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# Multiple Structural Breaks and Persistence of International Inflation

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Abstracts

We show, in this paper, that the inflation rates from thirteen industrialized countries are very persistent and contain also a large number of structural breaks in their means. While the apparent long memory behavior could be due to the presence of neglected occasional regime shifts, we still find that all the inflation rates are of long memory, even after allowing for various nonstationarities such as changing means.

KRF Classification : B030104
Keywords : Multiple Structural Breaks, Inflation, Long-memory, Whittle likelihood, Increment ratio

## Ⅰ. Introduction

There is significant current research interest on the persistence property of inflation rates. For instance, Fuhrer and Moore (1995) show that postwar U.S. inflation is very persistent by estimating its autocorrelation functions. A correct identification of the persistence of inflation rates, as well as the nature of their dynamics, is crucial for the proper modeling of monetary transmission mechanisms and of monetary policy. The persistence

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of inflation rates also affects the performance of monetary policy see e.g. Rudebusch (2002) and Levin and Williams (2003). Researchers have proposed various theoretical models to explain highly persistent inflation see e.g. many references cited in Levin and Piger (2004). The literature also reveals that inflation rates are subject to multiple structural breaks, see e.g. Rapach and Wohar (2005) and Clark (2006). As shown, for example, in Granger and Teräsvirta (1999), Diebold and Inoue (2001), and Granger and Hyung (2004), however, the apparently high persistence of inflation rates could be induced by the presence of neglected occasional structural breaks.

We examine, in this study, the memory property of the inflation rates from thirteen industrialized counties over the sample period from1960~1998. More specifically, we show, first, that the long memory parameters of their inflation rates are very high, sometimes larger than 1, by employing a recently proposed semiparametric estimator. We, also, find that all of the inflation rates are subject to multiple structural breaks in their means. We also correct previous finding about structural breaks of the same inflation data series reported in an earlier work by Rapach and Wohar (2005). We, finally, apply a new testing procedure for long memory, which is known to be robust to various nonstationarities such as changing means. We find little evidence against long memory in all of the thirteen international inflation rates. All in all, we may conclude that while the international inflation rates are subject to multiple structural breaks, they are of long memory, even after the presence of multiple structural breaks are accommodated. In the next section, we present the inflation rate data series examined in this study and provide some preliminary data analysis results.

## Ⅱ. Data on international inflation rates

We employ, in this study, quarterly observations on the annualized inflation rates from CPI for the following thirteen countries: Australia, Belgium, Canada, Denmark, France, Ireland, Italy, the Netherlands, New Zealand, Norway, Switzerland, the U.K., and the U.S. The sample period is 1960:4~1998:3, with a total of 152 observations for each country. Figure 1 shows the data series.[1] Inflation has been low and stable since the early 1990s for most countries. Ellison and Yates (2007), for instance, examine the changing behavior of inflation rates.

Initially, we estimate the long memory parameters of the inflation rates by employing the newly proposed semiparametric estimators by Shimotsu and Phillips (2005). They propose exact local Whittle estimators of long memory parameters as a general-purpose estimation procedure. As no short-run dynamics need to be specified, the estimators are robust to its misspecification. Shimotsu and Phillips consider the following fractional process for $X_t$:

$$(1-L)^d(X_t - X_0) = u_t I\{t \geq 1\} \text{ for } t = 0, \pm 1, \pm 2, \cdots,$$

