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Disaggregating annual real GDP data into quarterly figures

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Abstract

The first part of the paper reviews some procedures to distribute an annual time series across a quarterly one, either by using information from the annual totals only, or by using information from both the annual totals and a related quarterly series. In the second part of the paper the various procedures are applied to compute quarterly real GDP (or GNP) series for a number of countries. Since neither theoretical considerations nor the empirical literature provide a definite answer as to which disaggregation procedure should be used, we divide the ten procedures into four groups and compare the results with the actual quarterly GDP data of the larger countries. The results indicate that two procedures outperform the others, i.e. the procedure proposed by Litterman and one of the procedures suggested by Denton.

Keywords: data disaggregation, quarterly real GDP

1 Introduction

There are two reasons why we would like to disaggregate a time series. The first one relates to the inconsistency in the observation frequencies of macroeconomic variables. When we consider the European countries we see that for most (smaller) countries GDP (or GNP) is only reported on an annual basis, while many other variables are reported every quarter or even every month[1]. Instead of aggregating these quarterly variables to annual totals (and thus losing a lot of information), it is more reasonable to disaggregate the GDP (or GNP) time series into quarterly observations. Second, the need for time series disaggregation also arises from a possible change in the observation frequency of a given variable as is the case for the US GNP series. Since 1957 US GNP is reported on a quarterly basis, but annual observations of this series are available from 1900 onwards. Instead of omitting the annual observations prior to 1957 from the analysis, we should disaggregate them into quarterly figures and then use the entire sample period. In this paper we are mainly concerned with the first reason.

The paper is organised as follows. We start in section 2 by reviewing some of the proposed methods for the distribution of a time series[2]. In section 3 we construct the resulting quarterly series for real GDP (or GNP) for a set of countries and try to detect (dis)similarities. Finally, the results are summarized in section 4.

2 A review of some distribution procedures

To the purpose of the distribution of time series several procedures have been developed. In our overview we will divide them into two broad categories: those procedures which only use information from the annual totals and those which rely on additional information from other related series. Every procedure will be described for a periodicity $m=4$ (i.e. to distribute an annual series across a quarterly one). In this section the annual series will be denoted X_t (for t=1, 2, ..., n) while y_q and z_q (for q=1, 2, ..., 4n) will denote the quarterly series to be estimated and the quarterly related series, respectively.

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[1]. Recently, most European countries have started to develop quarterly GDP series. These data are collected in the databank of the Bank for International Settlements, but are not publicly available.

[2]. The *distribution* problem relates to the disaggregation of flow variables. Given the values of a flow variable (e.g. GDP) during n years, the distribution problem is to estimate 4n quarterly values of GDP which satisfy the condition that the four quarterly values relating to the same year add up to the annual total. The *interpolation* problem relates to the disaggregation of stock variables. Given the values of a stock variable (e.g. the money supply) at the end of n years, the interpolation problem is to estimate the remaining 3n quarterly values.

2.1 Procedures which only use information from the annual totals

The performances of the procedures belonging to the first category have already been discussed by Chan (1993). Relying on his conclusions we selected the procedures developed by Lisman and Sandee (1964), Boot, Feibes, and Lisman (1967), and Stram and Wei (1986).

LISMAN AND SANDEE

In Lisman and Sandee (1964) a very simple procedure is given to compute a quarterly time series if no assumption about its pattern can be made. In their approach the quarterly values for year t (for t=2, 3, ..., n-1) are weighted averages of the annual totals of the years t-1, t, and $t+1$ or in matrix notation:

$$\begin{bmatrix} y_{4t-3} \\ y_{4t-2} \\ y_{4t-1} \\ y_{4t} \end{bmatrix} = \begin{bmatrix} a & e & i \\ b & f & j \\ c & g & k \\ d & h & l \end{bmatrix} \cdot \begin{bmatrix} X_{t-1} \\ X_t \\ X_{t+1} \end{bmatrix} \qquad \text{for } t=2, 3, \ldots, n-1 \qquad (1)$$

To determine the value of the coefficients a through l, Lisman and Sandee impose the following conditions: (1) there should be a logical symmetry in time[3], (2) during each year the quarterly figures should add up to the annual total, (3) if the annual totals X_t remain constant, the quarterly figures should necessarily be equal to $X_t/4$, (4) if the annual figures increase by a constant amount p, the quarterly figures should increase by a constant amount $p/16$, and (5) if the annual figures alternate, the trend should be a sinusoid.

Lisman and Sandee then show that these five requirements lead to the following quarterly values:

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[3]. If the annual totals in three successive years are X_1, X_2, and X_3, then the quarterly values for year 2 should be the same but in reverse order from what they would have been had the annual totals been X_3, X_2, and X_1.

$$\begin{aligned} y_{4t-3} &= 0.0728X_{t-1} + 0.1983X_t - 0.0210X_{t+1} \\ y_{4t-2} &= -0.0103X_{t-1} + 0.3018X_t - 0.0415X_{t+1} \\ y_{4t-1} &= -0.0415X_{t-1} + 0.3018X_t - 0.0103X_{t+1} \\ y_{4t} &= -0.0210X_{t-1} + 0.1983X_t + 0.0728X_{t+1} \end{aligned} \qquad \text{for } t=2, 3, \ldots, n-1 \qquad (2)$$

This very simple procedure has however two important drawbacks. First, no quarterly values can be computed for the first and the last year of the time series. Second, it is a very arbitrary procedure.

BOOT, FEIBES, AND LISMAN

Boot, Feibes, and Lisman (1967) introduce two minimization criteria in order to correct for these defects. The first criterion is to minimize the sum of squared differences between the successive quarterly values y_q, subject to the constraint that during each year the sum of the quarterly figures equals the annual total.

$$\begin{aligned} &\underset{y}{Min} \sum_{q=2}^{4n} (y_q - y_{q-1})^2 \\ &s.t. \sum_{q=4t-3}^{4t} y_q = X_t \end{aligned} \qquad \text{for } t=1, 2, \ldots, n \qquad (3)$$

From the Lagrangean expression

$$L = \sum_{q=2}^{4n} (y_q - y_{q-1})^2 + 2\sum_{t=1}^{n} \lambda_t \left(\sum_{q=4t-3}^{4t} y_q - X_t \right) \qquad (4)$$

the first order conditions with respect to each y_q and the Lagrangean multipliers λ_t amount to:

$$\begin{bmatrix} y \\ \lambda \end{bmatrix} = \begin{bmatrix} A & C_n' \\ C_n & \mathbf{0}_{n x n} \end{bmatrix}^{-1} \cdot \begin{bmatrix} \mathbf{0}_{4n x 1} \\ X \end{bmatrix} \qquad (5)$$

where[4]: **y** is a columnvector of 4n quarterly figures, **λ** is a columnvector of n Lagrangean multipliers, **A** is a band matrix of order 4n x 4n, $\mathbf{C}_n$ is a convertor matrix of order n x 4n, **0** is a nullmatrix, and **X** is a columnvector of n annual figures.

Although this is still a very simple method, it is less arbitrary than the one used by Lisman and Sandee (1964). Furthermore with this procedure we can compute quarterly values for all the years in the sample including the first and the last one. However if the annual observations exhibit a linear trend, the computed quarterly values will lie on a long-stretched 'S' instead of on a straight line. Therefore the authors suggest to use another criterion that remedies this defect.

