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A PCA Factor Repeat Sales Index (1973-2001) To Forecast Apartment Prices in Paris (France)

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Abstract

In this paper we address the issue of building a repeat sales index, based on factors. This is an extension of a companion paper, Baroni, Barthélémy and Mokrane (2001, BBM) in which we had built a factorial index as a selected linear function of existing economics and financial variables. Here we offer a more general and robust model based on a Principal Components Analysis (PCA).

We apply this methodology to the Paris residential market. We use the CD-BIEN database that contains more than 220 000 repeat sales transactions for residential apartments in the Paris area covering the period 1973-2001 period.

Our PCA index for the Paris and close surrounding area is estimated and its characteristics and robustness are analysed depending on: estimation period, choice of observations, periodicity and reversibility. We then compare it to the traditional WRS repeat sales index developed by Case & Shiller (1987). Finally we show that contrary to the WRS index, our index can be used to forecast apartment prices.

Key words: Real estate indices, Repeat sales, Factors, PCA, Index forecasting

Résumé

Dans ce document de travail, nous cherchons à construire un indice immobilier en suivant une méthode de «ventes répétées », fondé sur des facteurs explicatifs. Il s'agit d'une prolongation du Working paper Baroni, Barthélémy et Mokrane (2001 et 2004, BBM) dans lequel nous avons construit un indice factoriel comme une fonction linéaire de variables économiques et financières. Ici, nous présentons un modèle plus général et plus robuste fondé sur une analyse en composantes principales (ACP).

Nous appliquons cette méthodologie au marché de l'immobilier d'habitation parisien. Nous utilisons la base CD-BIEN qui contient plus de 220 000 transactions en ventes répétées sur des appartements à usage d'habitation de la région parisienne sur la période 1973-2001.

Cet indice fondé sur une ACP est estimé, puis ses caractéristiques et sa robustesse sont analysées par rapport aux éléments suivants : période d'estimation, choix des observations, périodicité et réversibilité. Nous le comparons ensuite à l'indice classique sur ventes répétées (WRS) développé par Case et Shiller (1987). Finalement, nous montrons que contrairement à l'indice WRS, l'indice proposé peut être utilisé pour faire des prévisions sur l'évolution des prix des appartements.

Mots-clés : Indices immobiliers, Ventes répétées, Facteurs explicatifs, ACP, Prévision d'indices.

JEL Classification Code: C20, G00

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Introduction

In this paper we are concerned with the issue of forecasting real estate indexes. In a previous companion paper,[1] we have shown how to extract systematic factors for directly held residential properties in Paris and its immediate surrounding area. The method used consists of first finding consistent factors (rents, unemployment …) that drive price growth for repeat apartment transactions. We have shown that our so-called factorial transactions-based index explains a high proportion of Paris residential price movements over the 1983-2001 period. The model derived is "explanatory" and normative in the sense that it searches and highlights the variables that systematically drive Parisian residential prices.

One problem with such an index may be the choice of variables (see Baroni, Barthélémy, Mokrane 2001, 2004). Variable selection was made on the basis of stepwise regression. We found that two of the ten candidate variables (rents and unemployment) are able to capture a high proportion of price movements. With more variables, we were faced with collinearity issues. This paper circumvents this issue by developing a more general factorial methodology based on principal component analysis (PCA).

We offer a transactions-based factorial index which can directly be compared with the Case & Shiller Weighted Repeat Sales (WRS) index methodology[2]. The WRS index has been widely used to capture residential real estate price trends in the United States. Its mechanics are relatively simple to put through, since it does not require the user to collect individual characteristics for each transaction, as is the case for hedonic index models. The cost of such relative simplicity is of course the explicit assumption that the apartments that are repeatedly sold are quality-constant.

Since 1987, this method has evolved and new hybrid[3] models have been developed to include information from transactions that are not repeat-sales. However these methods necessitate abundant and accurate hedonic information, thus for the sake of comparing our transactions-based factor model which is based on repeat measures, we will generate a Paris index based on the standard Case & Shiller methodology. Our results show that the PCA index tracks very closely the WRS index we construct with the same data. What's more, the advantage of our PCA index is that it clearly identifies the main driving factors of long-term apartment price movements and can thus be used efficiently as a forecasting tool.

As a first step (Section 1), we describe our new PCA factorial methodology. We then present the data (Section 2) and results for the Paris residential market (Section 3). Section 4 compares our PCA index with an index one using the WRS methodology based on the same set of data. The forecasting features of the PCA index are presented in Section 5.

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[1] Baroni, Barthélémy & Mokrane (2001), thereafter denoted BBM.

[2] Case & Shiller (1987 & 1989).

[3] A non exhaustive list includes Clapp & Giacotto (1992), Goeztmann (1992), Gatzlaff & Haurin (1997), Quigley (1995), Englund, Quigley & Redfearn (1998), Englund & Quigley (1998), Hwang & Quigley (2002), Meese & Wallace, (1997).

1 The PCA factorial index

This section unfolds a factorial model based on the link between apartment prices and a set of economic and financial variables. We measure this link which underlines the 'true path' of the Paris residential market: in that way we develop a price index as a composite function of a number of explanatory indices.

1.1 The transaction dimension: the factors

1.1.1 Data transformation: the equivalent price returns

We consider *n* repeat transaction. For each observation i, we have the first transaction date $T_1(i)$, the purchase price $P_1(i)$, and the second transaction date $T_2(i)$ as well as the corresponding price $P_2(i)$. From those elements one can deduce the price return related to the observation *i*:

$$R_{re}(i) = \frac{P_2(i)}{P_1(i)}$$

We have k variables whose price returns are potentially linked to the apartment price returns. We have the information on the time series of those variables: for all $j = 1, \dots, k$ we have, for all $t = 1, \dots, T$, $X_j(t)$, the value of the *j*th variable at time *t*.

For each transaction *i*, we can compute the corresponding price return for all the k variables for the period that covers $T_1(i)$ to $T_2(i)$. The variables values are denoted $X_j\left[T_1(i)\right]$ and $X_j\left[T_2(i)\right]$ and the corresponding price return for the variable j is:

$$R_j(i) = \frac{X_j\left[T_2(i)\right]}{X_j\left[T_1(i)\right]}$$

To be able to compare returns between transactions, we can fix a reference period for the return, i.e. the year. We define *p* this reference period whose value is expressed in days. We denote $R_j^p(i)$ the corresponding price return for variable j and for the period related to transaction *i*:

$$R_j^p(i) = \left(R_j(i)\right)^{\frac{p}{T_2(i) - T_1(i)}} = \left(\frac{X_j\left[T_2(i)\right]}{X_j\left[T_1(i)\right]}\right)^{\frac{p}{T_2(i) - T_1(i)}} \qquad (1)$$

The question of the impact of the choice of the reference period *p* is addressed in subsection 2.3.

1.1.2 The factor construction

In this paper we assume that the logarithm of apartment price growth rates is a linear function of the equivalent log-returns on all the other variables at the same time period. This is a standard assumption (see Case & Shiller and subsequent papers on index construction).

Therefore, the relationship between the real estate period price returns $R_{re}^p(i)$ and those of the explanatory variables is:

$$R_{re}^{p}(i) = b \prod_{j=1}^{k} \left(R_{j}^{p}(i) \right)^{g_j} \qquad \text{(1bis)}$$

where k is the number of variables in the structural relation. Thus, for the price return in logarithm, we establish the following linear relation

$$LnR_{re}^{p}(i) = \ln(b) + \sum_{j=1}^{k} g_j \; LnR_{j}^{p}(i) \qquad (2)$$

where

- $LnR_{re}^{p}(i)$ is the logarithm of the period *p* real estate price return for transaction *i*,
- $LnR_{j}^{p}(i)$ are for each variable *j* the logarithm of the corresponding period price return.

As the k variables may be collinearly linked we will change the factorial base by using a Principal Components Analysis (PCA) on the k variables. We then obtain k new variables linearly independent. For each transaction *i*, we have:

$$\forall a = 1,\ldots,k, \quad LnFR_{a}^{p}(i) = \sum_{j=1}^{k} u_{a\,j} \; LnR_{j}^{p}(i) \qquad (3)$$

where

- $LnFR_{a}^{p}(i)$ is, for transaction *i*, the period *p* equivalent price return for factor a ,
- $u_{a\,j}$ is the weight of the variable *j* in the factor a . $u_{a\,j}$ is normalised and $\forall a \neq b$, $u_a \perp u_b$.

As for the initial variables, see relation (1), we assume that the relationship between the real estate returns and the equivalent factors returns are:

$$LnR_{re}^{p}(i) = a + \sum_{j=1}^{k} b_j \; LnF_{js}(i) + e(i) \qquad \text{(3bis)}$$

We then express the real estate period price return as a linear function of those new factors. By adding an error term, considering we observe a sample of apartment price returns, we have the following regression model:

$$\forall i = 1,\ldots,n, \quad LnR_{re}^{p}(i) = d + \sum_{a=1}^{k} b_a \; LnFR_{a}^{p}(i) + e(i) \qquad (4)$$

where $\forall i = 1,\ldots,n,\ \mathrm{E}[e(i)] = 0,\ \mathrm{V}[e(i)] = s^{2}$.

The homoskedastic hypothesis will be tested in practice and if it is rejected a weighted least squares estimator (WLS) can be used. By using (3) the previous regression model becomes:

$$\forall i = 1,\ldots,n, \quad LnR_{re}^{p}(i) = d + \sum_{a=1}^{k} b_a \left(\sum_{j=1}^{k} u_{a\,j} \; LnR_{j}^{p}(i) \right) + e(i) \qquad (5)$$

With this last equation, we can have the estimation of the parameter associated to the original variables X_j . From (1bis) and (5)

$$\sum_{a=1}^{k} b_a \left(\sum_{j=1}^{k} u_{a\,j}\, LnR_j^p(i) \right) = \sum_{j=1}^{k} \left(\sum_{a=1}^{k} \left(u_{a\,j} b_a \right) \right) LnR_j^p(i) = \sum_{j=1}^{k} g_j\, LnR_j^p(i) \qquad \text{(5bis)}$$

and by identification:

$$\forall j = 1,\dots,k, \quad g_j = \sum_{a=1}^{k} \left(u_{a\,j} b_a \right) \qquad \text{(5ter)}$$

The PCA index construction has two steps that are not in the same dimension. In the transaction dimension, we have just analysed the variables linked with apartment prices. The next subsection deals with the time dimension in which we build a price index as a linear combination of the other variables indices (with the factor loadings estimated by PCA).