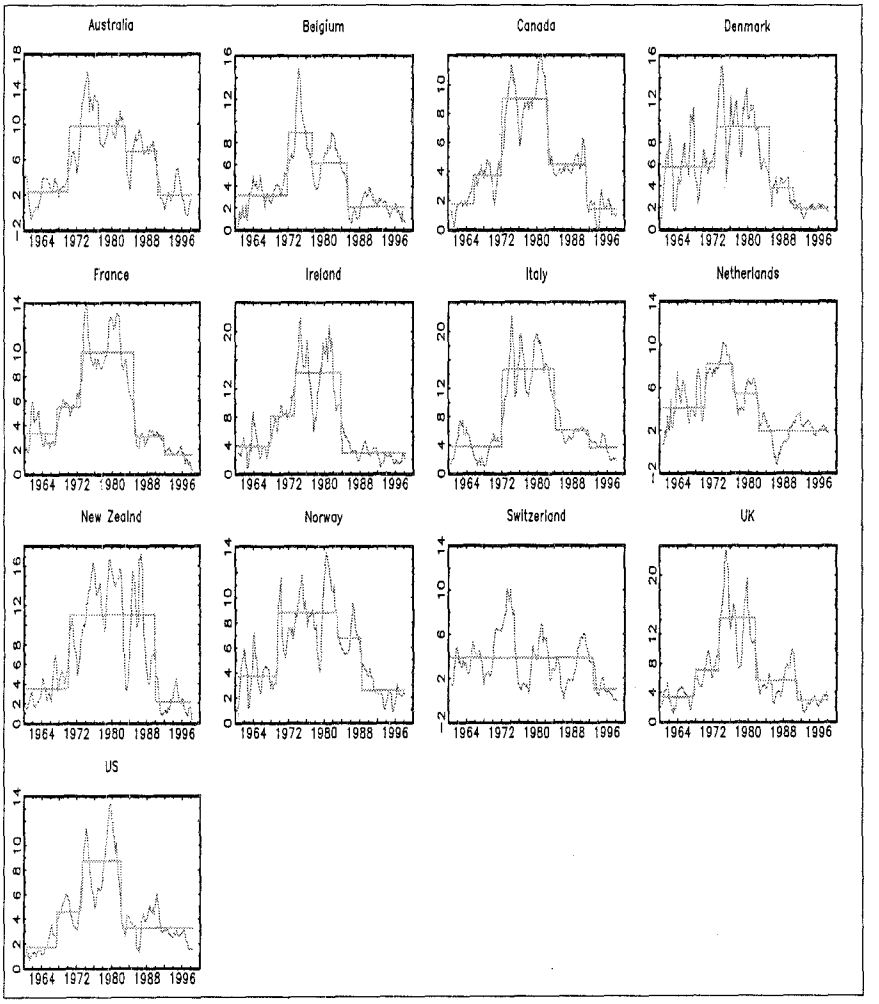
where $I\{\bullet\}$is an indicator function and $u_t$ is stationary with zero mean. $X_0$ is a random variable with a certain fixed distribution. Shimotsu and Phillips show that the exact local Whittle estimators are consistent and asymptotically normally distributed:

$$n^{1/2}(\hat{d} - d_0) \rightarrow_d N\left(0, \frac{1}{4}\right) \text{ as } n \rightarrow \infty,$$

1) The data series are previously employed in Rapach and Wohar (2005) and are available at the data archive of the *Journal of Money, Credit, and Banking*.

where $d_0$ denotes the true value of d and $n$ frequencies are employed in evaluating the Whittle likelihood. It is called exact because the procedure is based on the transformation of the Whittle likelihood function with a purely algebraic manipulation that holds exactly for any values of d. When the initial value $X_0$ is unknown, Shimotsu (2006) recommends estimating it with a combination of a sample mean and initial observation, $X_1$. He shows that a sample mean is an acceptable estimator for the

[Figure 1] Inflation rates and means for different regimes indicated by the Bai and Perron method



unknown initial value for small $d_0$. An initial observation is an acceptable estimator for large $d_0$. For additional details on the estimators, readers should consult e.g. Phillips and Shimotsu (2004), Shimotsu and Phillips (2005, 2006), and Shimotsu (2006).

Table 1 shows the feasible exact local Whittle estimates of long memory parameters of the inflation rates for different frequencies to evaluate the Whittle likelihood. The estimates are all positive and quite high, indicating that the inflation rates are very persistent or have long memory. For many inflation rates, the estimates are larger than 1, indicating that they are more persistent than a random walk. Finally, Figure 1 indicates that the inflation rates had many changes in their means during the sample period. In the next section, we examine the presence of multiple structural breaks in the means of the inflation rates.

**[Table 1] Feasible exact local Whittle estimates**

| | Frequencies | | |
|---|---|---|---|
| | $T^{0.7}$ | $T^{0.6}$ | $T^{0.5}$ |
| Australia | 1.1946 | 0.9112 | 0.8737 |
| Belgium | 1.1413 | 1.0760 | 1.1049 |
| Canada | 1.1104 | 1.0359 | 0.9676 |
| Denmark | 0.8223 | 0.5741 | 0.5566 |
| France | 1.1088 | 1.0927 | 1.0811 |
| Ireland | 1.0671 | 0.9136 | 1.0026 |
| Italy | 1.0983 | 0.8947 | 1.0486 |
| Netherlands | 0.9090 | 0.9721 | 0.9233 |
| New Zealand | 0.9161 | 0.6933 | 0.8122 |
| Norway | 0.9239 | 0.6123 | 0.7564 |
| Switzerland | 1.1330 | 0.9798 | 0.8059 |
| U.K. | 0.9968 | 0.7962 | 0.7686 |
| U.S. | 1.3929 | 1.2110 | 0.7328 |
| (s.e.) | (0.0870) | (0.1118) | (0.1443) |

