal change difference between the time 0 and the time t (call it $\tilde{\Delta}$) must be nearly:

10) $$\tilde{\Delta} = \frac{t}{T}\ (r(t+T_{t=0} - r(t)_{t=0})$$

This is reasonable if no transactions costs and no difference between borrowing amd lending rates are assumed, and if it is also assumed the uncertainty about the future value of interest rates rules out this kind of arbitrage operations over a wider horizon. In intuitive terms, the discussion above suggests that seasonality could be compatible with the efficiency of the Eurodollar Capital market if the time struc ture of interest rates behaved (seasonally) so that the arbitrage operations over time would not be convenient. An empirical test of the market efficiency is therefore possible, based on the study of seasonal behaviour of the time series of the ratios between interest rates for different maturities. The exam of the ratio between the three months and the six months rates does not show any seasonal component. A synthetic index is shown in tab.13, where the "average" ratio (computed with analogous criteria to those used for tables 1 and 2) for each week is given; this ratio has been standardized dividing it by the average ratio.

5. Notes on the concept of efficiency

The discussion has, so far, been concentrated on the "efficiency" of the Eurodollar market. In this last section, therefore, a closer analysis may be worth of the concept of efficiency itself.

It is firstly useful to recall how strongly the concept of the efficiency is related to the one of equilibrium of the market. In section 4 above the two assumptions have been recalled on which the Efficient Market Hypothesis is based; that is:

1. the operators in the market estimate an equilibrium value of the price (of the return) of a security. The way how these expectations are formed must not, of course, necessarily be the same of any equilibrium theory of financial markets. Operators may ignore the Sharpe-Lintner Capital Asset Pricing

Tab. 13

Average ratio (standardized) between three months and six months rates, per week. (period 1974-1979)

week	aver. ratio	week	aver. ratio
1	1.0002	27	1.0002
2	1.0008	28	0.9995
3	1.0000	29	0.9994
4	0.9998	30	0.9996
5	1.0005	31	0.9997
6	0.9996	32	0.9994
7	0.9997	33	0.9995
8	0.9992	34	0.9988
9	0.9998	35	1.0000
10	1.0000	36	1.0005
11	0.9994	37	1.0005
12	0.9995	38	0.9999
13	0.9999	39	0.9999
14	1.0000	40	1.0015
15	0.9999	41	1.0003
16	0.9997	42	0.9997
17	0.9998	43	1.0000
18	0.9996	44	1.0006
19	0.9987	45	1.0011
20	0.9992	46	1.0006
21	0.9969	47	1.0009
22	0.9994	48	1.0007
23	0.9990	49	1.0009
24	0.9995	50	1.0010
25	0.9997	51	1.0016
26	1.0005	52	1.0000

theory, or any other, and they may only guess. But the guess must be around an equilibrium value.

2. the rational behaviour of the operators is such that the market tends to push the level of prices as close as possible (and as soon as possible) to the equilibrium level. And the assumption of perfect competition of the market is not sufficient to insure this condition.

Assumptions 1 and 2 above intend, of course, to be realistic description of a (financial) market; in the sense that they should well capture the essential characteristiques of the market itself. But it is certainly not the unique possible description of the working of a market. An attempt is made, in the following, to show that, in the writings of Keynes, a completely different view of the subject can be found; moreover, that such view is able to provide a different explanation of market phenomena that could otherwise be interpreted as the effect of "inefficiency".

Keynes is, of course, only one (the most authoritative, perhaps) example; but he is not the unique one.
One only has to think of the attempts to define, in the writings by H.A.Simon, a broader concept of rational behaviour; and particularly of the idea of rationality as a process:

> "Economics has largely been preoccupied with the results of rational choice rather than the <u>process</u> of choice. Yet as economic analysis acquires a broader concern with the dynamics of choice under uncertainty, it will become more and more essential to consider choice processes".
> (Simon (1978) p.2)

The same concept of choice process will be later shown to play a decisive role in Keynes' analysis.