1.2 The time series dimension: the index

The estimation of the regression gives us the loading of factor a. As we have estimated the relationship in logs, we have:

$$\forall i = 1,\dots,n,\ \widehat{LnR}_{re}^p(i) = \hat{d} + \sum_{a=1}^{k} \hat{b}_a \ln\left(\frac{F_a[T_2(i)]}{F_a[T_1(i)]} \right) \qquad (6)$$

which gives the following estimated price return for transaction i:

$$\forall i = 1,\dots,n,\ \hat{R}_{re}^p(i) = \exp\left[\hat{d} + \sum_{a=1}^{k} \hat{b}_a \ln\left(\frac{F_a[T_2(i)]}{F_a[T_1(i)]} \right) \right] = \exp\left[\hat{d} + \sum_{a=1}^{k} \hat{b}_a\ LnFR_a^p(i) \right] \qquad (7)$$

In the time series dimension we can construct the k factor indices $F_a(t)$ from the series of returns $FR_a(t)$ and this $\forall t = 2,\dots,T$,

$$\forall a = 1,\dots,k,\quad \ln\left(FR_a(t)\right) = \ln\left(\frac{F_a(t)}{F_a(t-1)} \right) = \sum_{j=1}^{k} u_{a\,j} \ln\left(\frac{X_j(t)}{X_j(t-1)} \right) \qquad (8)$$

which gives

$$\forall a = 1,\dots,k,\quad FR_a(t) = \prod_{j=1}^{k} \left(\frac{X_j(t)}{X_j(t-1)} \right)^{u_{a\,j}} \qquad (9)$$

and then

$$\forall t = 2,\dots,T,\quad F_a(t) = F_a(t-1) \times FR_a(t), \text{ with } F_a(1) = 100$$

In the time series dimension, the apartment price return can be constructed by using the p time series variables $F_a(t)$,

$$\forall t = 2,\dots,T,\ \widehat{LnR}_{re}(t) = \hat{d} + \sum_{a=1}^{k} \hat{b}_a \ln\left(\frac{F_a(t)}{F_a(t-1)} \right) \qquad (10)$$

$$\forall t = 2,\dots,T,\ \hat{R}_{re}(t) = \exp\left(\hat{d} + \sum_{a=1}^{k} \hat{b}_a \ln\left(\frac{F_a(t)}{F_a(t-1)} \right) \right) = e^{\hat{d}} \times \prod_{a=1}^{k} \left(\frac{F_a(t)}{F_a(t-1)} \right)^{\hat{b}_a} \qquad (11)$$

The parameter t is expressed in the unit chosen for the index time period p which can be: the year, the semester, the quarter, …

Finally the PCA factorial repeat sales index is generated using the following equation:

$$\forall t = 2,\ldots, T,\ \widehat{\text{Index}}\ (t)\ =\ \widehat{\text{Index}}\ (t-1)\ \times \hat{R}_{re}(t)\ ,\ \text{with}\ \ \text{Index}(1) = 100$$

2 The data

2.1 Brief description of the database

We start by describing a data source that contains repeat sales transactions data. The CD-BIEN database contains a great part of property transactions signed in front of a notary since 1990 for Paris and its surrounding area (which includes the “département” Hauts-de-Seine, Seine Saint-Denis and Val de Marne). This market is the most active in France and represents more than a quarter of the country’s residential property market.
Such a database is unique in Europe. The data registration began in 1990 and at the end of 2001, the database contained more than 890 000 transactions of which 760 000 for housing sector. It is now updated every quarter. One very important aspect of this database for our study is that around a quarter of the date (220 680 for housing) are repeat sales transactions, i.e. for a given recorded transaction, the notary also recorded the price and the date at which the apartment was previously purchased.
For each transaction in the database, a number of characteristics are provided: the location, the type of property sold (housing, offices, retail…), the type of seller and buyer, eventually but unfortunately not always the surface, the floor, …
However, we have to note that the data provided in the database is not exhaustive, since the average ratio of the number of recorded transactions and the total number of actual transactions is 70%. The main reason for this is that not all transactions around Paris are recorded in from of a parisian notary. Indeed buyer and seller may agree to record the transaction in an other region.
The database is sourced back to the notaries themselves and can therefore be considered as reliable, except where inevitable keying mistakes do indeed occur. Concerning the prices provided, they relate to the price on the acquisition act, excluding stamp duty.

2.2 Repeat Measures Transactions

In order to compute the return linked to a repeat sale, one needs the previous transaction date and price, as well as the corresponding information for the subsequent transaction. We therefore extracted all transactions whose resell date was between the 01/01/1990 and 31/12/2001 and whose previous acquisition (date and price) was also included in the database. The transactions were either residential, office, retail or mixed used (residential & professional). From the initial 760 000 recorded transactions for the residential sector, 220 680 corresponded to our criteria (and the first transaction dated back to as early as 01/01/1973). This represents a proportion of nearly 30% of all transactions. We assume that this sample is indeed an unbiased representation of the overall database.

Each transaction will thus have the following characteristics recorded:

- General location (French « Département »),

- Registration number,
- Occupied or not at the transaction's time,
- Date 1st transaction, T_1
- Price 1st transaction, P_{T1}
- Resell date, T_2
- Resell price, P_{T2}

The fact that the apartment is occupied or not is only given for the resell transaction: an asset may be vacant, occupied or partially occupied. However, this information is difficult to fully exploit since the type of occupancy is not known at the initial acquisition date. We therefore have decided to use all available information independently of their occupation status.

3 The results

After estimating the index on the whole available period (1973-2001) we will analyse the robustness of the methodology according to:

- the estimation period (running from January 1982 to December 2001)
- the observations used in the regression (Atkinson's measure, random samples)
- the index reversibility.

3.1 The estimation for the period 1973 to 2001

The first step of the methodology consists on a PCA on the 10 following variables *long term rate (LtR), short term rate (StR), consumer price index (Consum), MSCI*[4] *equity market index (Equity), listed real estate (ListRE), rents (Rent), demographic index (Demog), unemployment (Unemp), savings as a percentage of disposable income (Saving), and yield spread (Spread).* For each of them, we have time series constructed with base 100 in 1973.

We now run the regression model presented in (4). This above proposed modelling (4) assumes that the variance associated to each purpose does not depend on observation (*i*). If these assumptions are not validated, the model must be amended so that its specification corresponds to our data structure. Inside each purpose class, the White test[5] clearly indicates heteroskedasticity. To study its correct nature (the search for variables that are at the source of heteroskedasticity), we use the Goldfeld-Quant (GQ) test.

We begin by ordering regression residuals as functions of variables, and then study whether residual variance is constant across classes. Several variables may be candidate sources for heteroskedasticity : the ones contained in the table above, which were identified by the White test, as well as temporal variables such as *duration*, *date1* and *date2*. The *p*-values indicate that the source of heteroskedasticity is due principally to *duration*.

This new specification for the factorial model illustrates the importance of variable *duration*, by being able to include it in the variance but not in the level (different levels of price returns

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[4] We used the Morgan Stanley Capital International (MSCI) Index for France, which runs farther back in time than the CAC40 Index .

[5] The tests presented thereafter are described in detail in Greene (1997).

depending on holding period and different factorial relationships) enables us to construct a synthetic index for mid-term and long-term apartment price growth rates.

The study of the graph mapping the residuals as a function of *duration* logically suggests an inverse relationship between the error term's variance for observation *i* and the total holding period for the asset as measured by *duration.* The new model selected is thus an amended version of (4) in which ε(*i*) is now considered to be a random variable with zero mean and variance equal to

$$s^{2}/\left[duration(i)\right]^{a} \tag{12}$$

The first step consists on estimating the parameter delta using Maximum Likelihood (ML) techniques (see Greene). The estimated value is 0.95.

The variables weights in the factors are presented in *Table A.1*.

< Insert *Table A.1* >

The time series for the ten factors are represented in *Figure 1*. As the variation of the second factor is quiet larger than the other ones we just represent a zoom of the previous in *Figure 2*.

The results are presented in *Table A.2*

< Insert *Table A.2* >

As we have a GLS estimation (with no constant) we give two "invalid" measures of the goodness of fit: the centered R^2 and the uncentered R^2.

< Insert *Figure 1* >

< Insert *Figure 2* >

3.2 Is the choice of the estimation period important?

The same methodology as developed previously is run from 1982:6 to 2001:12, that is to say 20 years. The ML estimation of the parameter in the heteroskedastic function is 0.9. We can just notice in *Figure 3*, that this time the first factor corresponds to the second one for estimation period 1973-2001.

< Insert *Figure 3*>

We will compare the two estimations made on those two different periods for the factors and for the indices.

3.2.1 Factor Comparisons

The factors and their time series are different but for few of them we clearly have the same evolution: for factors 1, 3, 5 and 9. In *Figure 4* we compare the two estimates corresponding to our different periods.

< Insert *Figure 4* >

The factors can be different but the structure used to build the index will be nearly the same as shown in next paragraph.

3.2.2 Index Comparisons

In *Figure 5*, we compare the two indices. Note that few differences appear from 1991 onwards (see *Figure 6*).

< Insert *Figure 5* >

< Insert *Figure 6* >

These robustness tests thus show that we may be confident in the fact that the PCA methodology offered above is not too sensitive to the choice of the time period.

3.3 Is the choice of observations important?

To study the index estimation robustness according to the selected observations, we use two different approaches. First, we drop the most influential observations using the Atkinson's criteria[6]. Secondly, we extract random sub-samples of 75%, 50% and 25%. The *Table C.1* and the *Table C.2* underline the GLS estimation robustness to the selected observations (the factor coefficients are even quite the same in all those sub-samples). This robustness implies the PCA index robustness as shown in *Figure 7* and in *Figure 8* (see *Table C.3*).

< Insert *Table C.1* >

< Insert *Table C.2* >

< Insert *Table C.3*>

< Insert *Figure 7* >

< Insert *Figure 8* >

3.4 Is the choice of the periodicity important?

Two coefficients are related to the concept of periodicity, one in each of the two dimensions:

- in the observations dimension, the periodicity corresponds to the period chosen to have equivalent price returns (see section 1.1.1).

- in the time series dimension, the periodicity corresponds to the time interval for the index.

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[6] To detect those values, we use the Atkinson's measure (Atkinson, A.C., *Plots, Transformations and Regression,* UK, 1985, Clarendon Press). The idea is to compare the estimation of the endogeneous variable with the i^{th} observation and without, and this, for all the observations. If we have n observations, p exogeneous variables, by noting h_{ii} the i^{th} diagonal element of the hat matrix, the Atkinson's measure for observation i is:

$$A_i = \left(D_i(n-p)s^2 / s(i)^2\right)^{1/2}$$

where $D_i = \left(\frac{\hat{u}_i}{s(1-h_{ii})^{1/2}}\right)^2 \left(\frac{h_{ii}}{1-h_{ii}}\right)\frac{1}{p}$ and the externally variance $s^2(i) = \frac{(n-p)s^2 - \hat{u}_i^2 / (1-h_{ii})}{n-p-1}$

Although these two parameters are linked (the periodicity of the equivalent price returns should be less or equal to the index periodicity), they can be fixed independently. The problem of the index periodicity is not dependent on our methodology and is related to the issue of time aggregation. Hence, we will focus in this section on the periodicity defined in the observations dimension.

Let $q = \dfrac{p}{T_2(i) - T_1(i)}$. We then have for variable j:

$$R_j^p(i) = \left(R_j(i)\right)^q = \left(\frac{X_j\left[T_2(i)\right]}{X_j\left[T_1(i)\right]}\right)^q \tag{13}$$

which gives for the logarithm

$$LnR_j^p(i) = \ln\left[\left(R_j(i)\right)^q\right] = q\ln\left[R_j(i)\right] \tag{14}$$

where $R_j(i)$ is the observed return whatever the detention period is.