The new criterion is to minimize the sum of squares of the second differences between the successive quarterly values y_q, subject to the same constraint that during each year the sum of the quarterly figures equals the annual total.

$$\begin{aligned} &\underset{y}{Min} \sum_{q=2}^{4n-1} (\Delta y_q - \Delta y_{q-1})^2 \\ &s.t. \sum_{q=4t-3}^{4t} y_q = X_t \end{aligned} \qquad \text{for } t=1, 2, \ldots, n \qquad (6)$$

where Δy_q is defined as $y_{q+1}-y_q$.

The first order conditions with respect to each y_q and the Lagrangean multipliers λ_t are now:

4. The matrix **A** contains the coefficients of the y_qs in the partial derivatives of the Lagrangean expression with respect to these y_qs:

$$\begin{bmatrix} 1 & -1 & 0 & 0 & \ldots & 0 & 0 & 0 & 0 \\ -1 & 2 & -1 & 0 & \ldots & 0 & 0 & 0 & 0 \\ 0 & -1 & 2 & -1 & \ldots & 0 & 0 & 0 & 0 \\ . & . & . & & & & & & \\ 0 & 0 & 0 & 0 & \ldots & -1 & 2 & -1 & 0 \\ 0 & 0 & 0 & 0 & \ldots & 0 & -1 & 2 & -1 \\ 0 & 0 & 0 & 0 & \ldots & 0 & 0 & -1 & 1 \end{bmatrix},$$

while the convertor matrix $\mathbf{C}_n$ is the Kronecker product of the identity matrix of order n and a rowvector of 4 ones:

$$\begin{bmatrix} 1 & 1 & 1 & 1 & \ldots & 0 & 0 & 0 & 0 \\ . & . & . & & & & & & \\ 0 & 0 & 0 & 0 & \ldots & 1 & 1 & 1 & 1 \end{bmatrix}.$$

$$\begin{bmatrix} y \\ \lambda \end{bmatrix} = \begin{bmatrix} B & C_n' \\ C_n & 0_{nxn} \end{bmatrix}^{-1} \cdot \begin{bmatrix} 0_{4nx1} \\ X \end{bmatrix} \qquad (7)$$

where[5] **B** is a band matrix of order 4n x 4n.

Compared to the previous procedure of Boot, Feibes, and Lisman this procedure has the advantage that the quarterly values will lie on a straight line if the annual observations exhibit a linear trend.

STRAM AND WEI

Stram and Wei (1986) develop a model-based procedure to transform an aggregate time series into a disaggegrate time series of periodicity *m*. In the following paragraph we will apply their general procedure to the case of distributing an annual time series across a quarterly one (i.e. $m=4$).

Let y_q be a quarterly series whose *d*th differences $w_q = (1-B)^d y_q$ follow a stationary Gaussian process and X_t an aggregate annual series whose *d*th differences $U_t = (1-B)^d X_t$ equally follow a stationary Gaussian process.

Their generalized least squares approach to the distribution problem can be stated as:

$$\underset{y}{Min}\ w'V_w^{-1}w \qquad s.t. \sum_{q=4t-3}^{4t} y_q = X_t \qquad \text{for } t=1, 2, \ldots, n \qquad (8)$$

where: **w** is a columnvector of 4n-d stationary quarterly figures after differencing d times and $\mathbf{V_w}$ is the covariance-matrix of w of order (4n-d)x(4n-d)

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[5]. The matrix **B** contains the coefficients of the y_qs in the partial derivatives of the Lagrangean expression with respect to these y_qs:

$$\begin{bmatrix} 1 & -2 & 1 & 0 & 0 & 0 & \ldots & 0 & 0 & 0 & 0 & 0 & 0 \\ -2 & 5 & -4 & 1 & 0 & 0 & \ldots & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & -4 & 6 & -4 & 1 & 0 & \ldots & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & -4 & 6 & -4 & 1 & \ldots & 0 & 0 & 0 & 0 & 0 & 0 \\ . & . & . & & & & & & & & & & \\ 0 & 0 & 0 & 0 & 0 & 0 & \ldots & 1 & -4 & 6 & -4 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \ldots & 0 & 1 & -4 & 6 & -4 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & \ldots & 0 & 0 & 1 & -4 & 5 & -2 \\ 0 & 0 & 0 & 0 & 0 & 0 & \ldots & 0 & 0 & 0 & 1 & -2 & 1 \end{bmatrix}$$

Wei and Stram (1990) propose to solve this problem in three steps.
First, they fit an ARIMA model to the annual series X_t such that the residuals from this model are white noise. This model is then used to obtain an estimate of the covariance matrix $\mathbf{V}_U$ of the aggregate series U.
The next step consists of distributing this model across an ARIMA model for the quarterly series y_q to be estimated, the residuals of which are again white noise. That model is also used to estimate the covariance matrix $\mathbf{V}_w$ of the quarterly series w.
Finally, the quarterly values y_q can then be estimated by the following formula:

$$y = \left[\frac{\Delta_{4n}^{d}}{\mathbf{0}_{dx4(n-d)} \mid C_d} \right]^{-1} \cdot \left[\frac{V_w F' V_U^{-1} \Delta_n^d}{\mathbf{0}_{dx(n-d)} \mid I_d} \right] . X \qquad (9)$$

where[6]: $\Delta_{4n}{}^{d}$ is a matrix of order (4n-d) x 4n, $\mathbf{C}_d$ is a convertor matrix of order d x 4d, $\mathbf{F}$ is a matrix of order (n-d) x (4n-d), and $\mathbf{V}_U$ is the covariance-matrix of U of order (n-d) x (n-d).

The major advantage of the Stram and Wei procedure is that it is a model-based method, whereas the previous ones are not. However, there are two practical limitations encountered in using this procedure. First, the fitting of a well specified aggregate ARIMA model to X_t remains a difficult and fairly subjective task. Second, the procedure does not work when m is even (as in our application) and some real roots of the autoregressive polynomial of the estimated aggregate ARIMA model are negative.

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[6]. The matrix Δ^d_{4n} is a matrix of the form:

$$\begin{bmatrix} \delta_0 & \delta_1 & . & . & . & \delta_d & 0 & 0 & 0 & 0 & 0 & . & . & . & 0 \\ 0 & \delta_0 & \delta_1 & . & . & . & \delta_d & 0 & 0 & 0 & 0 & . & . & . & 0 \\ . & . & . \\ 0 & 0 & 0 & . & . & . & 0 & 0 & 0 & \delta_0 & \delta_1 & . & . & . & \delta_d \end{bmatrix}$$

where δ_i is the coefficient of B^i in $(B-1)^d$, the convertor matrix $\mathbf{C}_d$ is the Kronecker product of the identity matrix of order d and a rowvector of 4 ones:

$$\begin{bmatrix} 1 & 1 & 1 & 1 & . & . & . & 0 & 0 & 0 & 0 \\ . & . & . \\ 0 & 0 & 0 & 0 & . & . & . & 1 & 1 & 1 & 1 \end{bmatrix},$$

and the matrix $\mathbf{F}$ is a block matrix of the form:

$$\begin{bmatrix} f & | \mathbf{0}_{1x4} & | \mathbf{0}_{1x4} & | \mathbf{0}_{1x4} & | \cdots & | \mathbf{0}_{1x4} \\ \mathbf{0}_{1x4} & | f & | \mathbf{0}_{1x4} & | \mathbf{0}_{1x4} & | \cdots & | \mathbf{0}_{1x4} \\ \mathbf{0}_{1x4} & | \mathbf{0}_{1x4} & | f & | \mathbf{0}_{1x4} & | \cdots & | \mathbf{0}_{1x4} \\ . . . \\ \mathbf{0}_{1x4} & | \mathbf{0}_{1x4} & | \mathbf{0}_{1x4} & | \cdots & | \mathbf{0}_{1x4} & | f \end{bmatrix}$$

where $\mathbf{f}=(f_0, f_1, \ldots, f_{3(d+1)})$ with f_i the coefficient of B^i in $(1+B+B^2+B^3)^{(d+1)}$.