The problem of seasonality itself has been examined by Keynes, always in connection to the behaviour of particular markets. In "Indian Currency and Finance" the problem is investigated of the seasonal rise and fall in Indian interest rates; and the reason why this phenomenon is not cancelled by the actions of arbitrageurs is found in the transactions costs:

> "If ... money can be employed in India at the high rate for one month only, even if the double cost of remittance for that period is so low as 1/16 d, the difference between the London and Indian rates must amount to5% per annum to make a transfer of funds <u>prima facie</u> profitable".
> (J.M.Keynes (1), p.172-173)

But, in a later different context, a more interesting explanation arises. In investigating the seasonal fluctuations in the rates of exchange of many european countries (sterling, franc, lira) after the abolition of the Gold Standard, Keynes emphasizes that the internal level of prices for each country is such that the mean of these fluctuating values is an equilibrium value: but this fact in itself, even if well known is not enough:

> "whilst purely seasonal fluctuations do not interfere with the forces which determine the ultimate equilibrium of the exchanges, nevertheless stability of the exchange from day to day cannot be maintained merely by the <u>fact</u> of stability in these underlying

> conditions. It is necessary also that the bankers should have a sufficiently certain <u>expectation</u> of such stability to induce them to look after the daily and seasonal fluctuations of the market in return for a moderate commission".
> (J.M.Keynes (2), p.92-93)

In this case, therefore, the market may even rightly estimate the expected exchange rate, and the non-efficiency phenomenon of seasonality still persist.

But the more general treatment, by Keynes, of the working of financial markets is of course in the General Theory: chapters V and XII in the first place. What is relevant to the present discussion, anyway, and useful to be recalled, is the strong thesis by Keynes that the uncertainty in the market does not only add the necessity of an estimation of the future to the decision process of the operators. The uncertainty implies a radical change in the decision process.

There is, firstly, a very weak possibility of sensible forecasts about the future yield of investments:

> "The outstanding fact is the extreme precariousness of the basis of knowledge on which our estimates of prospective yield have to be made. Our knowledge of the factors which will govern the yield of an investment some years hence is usually very slight and often negligible".
> (J.M.Keynes (3), p.149)

As a consequence, the <u>expected</u> value of the yield of an investment is not enough (as it was in the case of an exchange rates discussed above):

> "The state of long-term expectation ... does not depend, therefore, on the most probable forecast we can make. It also depends on the confidence with which we make this forecast - on how highly we rate the likelyhood of our best forecast turning out quite wrong".
> (J.M.Keynes, ibidem, p.148)

So far, Keynes might only seem to introduce the concept, well known in the portfolio theory (at least), that investors do not only keep into account the expected value of the relevant random variables, but their higher moments as well.

The Keynes' conslusion , on the contrary, was quite different. The knowledge the investors have about the real factors determining the future value of the variables they have to decide upon is so weak that it is hardly possible to talk about probability estimation: "our existing knowledge does not provide a sufficient basis for a calculated mathematical expectation". (ibidem, p.152) (and this immediately follows from the basic principles of probability as given by Keynes himself in the "Treatise on Probability").

Hence the well known proposition of Keynes derives that the market behaves according to a convention (of the persistence of the actual values) more than to an expectation; and that forecasts are made by the market taking into account the only factor able to have an influence, in a foreseeable way, on the "existing state of affairs": the beliefs of the market itself. The prospective yield has, de facto, a very slight weight:

"In point of fact, all sorts of considerations enter into the market valuation which are in no way relevant to the prospective yield". (ibidem, p.152)

Some relevant conclusions for the present discussion can now be drawn:

i) the equilibrium values of the relevant variables (e.g. the price of an asset) are given in Keynes in a dynamical, non static model, where the past history of such values is as relevant as the values of the other variables. For example, the existing market valuation may be an equilibrium one, just as a consequence of the fact that the convention is assumed that it will persist.

ii) Moreover, the Keynes' analysis seems close to a game theoretic one (the operators in the market keep into account how the other operators have acted and will probably act, in order to take decisions).

iii) Because of i) and ii), it is hard to conceive of this equilibrium as a unique one, more than it is in a static optimization model, where assumptions of strict convexity may be enough (and this is not the case: see e.g. Verrecchia (1979), where the proof, by means of the Brouwer's fixed point theorem, of the existence of the "consensus beliefs" does not insure its uniqueness).

iv) i) and ii) on the other hand imply that the actions of the market itself determine which one of the equilibrium values will be achieved. But this last point, also, makes the concept itself of efficiency (as ability of the market to process information in order to assess the equilibrium value), dubious once this equilibrium value is a product of the market behaviour itself.