Moreover from (5bis) we may write

$$\sum_{j=1}^{k}\left(\sum_{a=1}^{k}\left(u_{aj}b_a\right)\right)q\ln\left[R_j(i)\right] = q\sum_{j=1}^{k}\sum_{a=1}^{k}u_{aj}b_a\ln\left[R_j(i)\right] = \sum_{j=1}^{k}q\,g_j\ln\left[R_j(i)\right] \tag{15}$$

So, changing the periodicity is equivalent to multiply the regression terms by a constant c (i.e., from an annual index to a semi-annual index, c = 0.5). Then (6) becomes:

$$\forall i = 1,\ldots,n,\ c\times \widehat{LnR}_{re}^p(i) = c\times\hat{d} + \sum_{a=1}^{k}c\times\hat{b}_a\ LnFR_a^p(i) \tag{16}$$

Thus the estimated coefficients $\hat{b}_a$ and $\hat{d}$ are multiplied by c:

$$\forall i = 1,\ldots,n,\ \exp(c)\times\hat{R}_{re}^p(i) = \exp\left[c\hat{d} + \sum_{a=1}^{k}c\hat{b}_a\ LnFR_a^p(i)\right] = \exp(c)\times\exp\left[\hat{d} + \sum_{a=1}^{k}\hat{b}_a\ LnFR_a^p(i)\right] \tag{17}$$

We then find the same estimated model for $\hat{R}_{re}^p(i)$ and thus the same estimated index. But as mentioned above, the estimated coefficients are changing according to c. If we want to have constant coefficients for the factors it is possible to use the standardised variables in the factor construction.

We note $s_j^2 = \mathrm{Var}\left(\ln\left[R_j(i)\right]\right)$ the variance of the observed returns whatever the detention period is and we define $L\tilde{n}R_j^p(i)$ the standardised variable returns as following

$$L\tilde{n}R_j^p(i) = \frac{\ln\left[\left(R_j(i)\right)^q\right]}{\mathrm{Var}\left(\ln\left[\left(R_j(i)\right)^q\right]\right)} = \frac{q\ln\left[R_j(i)\right]}{\sqrt{\mathrm{Var}\left(q\ln\left[\left(R_j(i)\right)\right]\right)}} = \frac{q\ln\left[R_j(i)\right]}{q\,s_j} = \frac{\ln\left[R_j(i)\right]}{s_j} \tag{18}$$

which is independent of p. All the changes in the regression results will be reported in the constant term, which will be multiplied by c. Hence, the factor coefficients are independent of *p*. Moreover, we have shown that the results in the observations dimension are not dependent to the reference period we use[7]

3.5 The PCA index reversibility

As it is underlined in the literature (see for instance Shiller 1998, Clapp Giaccotto 1999), this kind of index is not stable in the sense that information today changes the past values of the index, in other words, the whole index . We then compare for different ending periods the estimate index. In *Figure 9* we can see the transactions with a resale date lying between 1996 to 2001 modify the index. If this modification seems not to be significant before 1989, it appears more influential after this date. These modifications are detailed in *Figure 10* where we study for the period 1990-2001 the modification of the index year by year.

< Insert *Figure 9* >

< Insert *Figure 10* >

The three indices 73-01, 73-00 and 73-99 are the same from 1995 onwards. Before this date, the estimation differs from one to another. More generally, new observations lead to a more pronounced bubble in the 1990s, a less steeper fall in 1994, and a less steeper increase in 1995.

4 Comparison with a WRS Index for Paris

To complete our systematic comparison of our PCA index, we now compare it with a weighted repeat sales index *à la* Case and Shiller. The main remark here is the striking similarities between two indices based on very different methodologies. One sticks to the transactions data by construction: the WRS index, and the other tries to capture systematic fundamental factors that affect apartment price growths: the PCA index. One should not therefore expect to find a perfect fit and the strong similarity is a signal that reinforces both methodologies and the indices they produce.

Nevertheless, there are slight differences between the two indices. The PCA index seems to absorb the end of the trough at the end 1990's. This can be seen on and *Figure 11*. Before the decline of the WRS index, those two measures have the same values in 1990:12. But, in 1992, the decrease is quite intensive for the WRS index. The PCA index tells a slightly different story: the trough shouldn't have been that important.

< Insert *Figure 11* >

< Insert *Figure 12* >

To conclude this section, one may formulate the main difference between the two methodologies in the following way: WRS replicates the way the apartment prices moved on average during a given time period, whereas the PCA index, based on the same observation set tells us how apartment should have moved if the market had stayed true to its fundamental

[7] In practice, changes in the index computing could come from the number of observations which decreases when the length of the period increases. In our case, the important number of observations leads to very similar indices.

driving factors. In this sense, WRS is more on the positive economy side, where PCA is on a normative economy side.

We now have two indices telling a very similar story of the way a Paris apartment market has evolved over the last 20 years. The fact that the PCA index is very similar to the WRS index naturally leads us to confidently use it in a forward looking sense.

5 Forecasts

To study the forecasting power of an index over T periods, it is standard procedure to examine the forecasting power of the model estimated on the first T^* periods. Then, the estimated model is used to forecast the $T - T^*$ following periods. On the other hand, as it is possible to estimate the index for the whole T periods (see sub-section 3.1), those values estimated on T periods are compared with the ones forecasted by the model on the first T^* periods. The two series comparison is made on the basis of the square root of the total square differences named the root mean square error (RMSE).

We illustrate the forecasting power of our index with two graphs:

- a forecast from the end of 1996 for a semi-annual index, the first forecast is made for 1997:06 ((see *Figure 13*).
- A forecast from the end of 1998 for a monthly index, the first forecast is made for 1999:01 (see *Figure 14*).

But in our case, because of the index reversibility such a method will not be totally convenient. For more consistency, we examine the forecasting power for the index growth and not for the index in levels (see *Figure 15* and *Figure 16*). We compute the RMSE of the index growth (see *Table C. 4*)

< Insert *Table C. 4* >

As expected, we notice the more reduced the forecast period is, the more precise the forecast. As we can see in *Figure 16*, when the forecast return is calculated monthly, it stays very near to the index return.

< Insert *Figure 13* >

< Insert *Figure 14* >

< Insert *Figure 15* >

< Insert *Figure 16* >

Conclusion

We have developed in this paper a Principal Components repeat sales methodology which is both robust and stable. What’s more, the index constructed is very similar to the one obtained using the WRS methodology. Slight differences do appear when the market seems to follow other logical rules (crisis or boom periods). In these periods our index shows how the market *should* behave as opposed to how the market has actually behaved. In this sense, our methodology is more normative than the traditional repeat sales methodologies. Comparing the PCA index to WRS can reveal the existence of a speculative bubble. The example of Paris during the period 1990-1994 is a good illustration for this ability.

Furthermore, we show that such a methodology has predictive capacities because it is based on explanatory variables for which forecasting services may exist. We are convinced this characteristic can be very helpful for investors who search for an index that captures not only the market movements, but also how it could or should move.

FIGURES

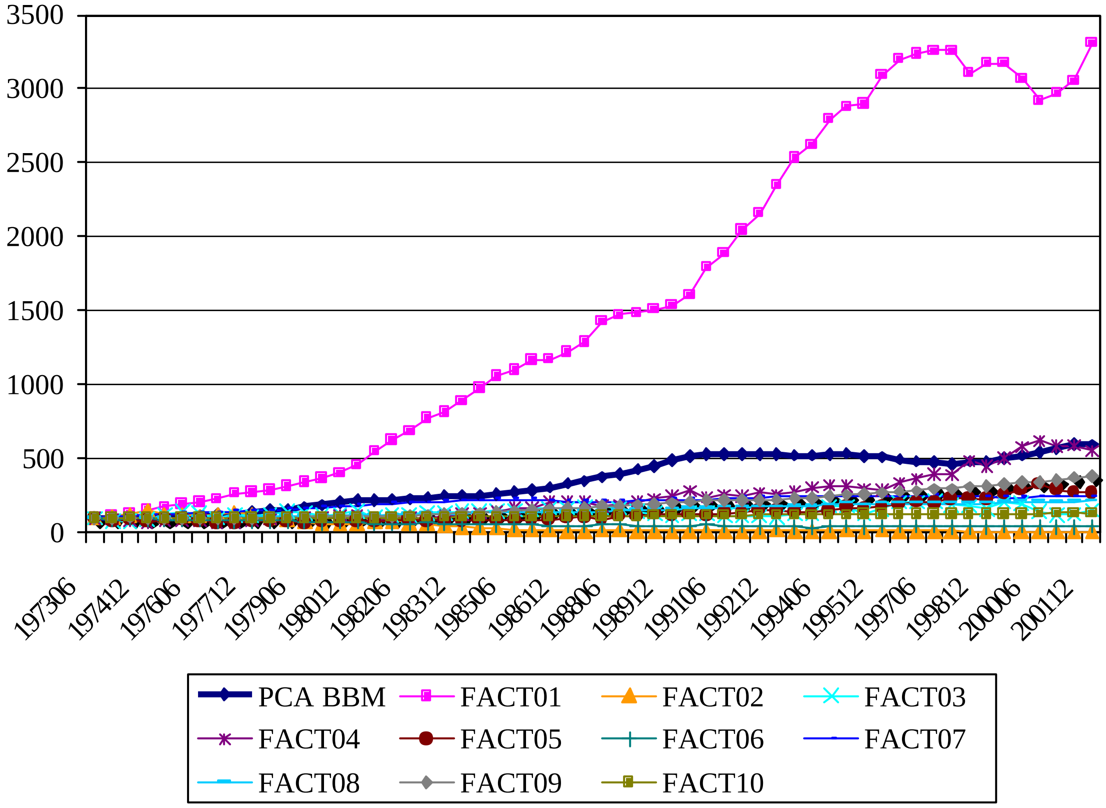

Figure 1: Factors indexes for Paris residential real estate index

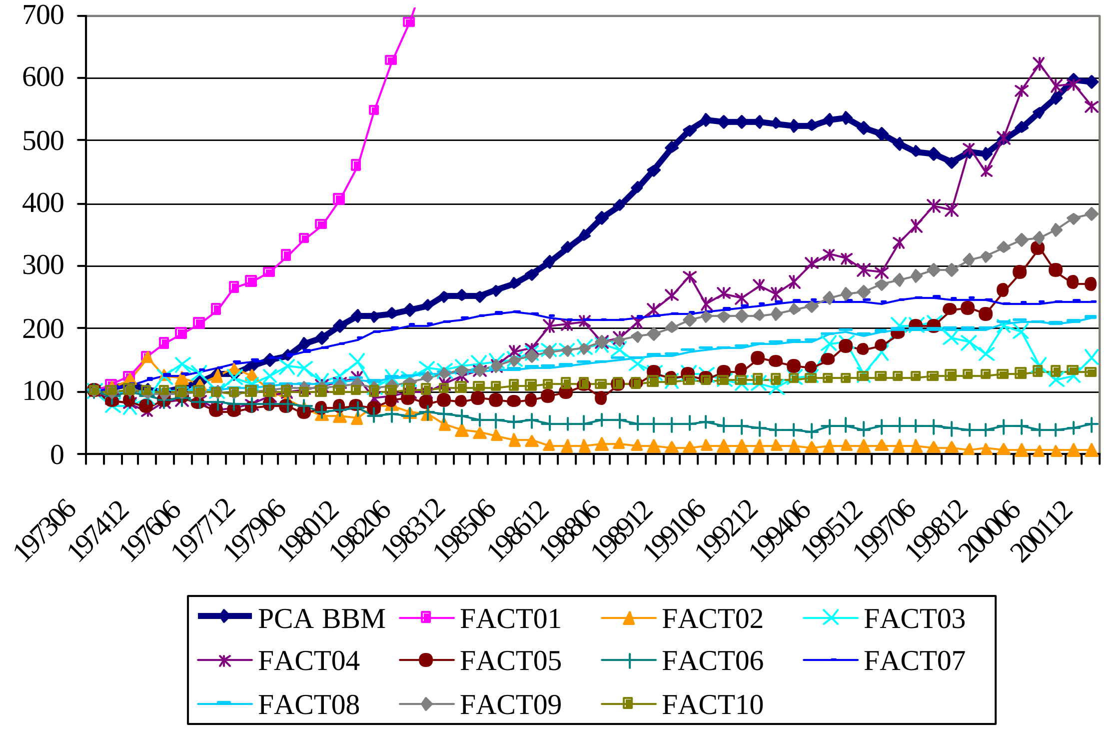

Figure 2: Factors indexes and estimated real estate index for Paris residential market from 1973:6 -2001:1