2.2 Procedures which use the information from the annual totals and from a related quarterly time series[7]

A common feature of all the procedures in this category is that they estimate the quarterly series y using information on a related quarterly series and subject to the constraint that during each year the sum of the quarterly figures equals the annual total. In practice, the quarterly related series is converted into an annual series (by premultiplying the matrix **Z** by the convertor matrix **C**), the annual series X is then regressed upon the computed annual related series CZ, and the resulting annual residuals are distributed across the quarterly series to be estimated y. We could make a distinction between the procedures that use the best linear unbiased estimator approach (Chow and Lin (1971), Fernandez (1981), and Litterman (1983)) and those that rely on the quadratic loss function approach (Denton (1971) and Fernandez (1981)). However, since Fernandez has demonstrated that the quadratic loss function approach also provides best linear unbiased estimators if the classical assumptions of the regression model are met by the quarterly residuals, we will present the various methods in a chronological order.

CHOW AND LIN

Chow and Lin (1971) discuss the problem of distribution for a periodicity $m=3$, i.e. estimating a monthly series given its quarterly data and monthly data on related series. The same procedure - mutatis mutandis - applies to the problem of estimating a quarterly series given its annual data and quarterly data on related series.

Following Chow and Lin (1971) we assume that the quarterly observations of the series to be estimated y satisfy a regression relationship with a number p of related series $z_1, \ldots, z_p$ which can be written as:

$$y = Z\beta + \epsilon \tag{10}$$

where: **Z** is a matrix of order 4n x p with p columns of quarterly observations on related series and ϵ is a columnvector of 4n error terms.

The first step consists of converting the quarterly observations of the related series into annual observations by summing those quarterly observations that belong to the same year

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[7]. We will not discuss the choice of the related serie(s), but we will confine ourselves to the proposed estimation methods.

or in matrix formulation by premultiplying **Z** and ϵ by the n x 4n-convertor matrix[8] **C**.

We now have a new regression model with annual data:

$$X = Cy = CZ\beta + C\epsilon \tag{11}$$

The best linear unbiased estimator **y** then becomes:

$$\begin{aligned} y &= Z\hat{\beta} + [VC'(CVC')^{-1}][X - CZ\hat{\beta}] \\ \hat{\beta} &= [Z'C'(CVC')^{-1}CZ\,]^{-1}Z'C'(CVC')^{-1}X \end{aligned} \tag{12}$$

The intuition behind this solution is that the quarterly estimates are based on two components, the first of which is a linear function of the quarterly values of the related series, while the second is a distribution of the annual residuals across the four quarters.

This estimator requires knowledge of the covariance-matrix **V**. In practice however, this matrix is unknown and has to be estimated by assuming some structure in the residuals ϵ. Chow and Lin discuss two possibilities, namely serially uncorrelated residuals and residuals that follow an AR(1) process. In the next section we will refer to these procedures as CHO1 and CHO2, respectively.

If the quarterly residuals are serially uncorrelated, each with variance σ^2, the estimator in equation (12) reduces to[9]:

$$\begin{aligned} y &= Z\hat{\beta} + \frac{1}{4}C'\hat{\epsilon} \\ \hat{\beta} &= (Z'C'CZ)^{-1}Z'C'X \end{aligned} \tag{13}$$

which means that the annual residuals will be equally distributed across the four quarters within the year. The problem with this procedure is that it might introduce spurious discontinuities between the last quarter of one year and the first quarter of the next year, since the annual residuals are not necessarily uniformly distributed.

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[8]. Chow and Lin (1971) premultiply their convertor matrix **C** with 1/3, which leaves them with quarterly data that are the average of the monthly data. In this paper we will not premultiply **C** with 1/4, since we imposed the constraint that during each year the sum of the quarterly figures equals the annual total. The same procedure was followed by Denton (1971) and by Fernandez (1981).

[9]. In that case $V=\sigma^2 I$ and $CVC'=4\sigma^2 I$.

If the quarterly residuals follow a first order autoregression ($\epsilon_q = \alpha\epsilon_{q-1} + e_q$) the covariance matrix will depend on the value of the autoregressive parameter α and on the value of the variance of the residuals e which is unknown. However the matrix $VC'(CVC')^{-1}$ only depends on the value of the (quarterly) autoregressive parameter α. To obtain a consistent estimate of this parameter α Chow and Lin propose to use an iterative procedure based on the knowledge that the first-order (annual) autocorrelation coefficient q is in fact the ratio of the off-diagonal element to the diagonal element of the matrix **CVC'**.

Using this iterative procedure for the problem of distributing annual totals across quarterly values, the relevant equation becomes:

$$q = \frac{\alpha^7 + 2\alpha^6 + 3\alpha^5 + 4\alpha^4 + 3\alpha^3 + 2\alpha^2 + \alpha}{2\alpha^3 + 4\alpha^2 + 6\alpha + 4} \qquad (14)$$

where q is the first-order autocorrelation coefficient of the annual residuals.

Starting with an initial guess of q the corresponding value of α can be calculated. We can then compute the annual residuals $\mathbf{X}\text{-}\mathbf{CZ}\boldsymbol{\beta}$, calculate their first-order autocorrelation coefficient as the next guess of q and proceed as before. Once convergence is reached, equation (12) can be used to estimate the quarterly series y.

DENTON

Denton (1971) considers the adjustment problem, i.e. the fact that the sum of the quarterly values y_q for each year (obtained from another source or from a regression on a related series) does not necessarily equal the annual total X_t. As the adjustment problem is narrowly related to the distribution problem we will discuss Denton's method here as an alternative procedure to distribute an annual series across a quarterly one.

To solve this adjustment problem Denton minimizes a quadratic loss function or penalty function $p(\mathbf{y},\mathbf{Z}\boldsymbol{\beta})$ in the differences between the quarterly values to be estimated y_q and the quarterly values of the regression $(Z\beta)_q$, subject to the constraint that during each year the sum of the quarterly figures equals the annual total. More formally, the problem can be stated as:

$$Min \;\; p(y, Z\beta) = (y - Z\beta)' G (y - Z\beta)$$

$$s.t. \sum_{q=4t-3}^{4t} y_q = X_t \qquad \text{for } t = 1, 2, \ldots, n \qquad (15)$$

This results in the following first order conditions with respect to each y_q and the Lagrangean multipliers λ_t:

$$\begin{bmatrix} y \\ \lambda \end{bmatrix} = \begin{bmatrix} G & C_n' \\ C_n & \mathbf{0}_{nxn} \end{bmatrix}^{-1} \cdot \begin{bmatrix} G & \mathbf{0}_{4nxn} \\ C_n & I_n \end{bmatrix} \cdot \begin{bmatrix} Z\beta \\ X-CZ\beta \end{bmatrix} \tag{16}$$

From (16) we can then calculate the vector of the quarterly figures **y** as:

$$\begin{aligned} y &= Z\hat{\beta} + [G^{-1}C'(CG^{-1}C')^{-1}][X-CZ\hat{\beta}] \\ \hat{\beta} &= [Z'C'(CG^{-1}C')^{-1}CZ\,]^{-1}Z'C'(CG^{-1}C')^{-1}X \end{aligned} \tag{17}$$

The specific solution will depend on the choice of the matrix **G**. The three possibilities considered by Denton are: (1) **G** equal to the identity matrix $\mathbf{I}_{4nx4n}$, (2) **G** equal to **D'D** where **D** is a matrix that transforms a series into first differences[10], and (3) **G** equal to **D'D'DD** where **DD** transforms a series into second differences. In the next section we will refer to these procedures as DEN1, DEN2, and DEN3, respectively.