$T$ denotes the sample size. Different frequencies are employed in evaluating the Whittle likelihood. (s.e.: standard error)

## Ⅲ. Multiple breaks in the inflation rates

It is well known in the literature that the apparent long memory behavior could be due to neglect of occasional regime shifts; see e.g. Granger and Teräsvirta (1999), Diebold and Inoue (2001), and Granger and Hyung (2004). Researchers have recently made efforts to discriminate long memory and structural breaks see e.g. Dolado et al. (2005), Smith (2005), Berkes et al. (2006), and Surgailis et al. (2007). We test, in this section, for the presence of multiple structural changes in the mean inflation rates by applying a powerful testing procedure developed by Bai and Perron (1998, 2003, 2006). We consider the following simplistic model with $r$ breaks ($r+1$ regimes) for the inflation rate $\pi_t$:

$$\pi_t = \beta_j + \epsilon_t \qquad (1)$$

for $t = T_{j-1}+1, \cdots, T_j$ and $j = 1, \cdots, r+1$, where $\beta_j (j = 1, \cdots, r+1)$ is the mean inflation rate in the $j$th regime and $\epsilon_t$ is an error term. Equation is called a pure structural change model where all parameters are subject to change. The unknown $r-$ partition, $(T_1, \cdots, T_r)$, represents break-points for the different regimes, with the convention that $T_0 = 0$ and $T_{r+1} = T$, where $T$ denotes the sample size. We omit here the details of Bai and Perron's procedure to save space. We refer readers to their original works.

Rapach and Wohar (2005) have previously studied the same inflation rate data series by employing the same inference procedure of Bai and Perron's. Rapach and Wohar find quite a large number of structural breaks for each country. In this paper, there is one important difference, however, that should be

mentioned. Recently, Zeileis and Kleiber (2005a, 2005b) reported that the original GAUSS program that implemented the Bai and Perron procedure contained some numerical problems that sometimes produced erroneous results. They proposed corrections. The new GAUSS program, currently available on the homepage of Pierre Perron, http://people.bu.edu/perron/, reflects these changes made by Zeileis and Kleiber (2005a, 2005b). Rapach and Wohar (2005) unfortunately employed an old version of the GAUSS program in their empirical work. We utilize, in this study, the corrected GAUSS program and find numerous differences from their previous findings. For instance, Table 2 compares the estimation results for the U.S. inflation rate. While the differences in the estimation results are not very serious for the U.S. data, the changes in the confidence band for the second break date is noticeable. For the other remaining countries, the differences in the estimation results are sometimes quite significant. We refer readers to Yoon (2007) for more details.

[Table 2] A comparison of the estimation results for the U.S. inflation rate

| | Regime 1 | Regime 2 | Regime 3 | Regime 4 |
|---|---|---|---|---|
| Rapach and Wohar (2005) | 1.72 (0.24)<br>1967:3 [1966:4, 1968:2] | 4.53 (0.24)<br>1973:1 [1971:3, 1973:2] | 8.75 (0.43)<br>1982:1 [1980:4, 1982:3] | 3.33 (0.35) |
| New | 1.72 (0.24)<br>1967:3 [1967:2, 1968:2] | 4.62 (0.09)<br>1973:2 [1972:4, 1973:4] | 8.73 (0.22)<br>1982:2 [1981:2, 1982:3] | 3.29 (0.35) |

The sample period is 1960:4 ~ 1998:3. In each cell, the mean inflation rate of each regime is reported, along with the estimated break date. The numbers in the parenthesis are standard errors. The numbers in the square brackets are the 95% confidence bands of the break dates.

Our new results on testing for multiple structural breaks in the inflation rates are summarized in Figure 1. Here, we plotted the estimated means of the inflation rates in the regimes indicated by Bai and Perron's methodology over the data series. We found

quite a large number of regime changes in most countries. According to Levin and Piger (2004), different inflation regimes could reflect the "influence of occasional shifts in the central bank's inflation objective." In summary, we found that the inflation rates from thirteen industrialized countries were subject to multiple structural breaks. The apparent long memory behavior of the inflation rates, as reported in the previous section, could be due to the presence of neglected multiple structural breaks. In the next section, we try to discriminate the long memory behavior of the inflation rates from their changing means.