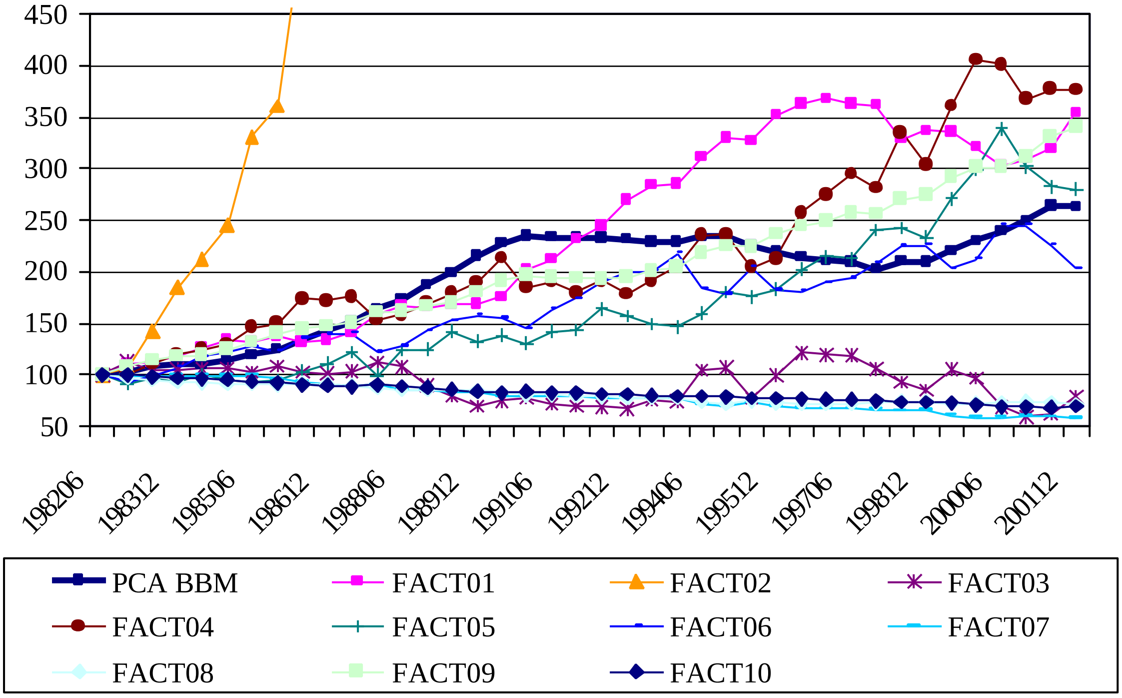

Figure 3: factors and estimated real estate index for Paris residential market from 1982:6 -2001:12

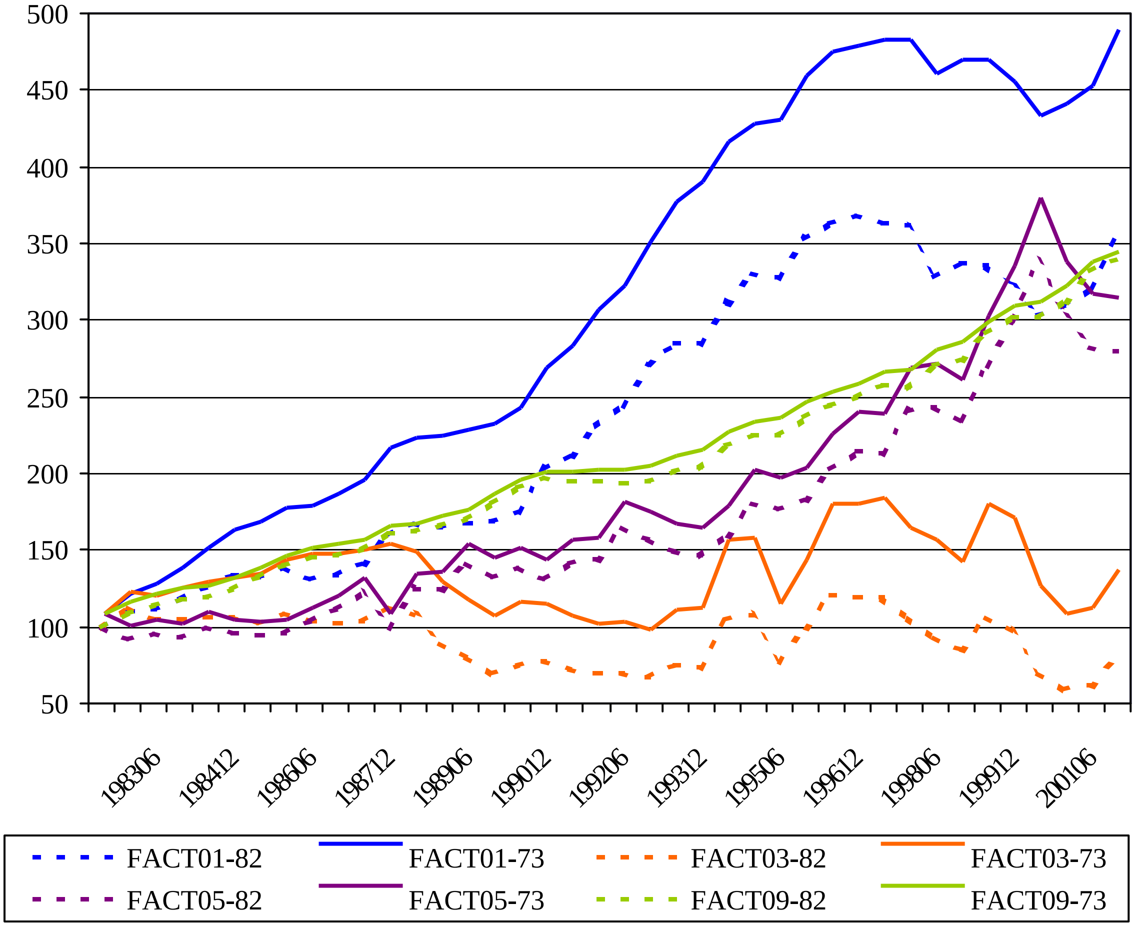

Figure 4: PCA GLS Residential Factors (6 months) - Two Estimation Period Comparison 1973-2001 & 1982-2001

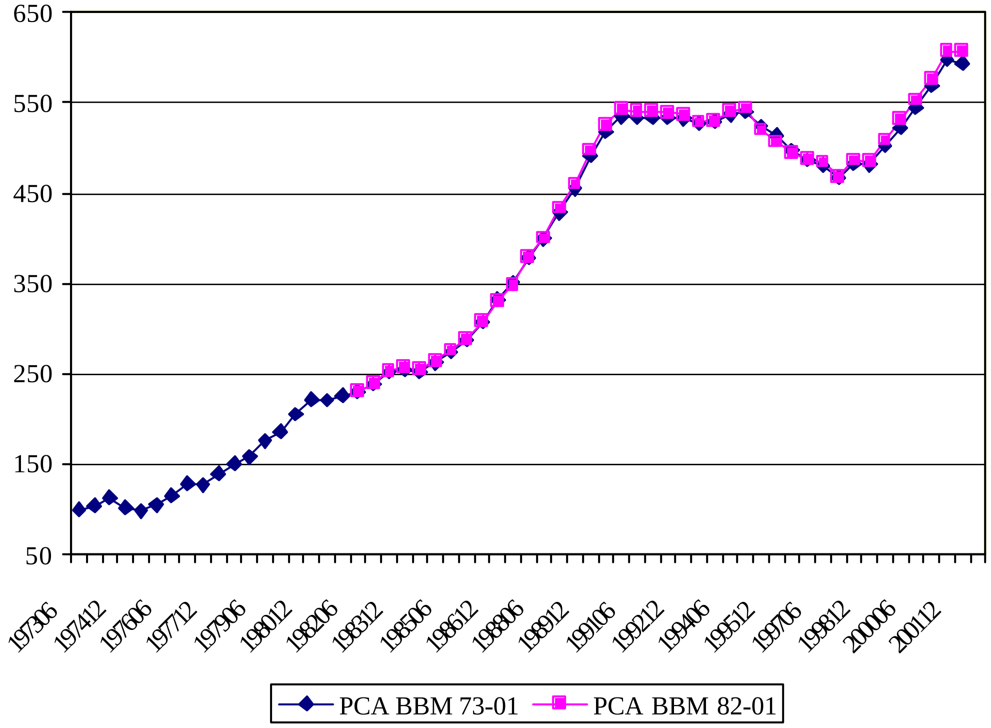

Figure 5: PCA Residential Index (6 months) - Two Estimation Period Comparison

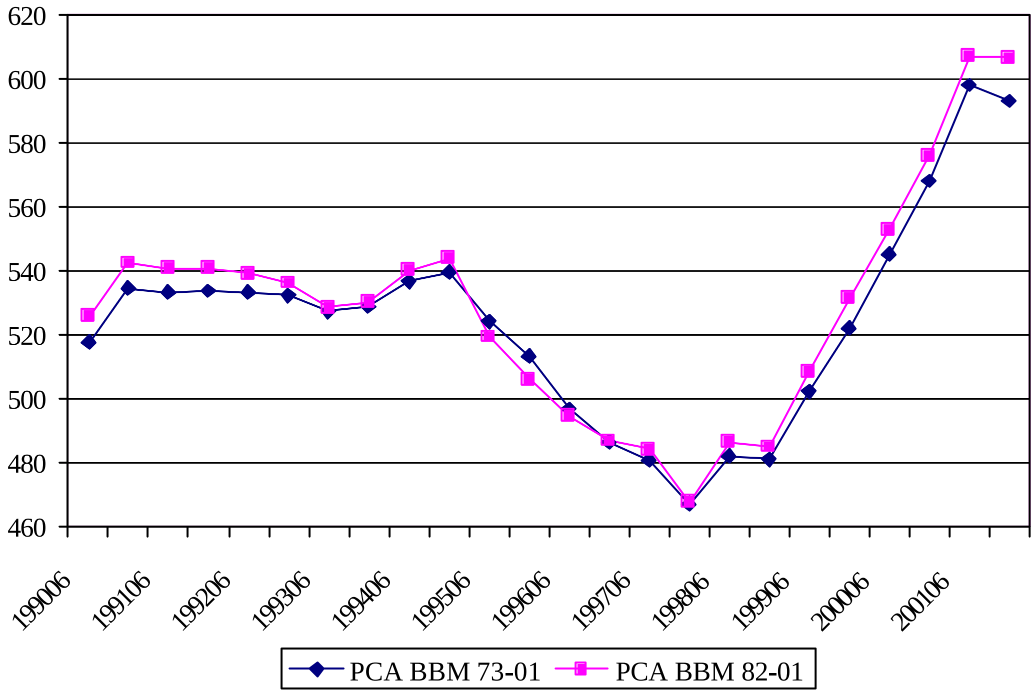

Figure 6: PCA GLS Residential Index (6 months) - Two Estimation Periods 1973- 2001 & 1982- 2001