If we simply want to minimize the sum of squares of the difference between the quarterly values to be estimated y and the quarterly values of the regression $Z\beta$, we choose **G** to be the identity matrix $\mathbf{I}_{4nx4n}$. In that case $\mathbf{G}^{-1}\mathbf{C}'(\mathbf{C}\mathbf{G}^{-1}\mathbf{C}')^{-1}$ simplifies to 0.25**C'**. Since this solution is identical to the one of Chow and Lin (1971) with homoscedastic and serially uncorrelated residuals it suffers from the same defects.

If we want to minimize the sum of squares of the difference between the first differences of the series y and the first differences of the series $Z\beta$, we choose **G** equal to **D'D**. This procedure reduces to the first procedure of Boot, Feibes, and Lisman (1967) in cases where there exist no related quarterly series.

If we want to minimize the sum of squares of the difference between the second differences of the series y and the second differences of the series $Z\beta$, we choose **G** equal to **D'D'DD**. This procedure reduces to the second procedure of Boot, Feibes, and Lisman (1967) in cases where there exist no related quarterly series.

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[10]. The matrix **D** is a matrix of order 4n x 4n that transforms a series into its first differences, assuming that the first quarterly value to be estimated y_0 is equal to the first quarterly value of the regression $(Z\beta)_0$:

$$\begin{bmatrix} 1 & 0 & 0 & . & . & . & 0 & 0 \\ -1 & 1 & 0 & . & . & . & 0 & 0 \\ 0 & -1 & 1 & . & . & . & 0 & 0 \\ . & . & . & & & & & \\ 0 & 0 & 0 & . & . & . & -1 & 1 \end{bmatrix}$$

FERNANDEZ

Fernandez (1981) in fact combines the two procedures described above. He starts from the regression model $\mathbf{y} = \mathbf{Z}\beta + \epsilon$ in which the error term follows a random walk[11]. He then transforms the whole model into first differences (to obtain stationary variables) and applies a procedure similar to the one of Chow and Lin. Finally he shows that this leads to the same result as using the Denton model with **G** equal to **D'D**.

In general he proposes the following procedure for distributing annual totals across quarterly values. First, find a transformation that converts the residuals of the quarterly regression model ϵ to a serially uncorrelated and stationary random variable. Second, given the adequate transformation, β may be estimated by generalized least squares and the annual residuals distributed as indicated by equation (17). In the next section the series obtained via this procedure will be referred to as FER.

LITTERMAN

Litterman (1983) proposes a method to estimate monthly values of a variable such that that their average is equal to the quarterly value. We will discuss his procedure - mutatis mutandis - for the problem of estimating quarterly values of a variable such that their sum equals the annual value. In fact, Litterman proposes a special case of the general procedure of Fernandez in that he assumes that the quarterly residuals follow an ARIMA(1,1,0) model:

$$\begin{aligned} \epsilon_q &= \epsilon_{q-1} + e_q \\ e_q &= \alpha e_{q-1} + \nu_q \end{aligned} \qquad \text{for } q=2, 3, \ldots, n \tag{18}$$

In that case the best linear unbiased estimator **y** becomes:

$$\begin{aligned} y &= Z\hat{\beta} + (D'H'HD)^{-1}C'[C(D'H'HD)^{-1}C']^{-1}\,[X - CZ\hat{\beta}] \\ \hat{\beta} &= \{Z'[C(D'H'HD)^{-1}C']^{-1}Z\}^{-1}Z'[C(D'H'HD)^{-1}C']^{-1}X \end{aligned} \tag{19}$$

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11. The error term can be modelled as: $\epsilon_q = \epsilon_{q-1} + e_q$.

where[12] **H** is a 4n x 4n matrix.

We now need an estimate of the parameter α in order to be able to calculate the estimator **y**. Litterman proposes the same procedure as Chow and Lin: a consistent estimate of this parameter α can be obtained by using an iterative procedure based on the knowledge that the first-order (annual) autocorrelation coefficient q is in fact the ratio of the off-diagonal element to the diagonal element of the covariance matrix $\sigma^2\mathbf{D'H'HD}$. For the problem of distributing annual totals across quarterly values, the relevant equation then becomes:

$$q = \frac{\alpha^{10} + 4\alpha^9 + 10\alpha^8 + 20\alpha^7 + 31\alpha^6 + 40\alpha^5 + 44\alpha^4 + 40\alpha^3 + 32\alpha^2 + 24\alpha + 10}{2\alpha^6 + 8\alpha^5 + 20\alpha^4 + 40\alpha^3 + 62\alpha^2 + 80\alpha + 44} \qquad (20)$$

where q is the first-order autocorrelation coefficient of the annual residuals. Starting with an initial guess of q the corresponding value of α can be calculated. We can then compute the annual residuals $\mathbf{X}$-$\mathbf{CZ}\beta$, calculate their first-order autocorrelation coefficient as the next guess of q and proceed as before. Once convergence is reached, equation (19) can be used to estimate the quarterly series y. In the next section we will refer to this series as LIT.

3 An empirical comparison of the various procedures considered above

In this section we use the various disaggregation methods described above to construct disaggregated quarterly series for real (1975 prices) GDP (or GNP) for thirteen countries[13]. As the related series we select the industrial production. The data on both series are taken from the *International Financial Statistics* of the IMF. For most countries the data cover the period 1959.1-1992.4. For some countries however, the IMF only

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[12]. The matrix **H** is a matrix of order 4n x 4n:

$$\begin{bmatrix} 1 & 0 & 0 & \dots & 0 & 0 \\ -\alpha & 1 & 0 & \dots & 0 & 0 \\ 0 & -\alpha & 1 & \dots & 0 & 0 \\ . & . & . & & & \\ 0 & 0 & 0 & \dots & -\alpha & 1 \end{bmatrix}$$

[13]. This group of countries is the combination of on the one hand the European countries that already took part in the EU before January 1 1995, and on the other hand the G-7. The European countries considered are Belgium, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal, Spain, and the United Kingdom. Luxembourg and Denmark are excluded from the analysis because of a lack of data. We also consider the non European countries of the G-7, namely Canada, Japan, and the United States. For Belgium, Germany, and Japan the IMF reports data on real GNP, while for Canada, France, Greece, Ireland, Italy, the Netherlands, Portugal, Spain, the United Kingdom, and the United States the data refer to real GDP.

starts reporting data on quarterly industrial production or on annual real GDP (or GNP) from 1961.1 (Italy and Spain), 1963.1 (Canada, the Netherlands, and the United States) or even 1966.1 (Portugal) onwards. As a consequence our samples vary in length from 108 to 136 observations. For each of the countries considered we calculate 10 quarterly series of the real GDP (or GNP) following the procedures outlined above[14].