## Ⅳ. Increment ratio tests for long memory

Surgailis et al. (2007) recently propose a new test, what they call the increment ratio $[IR]$ statistic, for long memory. They show that the test has good size and power properties and is robust to changes in mean, slowly varying trends, and other nonstationarities. We apply the $IR$ statistic, in this section, to the thirteen inflation rates studied in the previous sections. The $IR$ test is, only briefly, reviewed here. From a given sample of $X_1, \cdots, X_T$, the $IR$ statistic is

$$IR \equiv \frac{1}{T-3m} \sum_{k=0}^{T-3m-1} \frac{|\sum_{t=k+1}^{k+m}(X_{t+m}-X_t)+\sum_{t=k+m+1}^{k+2m}(X_{t+m}-X_t)|}{|\sum_{t=k+1}^{k+m}(X_{t+m}-X_t)|+|\sum_{t=k+m+1}^{k+2m}(X_{t+m}-X_t)|},$$

where $m$ is a bandwidth parameter. The test statistic is a sum of ratios of second-order increments of the partial sums process of observations, $\sum_{t=1}^{i} X_t$. Surgailis et al. (2007) recommend setting

$m = T^{1/3}$ or $m = T^{1/2}$. By definition, $0 \le IR \le 1$ almost surely. It is scale and location free; that is, it does not change when $X_t$ is replaced with $aX_t + b$, where $a \neq 0$ and $b$ are arbitrary constants. Surgailis et al. show that for a stationary Gaussian $X_t$, the IRstatistic converges in probability to

$$\Lambda(d) \equiv E\left[\frac{|Z_d(0)+Z_d(1)|}{|Z_d(0)|+|Z_d(1)|}\right],$$

for $-0.5 < d < 1.5$, $d \neq 0.5$. Also, $Z_d(\tau) \equiv \frac{1}{\sqrt{|4-4^{d+0.5}|}}$

$$\begin{cases} \Delta^2 B_{d+0.5}(\tau) & -.5 < d < .5 \\ \sqrt{2d(2d+1)}\int_o^1 \Delta B_{d-0.5}(\tau+s)ds & .5 < d < 1.5 \end{cases}$$ is a stationary Gaussian process with continuous time $\tau \in R$, with zero mean and unit variance. $B_H(\tau)$, $\tau \in [0, \infty)$, is a fractional Brownian motion with a Hurst parameter $0 < H < 1$. Note also that $H = d + 1/2$, $\Delta f(\tau) \equiv f(\tau+1) - f(\tau)$, and $\Delta^2 f(\tau) \equiv \Delta(\Delta f(\tau))$. Furthermore,

$$(T/m)^{1/2}(IR - E(IR)) \xrightarrow{d} N(0, \sigma^2(d)),$$

as $T, m, T/m \to \infty$ in the region $-\frac{1}{2} < d < \frac{5}{4}$, $d \neq 0.5$, where