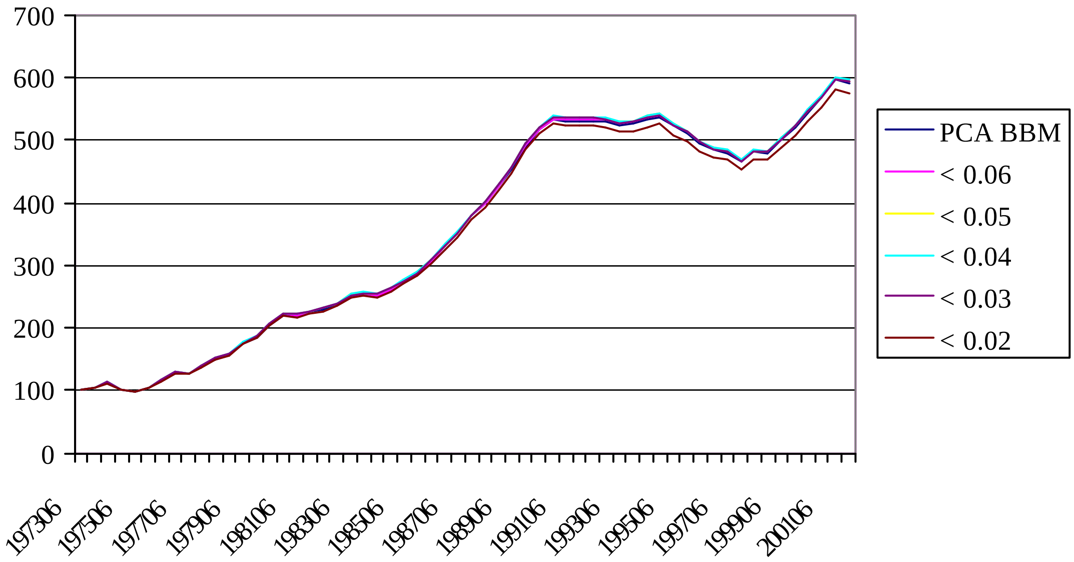

Figure 7 : PCA index robustness according to samples selected by Atkinson criteria

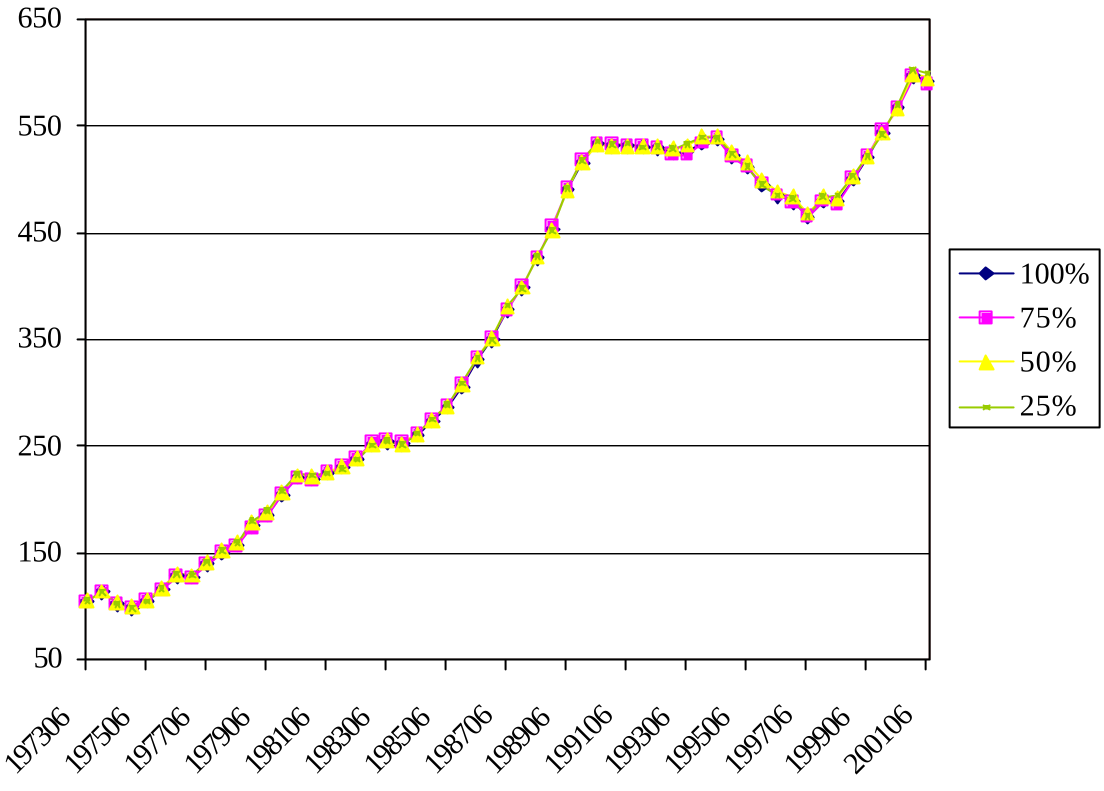

Figure 8: PCA index robustness according to sample size

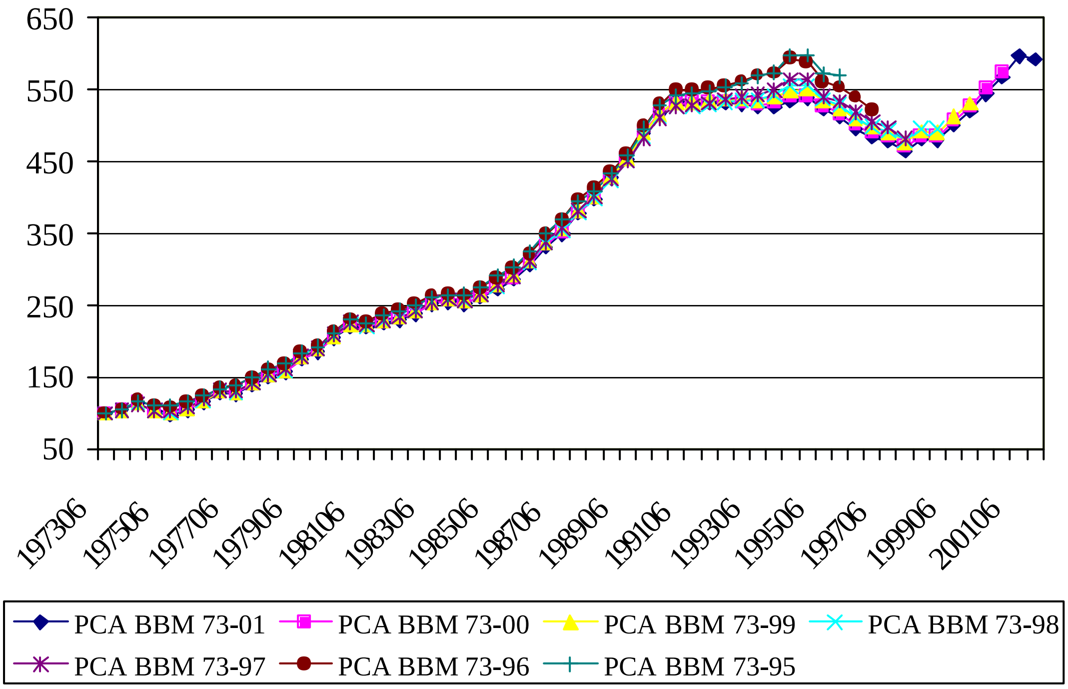

Figure 9: PCA BBM index reversibility

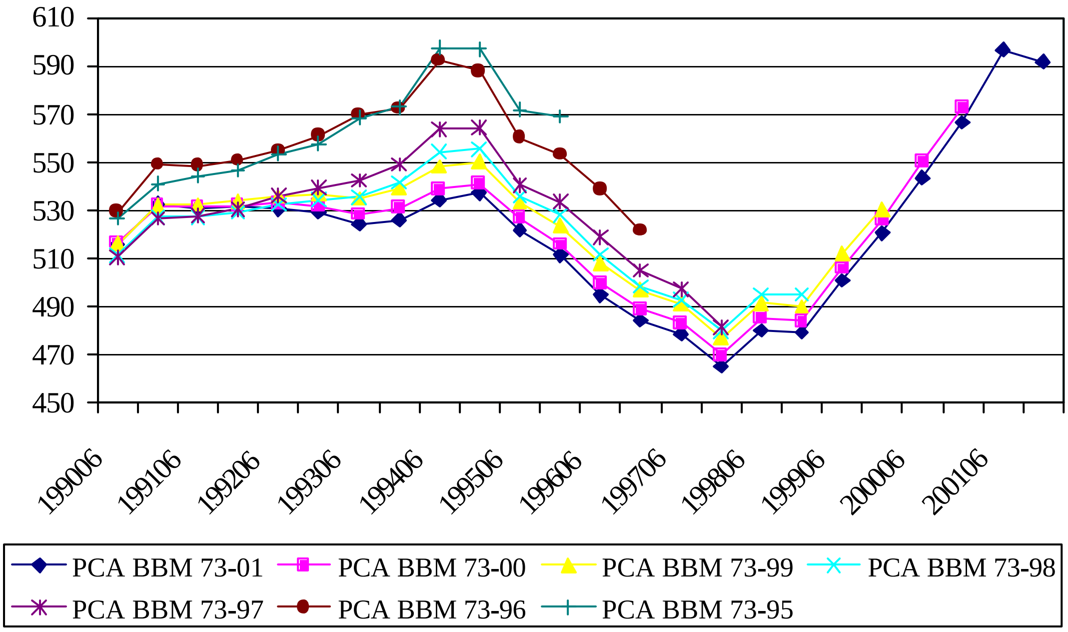

Figure 10: PCA Factorial BBM index reversibility (2)