3.1 Testing for nonstationarity

Before investigating the (dis)similar evolution of the constructed series, we first test for the nonstationarity of the quarterly GDP (or GNP) series[15]. To test the null hypothesis of a unit root we use the (adjusted) Dickey-Fuller test statistic. The number of lags is selected in the following way: we start from a regression with 8 lags and each time eliminate the last insignificant lag. We both test for nonstationarity of the levels (in logarithms) and of the differences (growth rates). The results are summarized in table 1.

From this table it is clear that almost all quarterly GDP (or GNP) series have a unit root and that the majority of the quarterly growth rates of GDP (or GNP) are stationary, although about one third still has a unit root. Since the majority of the computed series are therefore I(1), we will concentrate on comparing the evolution of the quarterly growth rates of GDP (or GNP) instead of the levels. Furthermore, the table shows that especially the procedures which only use the information from the annual totals lead to I(2) series for GDP (or GNP). In most countries the CHO2 and the DEN2 procedures result in a quarterly I(1) series for GDP (or GNP), except for Belgium (where CHO2 leads to an I(2) series) and the United States (where DEN2 leads to an I(0) series).

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[14]. We did not apply the method proposed by Stram and Wei (1986, 1990) because of the practical limitations discussed above. When the periodicity is even the disaggregation of the aggregate ARIMA model into an ARIMA model for the quarterly series is either impossible (if some real roots of the AR polynomial of the aggregate model are negative) or not unique .
Therefore, we only wrote TSP-procedures for the other 10 methods, namely:

- ° LISM = Lisman and Sandee (1964)
- ° BFL1 = Boot, Feibes, and Lisman (1967) first method
- ° BFL2 = Boot, Feibes, and Lisman (1967) second method
- ° CHO1 = Chow and Lin (1971) serially uncorrelated residuals
- ° CHO2 = Chow and lin (1971) AR(1) residuals
- ° DEN2 = Denton (1971) G=D'D
- ° DEN3 = Denton (1971) G=D'D'DD
- ° DEN4 = Denton (1971) G=D'D'D'DDD
- ° FER = Fernandez (1981) general procedure
- ° LIT = Litterman (1983)

[15]. To this end we used the unit root tests of Hendry's software package PcGive Professional 8.00.

Table 1: Augmented Dickey-Fuller test statistics

LISM	BFL1	BFL2	CHO1	CHO2	DEN2	DEN3	DEN4	FER	LIT
Belgium									
-1.574 [5] -2.200 [6]	-1.306 [6] -1.484 [8]	-1.542 [8] -1.979 [7]	-1.377 [2] -16.122* [0]	-1.298 [7] -2.062 [8]	-1.309 [7] -2.919* [6]	-1.355 [7] -2.658 [6]	-1.255 [7] -2.756 [6]	-1.342 [7] -2.789 [6]	-1.354 [7] -2.664 [6]
Canada									
-0.344 [6] -3.374* [5]	-0.138 [6] -1.302 [8]	-0.524 [8] -3.276* [8]	-1.265 [3] -7.900* [2]	-1.379 [0] -11.063* [0]	-0.878 [1] -7.366* [0]	-1.064 [1] -4.258* [1]	-0.981 [4] -5.745* [0]	-0.943 [1] -4.641* [1]	-1.057 [1] -4.261* [1]
France									
-2.723 [6] -1.771 [7]	-2.132 [6] -0.816 [8]	-2.395 [8] -1.576 [7]	-1.673 [2] -13.847* [1]	-1.827 [2] -2.984* [5]	-1.853 [2] -2.907* [5]	-2.149 [0] -3.677* [2]	-2.246 [0] -3.549* [2]	-1.869 [1] -2.669 [5]	-2.132 [0] -3.700* [2]
Germany									
-1.873 [8] -3.091* [7]	-2.037 [6] -4.535* [5]	-2.113 [8] -3.567* [7]	-1.744 [8] -9.756* [1]	-1.641 [8] -9.675* [0]	-1.649 [8] -9.536* [0]	-1.730 [8] -8.218* [0]	-1.726 [8] -8.445* [0]	-1.688 [8] -8.893* [0]	-1.728 [8] -8.214* [0]
Greece									
-1.551 [6] -1.770 [7]	-0.553 [8] -1.026 [8]	-1.025 [8] -1.441 [7]	-1.179 [4] -3.072* [7]	-1.095 [5] -3.098* [7]	-1.087 [5] -3.080* [7]	-0.861 [6] -3.008* [7]	-0.698 [6] -2.908* [7]	-1.040 [5] -2.980* [7]	-0.868 [6] -3.018* [7]
Ireland									
-1.806 [6] -5.046* [5]	-2.452 [8] -2.575 [8]	-2.003 [8] -4.572* [8]	-2.454 [8] -5.514* [6]	-1.966 [7] -5.672* [6]	-1.923 [7] -5.708* [6]	-2.715 [8] -3.197* [7]	-3.030 [8] -3.644* [8]	-2.473 [8] -3.681* [7]	-2.349 [8] -3.758* [7]
Italy									
-1.922 [6] -3.680* [6]	-1.109 [6] -2.408 [8]	-2.064 [8] -3.063* [7]	-2.804 [8] -6.624* [5]	-2.513 [6] -6.886* [5]	-2.466 [6] -6.966* [5]	-2.306 [6] -7.293* [5]	-2.265 [6] -7.312* [5]	-2.388 [6] -7.113* [5]	-2.307 [6] -7.285* [5]
Japan									
-5.493* [6] -1.645 [7]	-1.962 [8] -0.661 [8]	-2.769 [8] -0.927 [7]	-2.500 [3] -12.248* [0]	-2.221 [1] -4.338* [1]	-2.186 [1] -4.193* [1]	-2.775 [8] -0.804 [7]	-2.390 [5] -1.611 [4]	-2.516 [4] -2.929* [5]	-2.712 [8] -0.862 [7]

the Netherlands									
-3.250 [5]	-1.732 [6]	-2.496 [8]	-1.984 [2]	-1.960 [4]	-1.963 [4]	-1.927 [8]	-1.938 [8]	-1.915 [3]	-1.920 [8]
-2.142 [4]	-1.451 [8]	-2.014 [7]	-4.923* [3]	-3.807* [3]	-3.735* [3]	-2.366 [7]	-2.358 [7]	-2.459 [7]	-2.374 [7]
Portugal									
-3.305 [6]	-1.790 [8]	-2.400 [8]	-2.155 [4]	-1.896 [7]	-1.821 [7]	-1.853 [6]	-2.080 [7]	-2.100 [5]	-1.969 [4]
-2.476 [7]	-1.287 [8]	-2.154 [7]	-5.068* [3]	-4.958* [3]	-4.725* [6]	-2.693 [8]	-2.556 [8]	-4.065* [4]	-5.240* [3]
Spain									
-1.594 [8]	-1.869 [6]	-1.728 [8]	-2.042 [5]	-2.610 [1]	-2.327 [2]	-2.120 [2]	-2.102 [2]	-2.268 [2]	-2.117 [2]
-2.095 [7]	-1.558 [8]	-2.393 [7]	-2.651 [5]	-4.118* [2]	-3.964* [2]	-2.764 [1]	-2.457 [1]	-3.299* [2]	-2.788 [1]
the United Kingdom									
-3.203 [8]	-1.869 [6]	-2.442 [8]	-3.633* [0]	-2.638 [3]	-2.661 [3]	-2.950 [3]	-3.130 [3]	-2.713 [3]	-2.941 [3]
-3.002* [7]	-1.885 [8]	-3.695* [8]	-13.638* [0]	-10.569* [0]	-10.394* [0]	-8.265* [0]	-4.791* [3]	-10.022* [0]	-8.305* [0]
the United States									
-3.306 [8]	-3.087 [6]	-3.434 [8]	-3.573* [0]	-3.108 [2]	-3.742* [3]	-4.138* [3]	-4.285* [3]	-3.826* [3]	-4.104* [3]
-4.797* [5]	-4.762* [5]	-5.373* [8]	-9.948* [0]	-8.967* [1]	-6.783* [1]	-5.482* [1]	-5.049* [1]	-6.400* [1]	-5.551* [1]