6. Conclusions

Even if one agrees upon some of the doubts expressed so far about definition and concept of efficiency, the problem is left to explain why the Eurodollar market displays a seasonal phenomenon. The immediate factor producing such seasonal behaviour in the period December-January (following year) is not hard to determine; the demand for funds of United States firms at the end of the year, and the following release of funds after the closure of corporate books is likely to produce the observed rise and fall of interest rate in a market that is strictly connected with the USA capital market. On the other hand, the absence of a central bank (that in the national capital markets actively balances the seasonal factors) makes these factors easier to show themselves. The reason why the market itself is not able, apparently, to cancel a regular cyclical behaviour is more difficult to find: all the more that the Eurodollar market seems nearly to satisfy the set of sufficient conditions for efficiency as stated by Fama (1970) ((i) no transaction cost; (ii) all available information is costlessly available to all market partecipants; and it is also reasonable that

(iii) all agree on the implications of current information for the interest rates), and the spread between the seasonal maximum and minimum seems to be high enough to make an inter temporal arbitrage convenient. In fact, since the three conditions stated above are set of sufficient conditions, two only possible explanations seem left. The first is that it does not "fully reflect" the information available because, in its entirety, does not know them. This is a simple, but not convincing explanation. The phenomenon itself of "window dressing" of firms is too well known, and its implications on interest rates too obvious to be ignored. The second explanation refers to the structure of the market: that is not, for sure, a perfectly competitive one. The discussion above has, hopefully, shown that a borrower in the Eurodollar market can take advantage of diversified term structure of loans: in intuitive terms, he could try to avoid a borrowing operation in periods of high interest rates by properly adjusting borrowing and lend ing operations. By acting this way, he would in fact perform the function of arbitrageur (over time). This may be true in abstract term: but it might be hard in reality. There are several reasons why a "normal" customer (i.e. an agent in the market that borrows funds as means of payment) cannot in fact act as an arbitrageur . It may, firstly, be very difficult to exactly foresee the quantity, the moment in time, and so forth, of financial necessities. Exchange risk considerations may become a prevailing factor, when the field of action of an operator is mainly national. Also costs of arbitraging may become high for an operator whose function is not specifically this one. These, and other possible reasons, do in fact explain why in various markets there is a group of operators whose specific function is the one of earning on the margins provided by other sections of this market. When this group does not exist, or is not large enough, the compensating action of the market may not work. This is likely to happen in the Eurodollar market. In this (oligopolistic) market the absence of a stable and large group of intermediaries between banks and "final" borrowers may be the main reason why potential margins of profit are left unused.

Notes

1) The data used below are all derived from "The Financial Times", and refer to Friday of each week; each value is the average between maximum and minimum of the spread; three months and six months rates are considered. The period considered extends from January 2nd, 1974, to October 24th, 1980.

2) For the sake of exacteness the "average" interest rate, as given in tables 1. and 2., is computed according to the formula:

$$\hat{r}_i = 1 - \left[\prod_{j=1}^{6} (1+r_{ij})\right]^{1/6} \qquad (i= 1,\dots,52;\ j=1,\dots,6)$$

where:

$\hat{r}_i$ "average" interest rate for the i^{th} week

r_{ij} actual interest rate in the i^{th} week of the j^{th} year. The years considered are the 1974-1979; the 1980 has been excluded because incomplete.

3) But the first derivative may also be zero at an "inflection" point.

4) Some experiment showed that the coefficients, and the behaviour of the residuals, do not significantly change with degrees ranging between eight and twelve.

5) Again, the year 1980 has been ignored because incomplete.

6) For the semi-strong efficiency, the information set also includes "other information that is obviously publicly

available (e.g. announcements of annual earnings, stock splits, etc.)"; and strong one is "concerned with whether given investors or groups have monopolistic access to any information relevant for price formation". (Fama (1970), p.383).

7) For exacteness, defing:

$$\bar{x} = \left(\sum_{j=1}^{n} \frac{1+r(3)_j}{1+r(6)_j} \right) \frac{1}{n}$$

then the average ratio for the i^{th} week, m_i, is:

$$m_i = \left(\prod_{k=1}^{6} \frac{1+r(3)_{i+k.52}}{1+r(6)_{i+k.52}} \right)^{1/6} \bar{x} -1$$

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