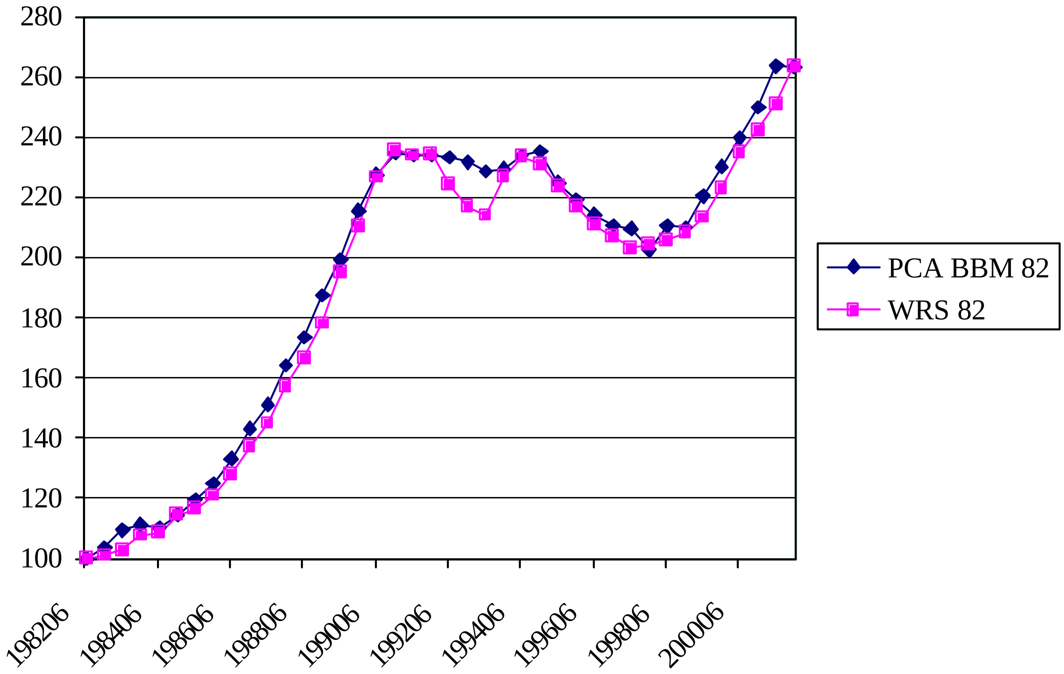

Figure 11: WRS & PCA Factorial BBM index for Paris

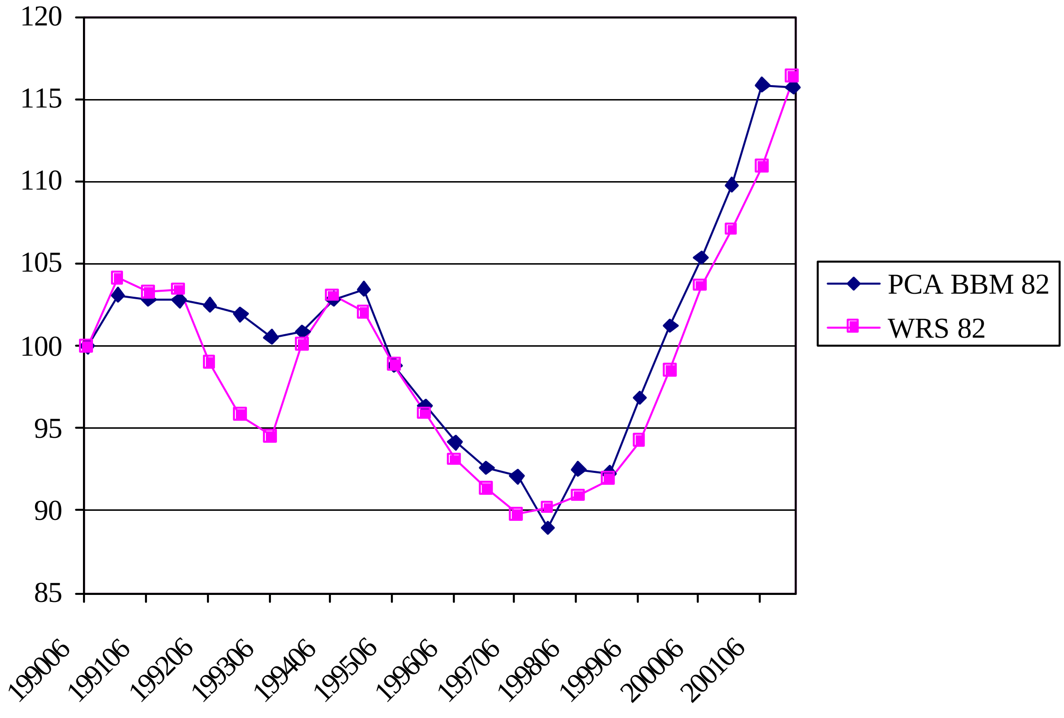

Figure 12: WRS & PCA Factorial BBM index for Paris

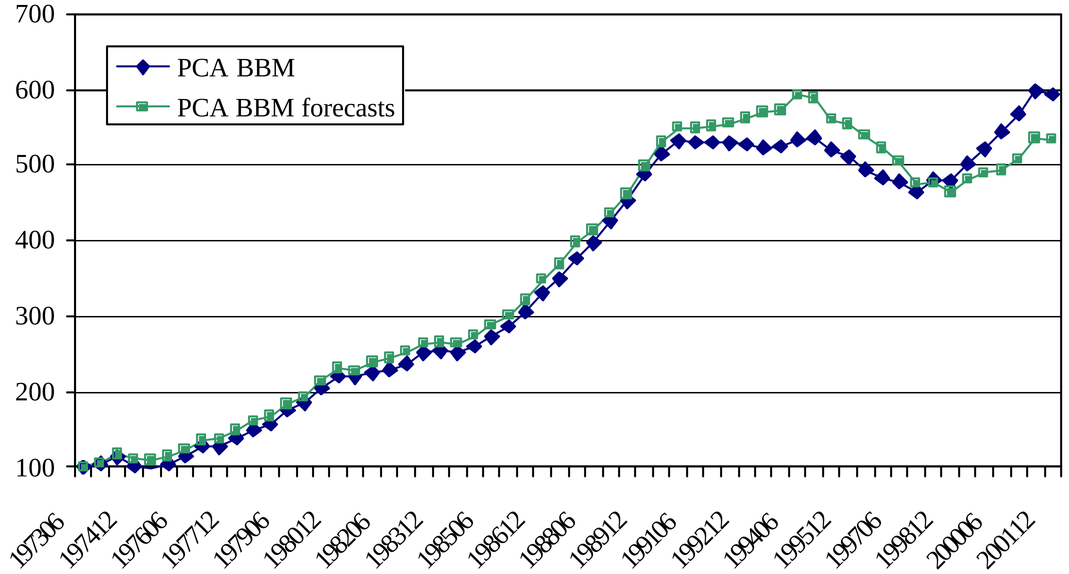

Figure 13: Prices forecasts from 1997:06 (semi-annual index)

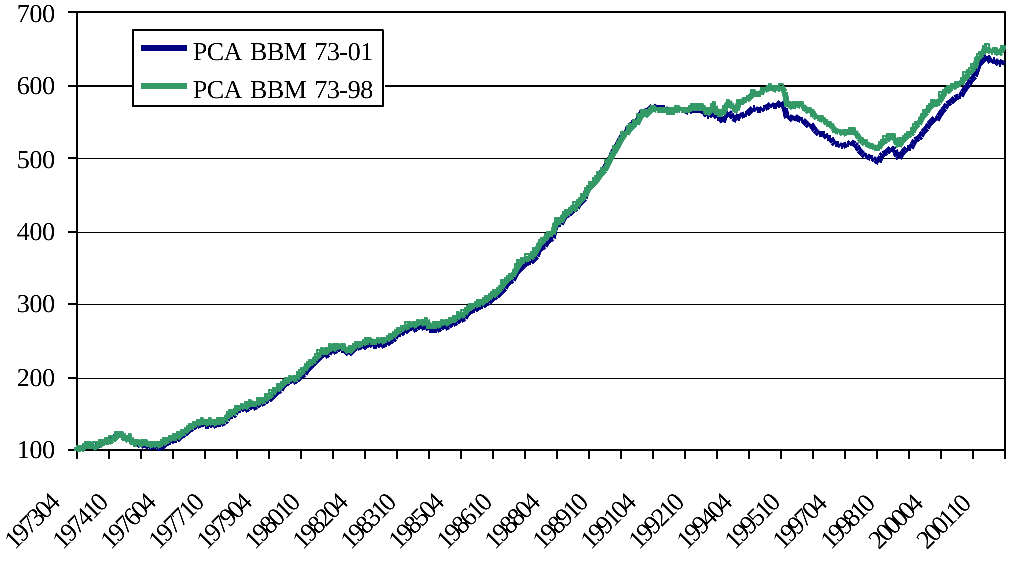

Figure 14: Prices forecasts from 1999:01 (monthly index)

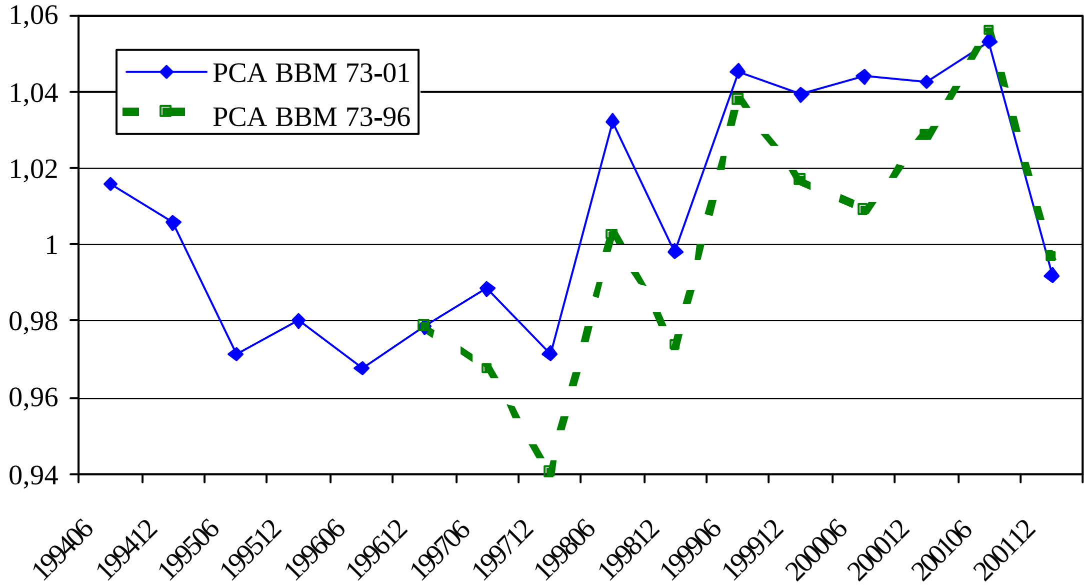

Figure 15: Returns forecasts from 1997:06 (semi-annual index)

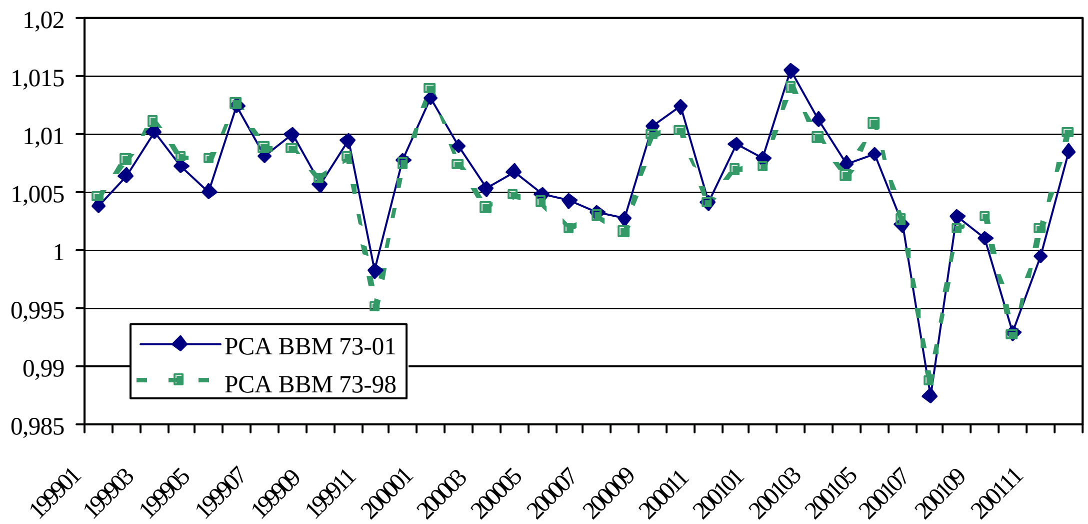

Figure 16: Returns forecasts from 1999:01 (monthly index)