Note: ° The first row denotes the value of the (augmented) Dickey-Fuller test statistic for the levels (regression with constant and trend), while the second row denotes the value of the (augmented) Dickey-Fuller test statistic for the growth rates (regression with constant). The number of lags is reported in parentheses.
° The values with an asterisk * reject the null hypothesis of a unit root at the 5% level; the critical values differ according to the number of observations in the sample (cf. McKinnon(1990)).

3.2 Correlation coefficients

For each country we then compute the correlation coefficients between the growth rates of the various series, the results of which can be found in table A.1 in the appendix. This table enables us to distinguish three groups of disaggregating procedures. For the countries considered, the first group consists of LISM, BFL1, and BFL2, i.e. the procedures that only use information on the annual totals. In most countries we also find a very strong correlation between CHO2, DEN2, DEN3, DEN4, FER, and LIT. The only exceptions are Portugal and to a lesser extent Ireland. These methods constitute the second group. Within this second group we might distinguish three subgroups: (1) DEN3 and LIT which are quasi perfectly correlated (in 11 out of 13 countries), (2) CHO2 and DEN2 which are also quasi perfectly correlated (in 10 out of 13 countries), and (3) the rest. Finally the third 'group' consists of the only procedure that is not systematically related to any of the other methods, namely CHO1, although in most countries this method is much more correlated with the methods of the second group than with those of the first group.

3.3 Nonparametric tests

Since we do not know from which distribution the quarterly growth rates are sampled, we will start by using two nonparametric tests. Since the quarterly growth rates of GDP (or GNP) are measured on a ratio scale[16], the appropriate nonparametric test would be the *permutation test for paired replicates*. However, for large samples this test is very tedious to compute. Therefore we restrict ourselves to the sign test and the Wilcoxon signed ranks test, both of which are designed for variables measured on at least an ordinal scale. The *sign test* only uses information on the sign of the paired differences in growth rates, whereas the *Wilcoxon signed ranks test* also considers the relative magnitude of these paired differences.

The null hypothesis of the sign test is a zero median difference between the growth rates. For large samples the test statistic, corrected for continuity[17], is approximately standard normally distributed. The results can be found in the appendix (table A.2). We can conclude that in the vast majority of cases the null hypothesis cannot be rejected. The exceptions being the combinations BFL2-DEN3 and BFL2-LIT for Japan and the Netherlands and the combination CHO1-FER for Japan.

The Wilcoxon signed ranks test is used to test whether both series of quarterly growth rates of GDP (or GNP) are samples from populations with the same medians and the

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[16]. We distinguish four scales of measurement: nominal, ordinal, interval, and ratio scales. When numbers or other symbols are simply used to classify a variable, it is said to be measured on a nominal scale. When in addition these classes can be ordered or ranked, the variable is measured on an ordinal scale. Moreover, when the difference between two numbers on the scale has meaning, then the variable is measured on an interval scale. Finally, the variable is measured on a ratio scale when the scale has a true zero point as its origin.

[17]. For the sign test the test statistic, corrected for continuity, is:

$$z = \frac{2x + 1 - N}{\sqrt{N}}$$

In this formula x is the smallest observed number of differences of a certain sign and N is the number of observations.

same continuous distribution. For large samples the test statistic[18] is approximately standard normally distributed. As for the sign test, the results of the Wilcoxon test can be found in the appendix (table A.3). For this test the null hypothesis cannot be rejected, except for two cases relating to Japan (namely the combinations BFL2-DEN3 and BFL2-LIT).

3.4 Parametric test on the means of the quarterly growth rates

Since our sample is relatively large (from 107 to 135 observations), we also use a t-test for the null hypothesis of a zero mean paired difference. This test statistic[19] is t distributed with N degrees of freedom. From the results that are summarized in the appendix (table A.4) we can see that again the null hypothesis cannot be rejected except for the two cases mentioned above (albeit only at the 10% level).

3.5 Parametric tests on the variances of the quarterly growth rates

Since there are no significant differences in the mean growth rates of the quarterly series of GDP (or GNP) for the various countries, we proceed by testing whether or not the series have the same variance. To this end we first use as a test statistic the ratio of the two variances which is F distributed with (N_1-1, N_2-1) degrees of freedom. The results can be found in the appendix (table A.5). Second, we use an F-test which is corrected for

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18. For the Wilcoxon signed ranks test the test statistic is:

$$z = \frac{x - N(N+1)/4}{\sqrt{N(N+1)(2N+1)/24}}$$

In this formula x is the sum of the ranks of the positive paired differences and N is the number of observations.

19. For the t-test the test statistic is:

$$t = \frac{\mu_D}{\sigma_D}\sqrt{N}$$

In this formula μ_D is the mean paired difference, σ_D is the standard deviation of the paired differences, and N is the number of observations.

the fact that the two series whose variances are being compared are correlated[20]. These results can also be found in the appendix (table A.6). For both tests the null hypothesis of equal variances is rejected for the majority of the combinations, except for the methods that only use information on the annual totals. From the tables we also see that the latter procedures have the lowest variance, whereas CHO1, CHO2, and DEN2 have the largest variance.

3.6 A comparison with the actual quarterly real GDP data for Canada, Italy, Japan, the United Kingdom, and the United States

Finally, we compare our computed quarterly growth rates of real GDP with the actual ones for Canada, Italy, Japan, the United Kingdom, and the United States by calculating both the Mean Absolute Error (MAE) and the Root Mean Squared Error (RMSE)[21]. In table 2 we report the three best performing procedures for each test statistic. From this we can conclude that DEN3 and LIT seem to outperform the other distribution procedures, both in terms of the MAE and the RMSE. Ranking the procedures from 3 to 1 and adding these ranks across the countries considered leads to a score of 16 for DEN3 (7 and 9 for MAE and RMSE, respectively) and a score of 15 for LIT (8 and 7 for MAE and RMSE, respectively), whereas the third best performing procedure DEN4 only scores 9 (2 and 7 for MAE and RMSE, respectively).

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[20]. For this 'corrected' F-test the test statistic is:

$$F_r = \frac{F-1}{[(F+1)^2 - 4r^2F]^{1/2}}$$

In this formula F is the ratio of the largest variance over the smallest (F > 1) and r is the correlation coefficient.