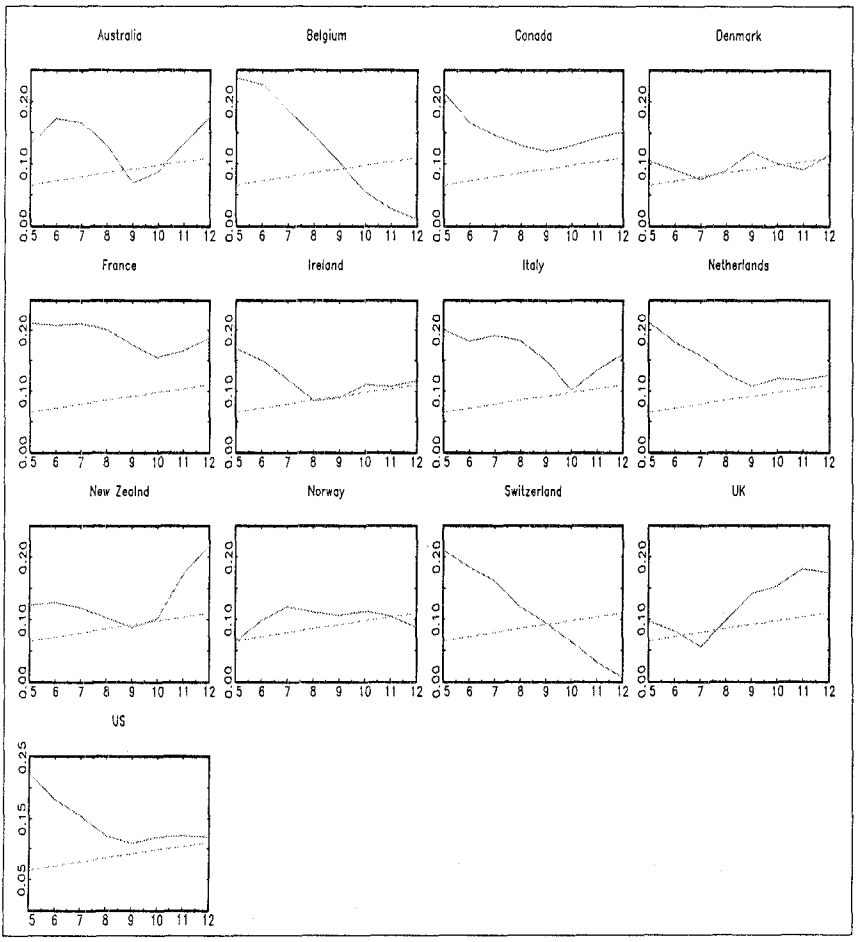
$$\sigma^2(d) \equiv 2\int_0^\infty cov\left(\frac{|Z_d(0)+Z_d(1)|}{|Z_d(0)|+|Z_d(1)|}, \frac{|Z_d(\tau)+Z_d(\tau+1)|}{|Z_d(\tau)|+|Z_d(\tau+1)|}\right)d\tau.$$

We test the $I(0)$ null hypothesis against the stationary long memory $I(d)$, $0 < d < 1/2$, alternative. The critical region is

$$IR - \Lambda(0) > z_\alpha \sigma(0) \sqrt{\frac{m}{T-3m}} .$$

Here $\Lambda(0) \approx 0.5881$, $\sigma(0) \approx 0.2080$, and $z_\alpha$ is the standard normal quantile. In this study, all the bandwidths between $m = T^{1/3}$ and $T^{1/2}$are employed to show the robustness of the test results. Yoon (2008) contains an application of the $IR$ statistic to the long returns from various equity and currency markets.

**[Figure 2]** Increment ratio tests for inflation rates




The broken line shows the 95% critical values. When the test statistic is above the critical value at a certain bandwidth, the null of $I(0)$ is rejected.

Figure 2 illustrates the $IR$ test results for various bandwidths for each inflation rate. On the horizontal axis are the different values of $m$. The broken lines indicate the 95% critical values. When the test statistic, $IR-\Lambda(0)$, is above the critical value, $z_{\alpha}\sigma(0)\sqrt{\frac{m}{T-3m}}$, at a particular bandwidth, the null of $I(0)$ is rejected. Figure 2 shows that almost all of the $IR$ test statistics are higher than the critical values for all countries. The most evidence for $I(0)$ is found for Belgium and Switzerland only for $m=10, 11, 12$. All in all, we find, in this study, that the inflation rates from thirteen industrialized countries are of long memory, even after allowance is made for various nonstationarities such as changing means. Finally, we add that this finding is not necessarily at odds with that, for instance, in Levin and Piger (2004). They find that "high inflation persistence is not an inherent characteristic of industrial economies." By the nature of the IR test, we do not know how persistent the inflation rates are; we can only tell that they are not stationary $I(0)$ processes.

## V. Conclusion

We examined, in this study, the long memory behavior of the inflation rates from thirteen industrialized countries. While the semiparametric long memory parameter estimates indicated that the inflation rates were very persistent, they were also subject to multiple structural breaks in their means. Therefore, their apparent long memory behavior could be due to the presence of neglected occasional regime shifts. Employing a new procedure for testing $I(0)$ against long memory, known to be robust to changes in the mean, slowly varying trends, and other nonstationarities, we

showed that the inflation rates were still long memory in spite of multiple structural breaks.

## ◈ *References* ◈

Bai, Jushan and Pierre Perron, 1998, Estimating and testing linear models with multiple structural changes, *Econometrica*, 66, 47-78.

Bai, Jushan and Pierre Perron, 2003, Computation and analysis of multiple structural change models, *Journal of Applied Econometrics*, 18, 1-22.