APPENDIX

Appendix A : GLS estimation

	Fact01	Fact02	Fact03	Fact04	Fact05	Fact06	Fact07	Fact08	Fact09	Fact10
Equity	-0,142	-0,534	0,017	0,494	0,632	-0,215	-0,010	0,041	-0,035	0,044
Consum	0,379	-0,190	-0,099	-0,102	0,141	0,395	0,675	-0,259	-0,255	0,190
Rent	0,419	-0,059	-0,157	0,108	-0,036	0,107	-0,020	0,742	-0,265	-0,387
LtR	0,432	-0,031	-0,059	-0,010	0,148	-0,056	0,058	-0,217	0,727	-0,452
StR	0,435	0,037	-0,030	0,071	-0,027	-0,133	-0,143	0,267	0,309	0,773
Demog	0,397	0,046	-0,122	0,260	0,006	0,216	-0,614	-0,469	-0,337	-0,033
ListRE	-0,031	-0,602	0,131	0,300	-0,705	0,103	0,033	-0,053	0,133	-0,012
Unemp	0,340	0,054	0,415	-0,006	-0,129	-0,725	0,181	-0,158	-0,315	-0,093
Saving	-0,084	0,528	-0,185	0,740	-0,141	-0,019	0,328	-0,038	0,052	-0,009
Spread	0,047	0,165	0,850	0,155	0,149	0,427	-0,036	0,110	0,080	-0,014

Table A.1: Variables weights in the factors for the period 1973:6 -2001:12

Observations 220 680 *R2nc 0.647* *R2c 0.556*

Variable	**Estimate**	**Standard error**	**t-value**	***p*-value**
Cte	-0.000541	0.001236	-0.437707	0.662
Fact01	3.308769	0.070714	46.790754	0.000
Fact02	0.015199	0.012054	1.260946	0.207
Fact03	-1.501640	0.022057	-68.080967	0.000
Fact04	2.140413	0.053351	40.119231	0.000
Fact05	-0.013864	0.012000	-1.155316	0.248
Fact06	2.739667	0.051412	53.288740	0.000
Fact07	-4.135938	0.102498	-40.351508	0.000
Fact08	-1.819002	0.129493	-14.047162	0.000
Fact09	-3.729287	0.097007	-38.443491	0.000
Fact10	-2.079017	0.154086	-13.492606	0.000

Table A.2 : GLS results from 1973:6 to 2001:12 (heteroskedasticity power of 0.95)

Appendix B: Residual Analysis

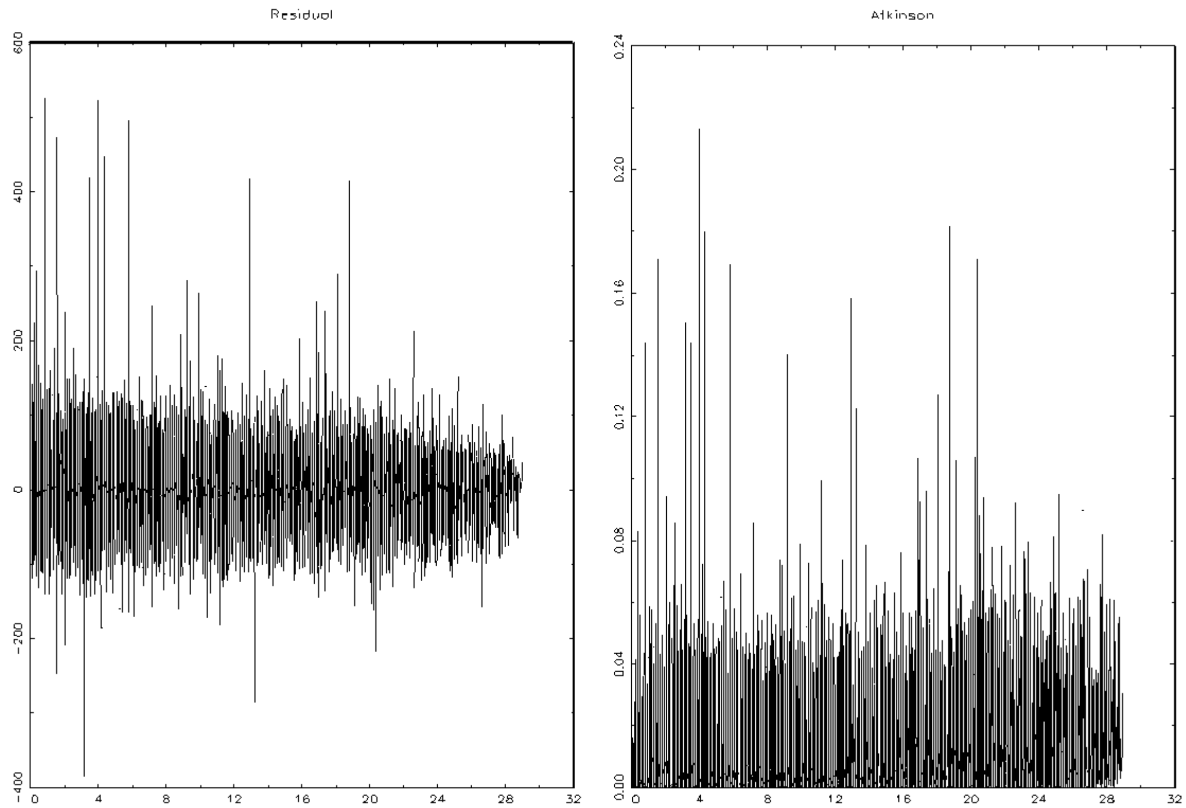

Table B.3: Residual Analysis of the GLS regression model with all the observations

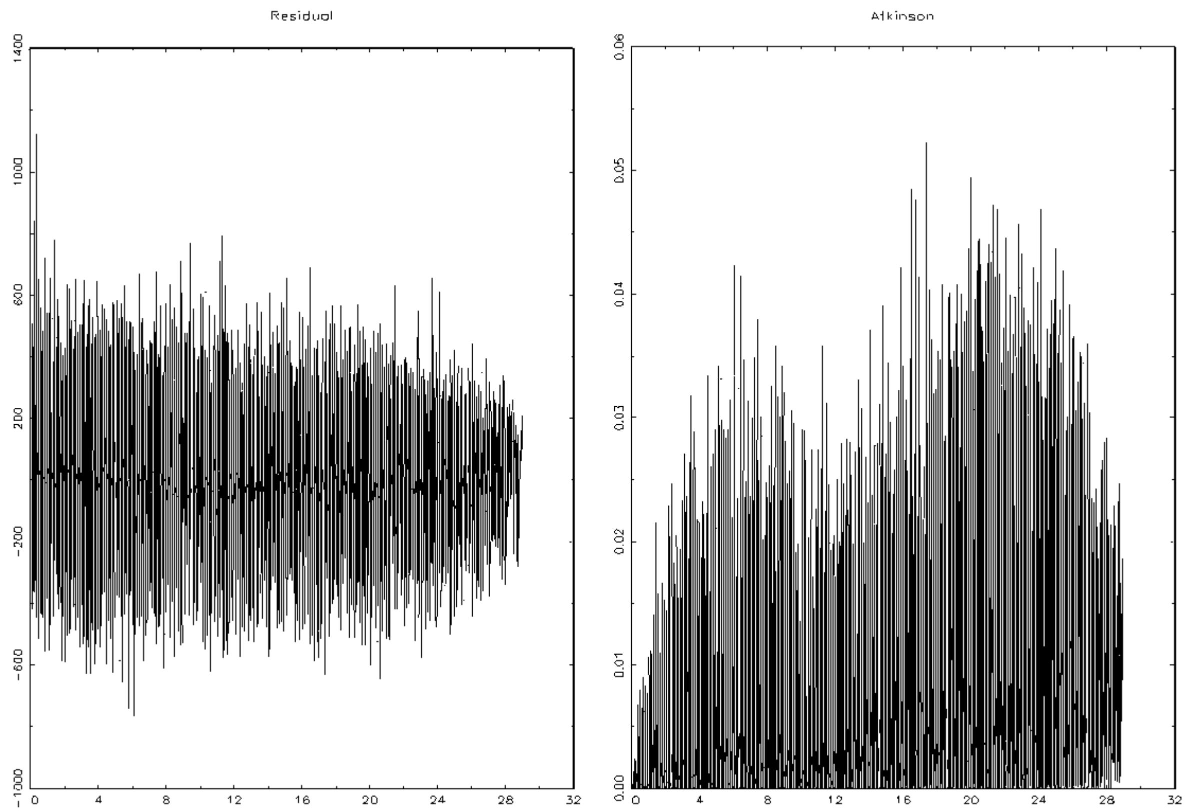

Table A.4: Residual Analysis of the GLS regression model with selected observations (Atkinson < 0.06)

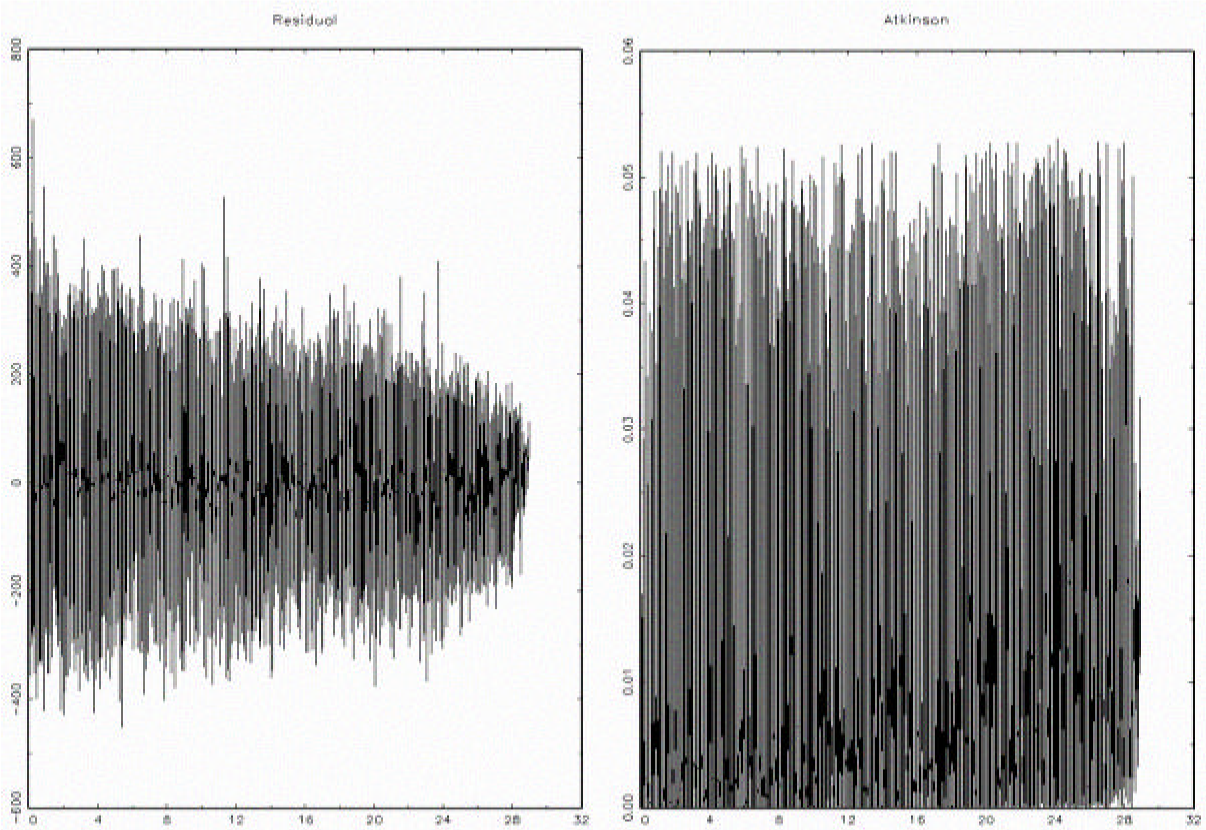

Table A.5: Residual Analysis of the GLS regression model with selected observations (Atkinson < 0.05)