[21]. Belgium, France, Germany, Greece, Ireland, the Netherlands, Portugal, and Spain were not withheld, because data on actual quarterly real GDP (or GNP) were not available before 1970.1 or even later. Even for the other countries, this is a 'second best' solution, since the 'actual' quarterly real GDP data are derived from some quarterly model and are no real observations.

The MAE is calculated as $\frac{\sum_{q=1}^{N} |y_q - z_q|}{N}$ where y_q is the computed series and z_q the actual one.

The RMSE is calculated as $\sqrt{\frac{\sum_{q=1}^{N} (y_q - z_q)^2}{N}}$.

Table 2: The three best performing distribution procedures in terms of Mean Absolute Error and Root Mean Squared Error

Mean Absolute Error (MAE)		Root Mean Squared Error (RMSE)	
Canada			
LIT DEN3 DEN4	0.005180 0.005180 0.005287	DEN3 LIT DEN4	0.006722 0.006722 0.006822
Italy			
BFL1 BFL2 LISM	0.008223 0.008369 0.008809	DEN4 DEN3 LIT	0.013650 0.013688 0.013719
Japan			
LISM BFL1 BFL2	0.007710 0.007810 0.007922	LISM BFL2 BFL1	0.011360 0.011733 0.011775
the United Kingdom			
LIT DEN3 FER	0.005146 0.005152 0.005221	LIT DEN3 FER	0.006640 0.006645 0.006666
the United States			
DEN3 LIT DEN4	0.004323 0.004324 0.004351	DEN4 DEN3 LIT	0.005447 0.005485 0.005511

4 Conclusions

Unfortunately we do not dispose of a theoretical basis to discriminate between the various disaggregation procedures outlined above, since many of them rest on assumptions concerning the underlying data. Therefore we cannot formulate a conclusion to cover all countries or all observation periods.

A preliminary exploration of the empirical literature - primarily on money demand - leads us to conclude that many authors are very vague as to the method they use to disaggregate their annual data. Kremers and Lane (1990, p.784) e.g. state that "annual data are interpolated according to the quarterly pattern of industrial production" without further reference to the exact procedure used. Similarly, Fase and Winder (1992, p.31) state "quarterly data are constructed by means of data on industrial output". If we restrict ourselves to those authors that do mention (but not motivate the choice of) the procedure used, the method of Chow and Lin[22] (1971) clearly is the most popular one (Campbell (1991), Hoffmaister (1992), Butkiewicz and Yohe (1993), Artis, Bladen-Hovell, and Zhang (1994), ...). Hoffmaister (1992) also uses the method of Litterman (1983) to distribute nontraditional exports, Fernandez's (1981) method is used by Chowdhury (1993) to obtain quarterly estimates of government spending, and Duffy (1991) uses the second method of Boot, Feibes, and Lisman (1967) to distribute his annual population data across quarterly figures.

Since neither theory nor the empirical literature can provide a definite answer as to which disaggregation method is the 'best' one, we apply 10 of them to the GDP (or GNP) of 13 different countries. We test for nonstationarity of the levels and the growth rates and calculate the correlation coefficient for each pair of procedures. We then test whether the growth rates of the constructed quarterly series are significantly different from one another, either in mean or in variance. The various test statistics used to this end enable us in some cases to reject the null hypothesis that each pair of samples was drawn from the same population. In the vast majority of cases the dissimilarity is related to the variance and not to the mean of the series.

Based on these test results, we can divide the 10 distribution procedures used into four groups: (1) the methods that only use information from the annual totals of GDP (or GNP) (i.e. LISM, BFL1, and BFL2), (2) the method of Chow and Lin with serially correlated residuals and the method of Denton in first differences (i.e. CHO2 and DEN2), (3) the method of Denton with second differences and the method proposed by Litterman (i.e. DEN3 and LIT), and (4) the rest (i.e. CHO1, DEN4, and FER).

Finally, we compare the computed quarterly growth rates of real GDP with the actual data for a number of countries. This not only confirmes the division of the distribution procedures into the above four groups, but also enables us to conclude that the third group (i.e. DEN3 and LIT) outperforms the rest. We therefore recommend to compute quarterly GDP data by either of these two methods. Since we are well aware that this result is confined to the periods and countries considered in this paper, we also think that a sensitivity analysis (by also using one method out of each of the other three groups) is worthwile.

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22. However, they do not specify whether they use CHO1 or CHO2.

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Table A.1 Correlation coefficients of growth rates of quarterly series of GDP (or GNP)

	LISM	BFL1	BFL2	CHO1	CHO2	DEN2	DEN3	DEN4	FER	LIT
					Belgium					
LISM	1	0.968	0.952	0.228	0.488	0.509	0.616	0.551	0.559	0.614
BFL1		1	0.975	0.246	0.522	0.543	0.649	0.582	0.594	0.646
BFL2			1	0.272	0.516	0.538	0.650	0.583	0.589	0.647
CHO1				1	0.853	0.847	0.792	0.809	0.839	0.793
CHO2					1	1.000	0.984	0.989	0.994	0.985
DEN2						1	0.988	0.991	0.996	0.989
DEN3							1	0.994	0.991	1.000
DEN4								1	0.987	0.994
FER									1	0.991
LIT										1
					Canada					
LISM	1	0.956	0.927	0.243	0.339	0.642	0.734	0.740	0.684	0.734
BFL1		1	0.967	0.288	0.394	0.708	0.798	0.799	0.746	0.797
BFL2			1	0.365	0.460	0.726	0.818	0.825	0.768	0.818
CHO1				1	0.722	0.657	0.613	0.608	0.637	0.613
CHO2					1	0.915	0.853	0.839	0.895	0.854
DEN2						1	0.988	0.981	0.997	0.988
DEN3							1	0.998	0.996	1.000
DEN4								1	0.991	0.998
FER									1	0.996
LIT										1
					France					
LISM	1	0.970	0.954	0.193	0.368	0.385	0.677	0.703	0.456	0.673
BFL1		1	0.955	0.157	0.349	0.366	0.673	0.701	0.438	0.669
BFL2			1	0.194	0.357	0.375	0.683	0.708	0.453	0.678
CHO1				1	0.922	0.919	0.786	0.763	0.900	0.789
CHO2					1	1.000	0.923	0.905	0.994	0.926
DEN2						1	0.930	0.913	0.996	0.933
DEN3							1	0.998	0.957	1.000
DEN4								1	0.943	0.998
FER									1	0.959
LIT										1
					Germany					
LISM	1	0.943	0.916	0.267	0.498	0.508	0.606	0.591	0.557	0.606
BFL1		1	0.945	0.320	0.554	0.564	0.658	0.644	0.609	0.658
BFL2			1	0.422	0.617	0.627	0.718	0.704	0.673	0.718
CHO1				1	0.873	0.871	0.836	0.840	0.856	0.836
CHO2					1	1.000	0.990	0.992	0.997	0.990
DEN2						1	0.991	0.993	0.998	0.991
DEN3							1	1.000	0.997	1.000
DEN4								1	0.998	1.000
FER									1	0.998
LIT										1