Bai, Jushan and Pierre Perron, 2006, Multiple structural change models: A simulation analysis, in Econometric Theory and Practice: Frontiers of Analysis and Applied Research, D. Corbae, S. N. Durlauf, B. E. Hansen (eds.), Cambridge University Press, 212-237.

Berkes, István, Lajos Horváth, Piotr Kokoszka and Qi-Man Shao, 2006, On discriminating between long-range dependence and changes in mean, *Annals of Statistics*, 34, 1140-1165.

Clark, Todd E., 2006, Disaggregate evidence on the persistence of consumer price inflation, *Journal of Applied Econometrics*, 21, 563-587.

Diebold, Francis X. and Atsushi Inoue, 2001, Long memory and regime switching, *Journal of Econometrics*, 105, 131-159.

Dolado, Juan J., Jesus Gonzalo, and Laura Mayoral, 2005, What is what? A simple time-domain tests of long-memory vs. structural breaks, manuscript.

Ellison, Martin and Tony Yates, 2007, Escaping volatile inflation, Journal of Money, Credit, and Banking, 39, 981-993.

Fuhrer, Jeffrey C. and George R. Moore, 1995, Inflation persistence, *Quarterly Journal of Economics*, 110, 127-159.

Granger, Clive W. J. and Namwon Hyung, 2004, Occasional structural breaks and long memory, *Journal of Empirical Finance*, 11, 399-421.

Granger, Clive W. J. and Timo Teräsvirta, 1999, A simple nonlinear time series model with misleading linear properties, Economics Letters, 62, 161-165.

Levin, Andrew T. and Jeremy M. Piger, 2004, Is inflation persistence intrinsic in industrial economies? Working paper series 334, European Central Bank.

Levin, Andrew T. and John C. Williams, 2003, Robust monetary policy with competing reference models, *Journal of Monetary Economics*, 50, 945-975.

Phillips, Peter C. B. and Katsumi Shimotsu, 2004, Local Whittle estimation of nonstationary and unit root case, Annals of Statistics, 32, 656-692.

Rapach, David E. and Mark Wohar, 2005, Regime changes in international real interest rates: Are they a monetary phenomenon? Journal of Money, Credit, and Banking, 37, 887-906.

Rudebusch, Glenn D., 2002, Assessing nominal income rules for monetary policy with model and data uncertainty, *Economic Journal*, 112, 402-432.

Shimotsu, Katsumi, 2006, Exact local Whittle estimation of fractional integration with unknown mean and time trend, Queen's Economics Department Working Paper No. 1061.

Shimotsu, Katsumi and Peter C. B. Phillips, 2005, Exact local Whittle estimation of fractional integration, Annals of Statistics, 33, 1890-1933.

Shimotsu, Katsumi and Peter C. B. Phillips, 2006, Local Whittle estimation of fractional integration and some of its variants, *Journal of Econometrics*, 130, 209-233.

Smith, Aaron, 2005, Level shifts and the illusion of long memory in economic time series, Journal of Business and Economic

Statistics, 23, 321-335.

Surgailis, Donatas, Gilles Teyssière, and Marijus Vaičiulis, 2007, The increment ratio statistic, forthcoming in Journal of Multivariate Analysis.

Yoon, Gawon, 2007, Multiple structural breaks in international inflation and real interest rates: Comments on Rapach and Wohar (2005), manuscript.

Yoon, Gawon, 2008, Long memory in return volatility, forthcoming in Applied Economics Letters.

Zeileis, Achim and Christian Kleiber, 2005a, Validating multiple structural change models－A case study, *Journal of Applied Econometrics*, 20, 685-690.

Zeileis, Achim and Christian Kleiber, 2005b, Validating multiple structural change models－An extended case study, Report 12, Department of Statistics and Mathematics, Wirtschaftsuniversität Wien.

# 국제물가상승률에서 나타나는 구조적변동성과 충격의 지속성간의 관계분석

윤 가 원*

## 논문초록

이 논문에서 우리가 보여주고 있는 것은, 첫째 13개의 산업화된 국가들의 인플레이션율이 상당한 long-memory의 성질을 가질 수 있다는 것이고, 둘째는 동시에 평균에 다수의 구조적 변동성을 가지고 있을 수 있다는 것이다. 이 둘 사이의 구별을 위해서, 평균의 구조적 변동성을 고려한 long-memory검정을 한 결과 발견된 사실은 대부분의 국가들에서 인플레이션율이 long-memory의 성질을 가지고 있다는 것이다.

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