Appendix C

Atk <	Cte	Fact01	Fact02	Fact03	Fact04	Fact05	Fact06	Fact07	Fact08	Fact09	Fact10	R^2_{nc}%	*N*
All obs.	-0,000541	3,309	0,015	-1,502	2,140	-0,014	2,740	-4,136	-1,819	-3,729	-2,079	64.71	220 680
	0,001236	*0,071*	*0,012*	*0,022*	*0,053*	*0,012*	*0,051*	*0,102*	*0,129*	*0,097*	*0,154*		
0.06	-0,000452	3,336	0,019	-1,510	2,159	-0,013	2,750	-4,172	-1,865	-3,755	-2,113	66.21	220 565
	0,001196	*0,068*	*0,012*	*0,021*	*0,052*	*0,012*	*0,050*	*0,099*	*0,125*	*0,094*	*0,149*		
0.05	-0,000657	3,339	0,018	-1,513	2,160	-0,010	2,756	-4,163	-1,871	-3,746	-2,151	66.89	220 409
	0,001178	*0,067*	*0,011*	*0,021*	*0,051*	*0,011*	*0,049*	*0,098*	*0,123*	*0,092*	*0,147*		
0.04	-0,001253	3,337	0,015	-1,515	2,158	-0,008	2,749	-4,145	-1,884	-3,714	-2,217	68.35	219 949
	0,001141	*0,065*	*0,011*	*0,020*	*0,049*	*0,011*	*0,047*	*0,094*	*0,120*	*0,089*	*0,142*		
0.03	-0,001857	3,338	0,002	-1,522	2,143	0,001	2,741	-4,147	-1,881	-3,684	-2,340	70.44	218 822
	0,001084	*0,062*	*0,010*	*0,019*	*0,046*	*0,010*	*0,045*	*0,089*	*0,114*	*0,085*	*0,135*		
0.02	-0,004007	3,301	-0,029	-1,519	2,083	0,019	2,695	-4,079	-1,870	-3,556	-2,459	73.56	215 408
	0,000991	*0,056*	*0,009*	*0,018*	*0,042*	*0,010*	*0,041*	*0,081*	*0,104*	*0,077*	*0,123*		

Table C.1: Model's coefficient estimates robustness according to influential observations

%	Cte	Fact01	Fact02	Fact03	Fact04	Fact05	Fact06	Fact07	Fact08	Fact09	Fact10	R^2_{nc}%	*N*
100%	-0.000541	3.318	0.0152	-1.52	2.140	-0.01386	2.739	-4.135	-1.819	-3.729	-2.079	64.71	220 680
	0.001236	*0.071*	*0.0120*	*0.022*	*0.0533*	*0.012*	*0.051*	*0.102*	*0.12*	*0.0970*	*0.1540*		
75%	-0.00209	3.314	0.033	-1.495	2.118	0.012	2.788	-4.074	-1.850	-3.729	-1.870	64.77	165 535
	0.001423	*0.082*	*0.014*	*0.025*	*0.061*	*0.014*	*0.060*	*0.118*	*0.150*	*0.112*	*0.177*		
50%	-0.00103	3.289	0.025	-1.462	2.158	-0.141	2.735	-4.096	-1.765	-3.671	-2.302	64.47	110 344
	0.001754	*0.101*	*0.018*	*0.030*	*0.076*	*0.017*	*0.074*	*0.146*	*0.184*	*0.139*	*0.219*		
25%	0.00206	3.250	0.040	-1.443	2.203	-0.328	2.518	-4.249	-1.783	-3.595	-2.348	63.78	55 150
	0.002513	*0.144*	*0.025*	*0.043*	*0.109*	*0.025*	*0.097*	*0.213*	*0.265*	*0.196*	*0.312*		

Table C.2: Model's coefficient estimates robustness according to the number of observations

	All	Atkinson					Sub-sample		
DATES		< 0.06	< 0.05	< 0.04	< 0.03	< 0.02	75%	50%	25%
june-73	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
dec-73	104,5	104,6	104,5	104,5	104,4	104,1	104,0	104,9	105,3
june-74	113,6	113,5	113,5	113,4	112,9	112,3	114,0	113,9	113,1
dec-74	102,1	102,2	102,2	102,0	101,5	100,5	102,1	103,1	102,1
june-75	98,3	98,5	98,5	98,4	98,0	96,9	98,5	99,5	98,2
dec-75	104,8	105,1	105,1	105,0	104,6	103,5	105,1	105,9	104,6
june-76	115,6	116,0	116,1	116,0	115,7	114,3	115,2	116,9	116,6
dec-76	128,5	128,9	129,1	129,0	128,6	126,9	127,6	130,0	130,3
june-77	127,1	127,7	127,9	127,9	127,5	125,5	126,1	129,0	129,2
dec-77	139,4	140,0	140,3	140,3	139,9	137,8	138,7	141,1	141,2
june-78	150,4	151,0	151,3	151,4	150,9	148,5	150,1	152,2	152,0
dec-78	157,2	157,9	158,2	158,4	157,9	155,3	156,5	159,3	159,7
june-79	175,0	175,9	176,3	176,6	176,1	173,0	173,5	177,9	179,9
dec-79	185,4	186,4	186,8	187,0	186,4	183,0	184,3	188,0	189,2
june-80	204,8	205,8	206,4	206,7	206,0	202,2	204,4	207,2	208,0
dec-80	220,5	221,6	222,4	222,9	222,3	218,2	220,3	222,9	224,0
june-81	219,5	221,0	221,7	222,1	221,6	217,2	218,3	221,3	222,5
dec-81	224,9	226,2	227,0	227,3	226,6	222,2	225,5	225,8	224,4
june-82	230,0	231,2	231,9	232,2	231,4	226,9	231,4	230,6	228,4
dec-82	237,9	238,9	239,8	240,2	239,4	234,9	239,0	238,5	237,6
june-83	251,4	252,4	253,3	253,8	252,8	248,4	253,3	251,6	250,5
dec-83	254,2	255,2	256,1	256,8	255,9	251,3	255,7	254,8	254,7
june-84	251,7	252,8	253,6	254,3	253,4	248,9	253,4	252,2	251,5
dec-84	260,8	262,0	262,9	263,7	262,7	258,0	262,0	261,8	262,1
june-85	273,0	274,1	275,0	276,0	274,7	269,7	274,5	274,6	275,1
dec-85	286,3	287,3	288,2	289,2	287,9	282,7	287,7	287,8	288,6
june-86	305,9	307,1	307,9	308,9	307,6	301,9	307,5	308,0	308,5
dec-86	330,9	332,3	333,0	333,7	332,3	325,7	332,4	333,2	332,4
june-87	349,5	351,0	351,7	352,4	350,9	343,8	351,8	351,5	349,2
dec-87	377,7	379,2	380,3	381,1	379,7	371,5	377,5	380,6	381,9
june-88	398,1	399,6	400,9	401,6	400,6	392,6	399,4	398,6	397,5
dec-88	426,4	428,3	429,6	430,9	429,9	421,5	426,9	427,0	428,1
june-89	453,3	455,3	456,7	458,0	456,9	448,2	455,3	452,5	451,9
dec-89	489,8	491,8	493,3	494,9	493,4	483,8	491,1	490,0	491,6
june-90	516,1	517,9	519,6	521,4	519,9	509,8	518,3	516,2	517,8
dec-90	533,1	534,8	536,8	538,5	536,9	526,1	534,0	532,8	535,4
june-91	531,5	533,6	535,4	537,1	535,5	524,5	532,4	531,2	532,8
dec-91	531,6	534,0	535,7	537,4	535,9	524,3	531,3	531,7	533,6
june-92	530,8	533,5	535,0	536,6	535,0	523,2	531,6	530,5	529,8
dec-92	529,6	532,4	533,8	535,3	533,5	521,0	528,7	530,6	530,9
june-93	524,7	527,4	528,7	529,9	527,5	513,9	523,3	528,5	528,7
dec-93	526,2	529,1	530,0	531,2	528,6	514,3	523,5	532,0	533,5
june-94	534,5	536,9	538,3	539,3	536,7	521,8	533,8	540,2	539,3
dec-94	537,6	539,9	541,5	542,5	540,2	525,8	537,9	541,0	538,9
june-95	522,2	524,5	525,6	526,4	523,5	509,2	521,3	525,6	523,8
dec-95	511,7	513,6	514,9	515,3	512,3	498,0	511,7	515,3	512,0
june-96	495,1	497,2	498,6	499,3	496,5	482,5	496,1	499,3	495,0
dec-96	484,5	486,8	488,2	489,2	486,6	473,0	485,1	488,6	485,0
june-97	478,9	481,1	482,6	483,8	481,2	467,7	478,5	483,5	482,1
dec-97	465,3	467,4	468,6	469,5	467,1	454,3	465,2	468,0	465,5
june-98	480,2	482,3	483,4	484,7	482,1	469,2	479,8	483,7	483,8
dec-98	479,4	481,3	482,3	483,5	480,9	467,7	477,1	482,8	484,8
june-99	501,1	502,6	503,9	504,8	502,2	488,5	501,1	503,5	503,2
dec-99	520,8	522,3	523,7	524,8	522,2	508,4	521,5	522,4	522,1
june-00	543,7	545,3	546,5	547,7	545,0	531,0	545,2	543,2	542,0
dec-00	566,8	568,5	569,7	571,0	567,7	552,5	566,1	567,4	569,5
june-01	597,0	598,3	599,8	601,1	597,2	580,4	596,0	598,8	602,2
dec-01	592,2	593,5	595,2	596,4	592,8	575,4	589,8	594,8	599,2

Table C.3: Indices robustness according to the observations used for the estimation

Periodicity	Forecast from year	RMSE	MAE	U
Annual	2000	0.00424	0.00425	**0.00405**
Annual	1999	0.00705	0.00553	**0.00660**
Annual	1998	0.00906	0.00689	**0.00844**
Annual	1997	0.01708	0.01321	**0.01605**
Annual	1996	0.04359	0.03957	**0.04174**
Semi-annual	2000	0.00212	0.00206	**0.00207**
Semi-annual	1999	0.00385	0.00366	**0.00372**
Semi-annual	1998	0.00594	0.00564	**0.00573**
Semi-annual	1997	0.00988	0.00913	**0.00956**
Semi-annual	1996	0.02257	0.01964	**0.02209**
Quarterly	2000	0.00159	0.00138	**0.00157**
Quarterly	1999	0.00289	0.00266	**0.00283**
Quarterly	1998	0.00438	0.00426	**0.00427**
Quarterly	1997	0.00734	0.00664	**0.00719**
Quarterly	1996	0.01538	0.01337	**0.01516**
Bi-monthly	2000	0.00905	0.00872	**0.00898**
Bi-monthly	1999	0.00144	0.00131	**0.00142**
Bi-monthly	1998	0.00243	0.00218	**0.00240**
Bi-monthly	1997	0.00406	0.00344	**0.00402**
Bi-monthly	1996	0.00811	0.00696	**0.00805**
Monthly	2000	0.00623	0.00490	**0.00615**
Monthly	1999	0.00814	0.06933	**0.08091**
Monthly	1998	0.00149	0.00127	**0.00148**
Monthly	1997	0.00239	0.00193	**0.00238**
Monthly	1996	0.00441	0.00369	**0.00439**

Table C. 4: forecasts measures according to the periodicity and the time

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