Greece										
LISM	1	0.958	0.928	0.171	0.239	0.249	0.333	0.357	0.300	0.328
BFL1		1	0.986	0.176	0.248	0.258	0.353	0.386	0.310	0.348
BFL2			1	0.169	0.244	0.253	0.354	0.392	0.303	0.349
CHO1				1	0.979	0.979	0.961	0.950	0.974	0.962
CHO2					1	1.000	0.993	0.985	0.998	0.993
DEN2						1	0.994	0.987	0.998	0.994
DEN3							1	0.998	0.997	1.000
DEN4								1	0.992	0.998
FER									1	0.997
LIT										1
Ireland										
LISM	1	0.939	0.896	0.127	0.188	0.211	0.639	0.821	0.491	0.500
BFL1		1	0.967	0.122	0.197	0.221	0.703	0.879	0.501	0.552
BFL2			1	0.113	0.195	0.218	0.724	0.941	0.459	0.565
CHO1				1	0.975	0.973	0.749	0.404	0.893	0.862
CHO2					1	1.000	0.817	0.483	0.905	0.919
DEN2						1	0.831	0.503	0.913	0.928
DEN3							1	0.893	0.901	0.978
DEN4								1	0.673	0.783
FER									1	0.939
LIT										1
Italy										
LISM	1	0.949	0.915	0.310	0.554	0.579	0.698	0.707	0.627	0.695
BFL1		1	0.975	0.303	0.563	0.589	0.734	0.751	0.637	0.731
BFL2			1	0.279	0.544	0.568	0.736	0.761	0.612	0.733
CHO1				1	0.891	0.883	0.788	0.766	0.866	0.790
CHO2					1	0.999	0.966	0.952	0.995	0.967
DEN2						1	0.972	0.959	0.998	0.973
DEN3							1	0.998	0.980	1.000
DEN4								1	0.968	0.998
FER									1	0.981
LIT										1
Japan										
LISM	1	0.961	0.938	0.313	0.787	0.807	0.935	0.917	0.895	0.935
BFL1		1	0.986	0.339	0.837	0.854	0.991	0.980	0.916	0.991
BFL2			1	0.368	0.840	0.860	0.996	0.981	0.931	0.996
CHO1				1	0.608	0.601	0.361	0.301	0.545	0.363
CHO2					1	0.999	0.848	0.786	0.964	0.850
DEN2						1	0.864	0.803	0.975	0.866
DEN3							1	0.991	0.922	1.000
DEN4								1	0.865	0.990
FER									1	0.923
LIT										1

the Netherlands										
LISM	1	0.961	0.943	0.246	0.378	0.393	0.596	0.614	0.478	0.587
BFL1		1	0.970	0.286	0.422	0.437	0.643	0.665	0.526	0.635
BFL2			1	0.301	0.425	0.441	0.648	0.668	0.528	0.639
CHO1				1	0.937	0.935	0.865	0.848	0.923	0.869
CHO2					1	1.000	0.962	0.950	0.990	0.965
DEN2						1	0.966	0.954	0.992	0.969
DEN3							1	0.998	0.982	1.000
DEN4								1	0.973	0.998
FER									1	0.984
LIT										1
Portugal										
LISM	1	0.942	0.909	0.164	0.158	0.354	0.899	0.879	0.546	0.849
BFL1		1	0.986	0.212	0.219	0.417	0.967	0.954	0.587	0.902
BFL2			1	0.187	0.218	0.420	0.973	0.961	0.566	0.901
CHO1				1	0.939	0.915	-0.014	-0.043	0.897	0.076
CHO2					1	0.976	0.004	-0.021	0.897	0.087
DEN2						1	0.212	0.183	0.961	0.272
DEN3							1	0.997	0.381	0.911
DEN4								1	0.348	0.907
FER									1	0.423
LIT										1
Spain										
LISM	1	0.973	0.960	0.263	0.496	0.518	0.839	0.872	0.639	0.835
BFL1		1	0.962	0.317	0.535	0.556	0.866	0.904	0.669	0.862
BFL2			1	0.345	0.552	0.574	0.882	0.914	0.692	0.879
CHO1				1	0.828	0.824	0.648	0.602	0.786	0.652
CHO2					1	1.000	0.875	0.830	0.983	0.879
DEN2						1	0.887	0.844	0.988	0.891
DEN3							1	0.995	0.947	1.000
DEN4								1	0.914	0.995
FER									1	0.949
LIT										1
the United Kingdom										
LISM	1	0.943	0.913	0.204	0.486	0.499	0.630	0.657	0.524	0.627
BFL1		1	0.982	0.251	0.533	0.545	0.687	0.712	0.570	0.684
BFL2			1	0.294	0.533	0.545	0.688	0.716	0.571	0.685
CHO1				1	0.811	0.809	0.747	0.725	0.803	0.749
CHO2					1	1.000	0.978	0.960	0.999	0.979
DEN2						1	0.981	0.964	0.999	0.981
DEN3							1	0.995	0.986	1.000
DEN4								1	0.970	0.995
FER									1	0.986
LIT										1

the United States										
LISM	1	0.943	0.911	0.346	0.419	0.644	0.754	0.775	0.677	0.750
BFL1		1	0.956	0.421	0.484	0.706	0.809	0.815	0.737	0.806
BFL2			1	0.466	0.500	0.697	0.823	0.848	0.732	0.817
CHO1				1	0.850	0.772	0.717	0.694	0.749	0.720
CHO2					1	0.954	0.881	0.841	0.938	0.886
DEN2						1	0.976	0.949	0.998	0.979
DEN3							1	0.993	0.986	1.000
DEN4								1	0.962	0.990
FER									1	0.988
LIT										1

Table A.2: The z-values of the sign test

	BFL1	BFL2	CHO1	CHO2	DEN2	DEN3	DEN4	FER	LIT
Belgium									
LISM	-0.177	-0.710	-0.177	-0.710	-0.532	0.000	-0.355	-0.355	0.000
BFL1		0.000	-0.172	-0.172	0.000	0.000	-0.516	-0.172	0.000
BFL2			-0.172	-0.689	-0.516	0.000	0.000	-0.516	-0.172
CHO1				-0.344	-0.344	0.000	-0.172	-0.172	0.000
CHO2					0.000	-0.861	-0.172	-0.172	-0.689
DEN2						-0.861	0.000	0.000	-0.861
DEN3							-0.172	-0.516	-0.689
DEN4								-0.344	0.000
FER									-0.516
Canada									
LISM	-0.380	-0.190	-0.190	0.000	0.000	0.000	-0.190	0.000	0.000
BFL1		0.000	-0.917	-0.367	-0.733	-0.733	-0.183	-0.733	-0.733
BFL2			-0.917	-0.183	0.000	-0.550	-0.733	-0.183	-0.550
CHO1				-0.183	-0.733	-1.283	-1.467	-0.733	-1.283
CHO2					0.000	0.000	-0.183	0.000	0.000
DEN2						0.000	-0.367	-0.183	0.000
DEN3							-0.183	0.000	-0.183
DEN4								-0.183	-0.183
FER									0.000
France									
LISM	0.000	0.000	-1.242	-0.177	-0.177	-0.177	0.000	-0.177	-0.177
BFL1		-0.516	-0.689	0.000	0.000	-0.344	-0.689	-0.172	-0.344
BFL2			-0.516	0.000	0.000	-0.172	-0.172	0.000	-0.344
CHO1				-1.033	-1.033	-1.033	-1.033	-0.861	-1.205
CHO2					0.000	0.000	0.000	0.000	0.000
DEN2						0.000	0.000	0.000	0.000
DEN3							0.000	0.000	-0.344
DEN4								-0.172	-0.172
FER									0.000
Germany									
LISM	-0.532	0.000	-0.355	-0.887	-0.887	-0.887	-0.887	-0.887	-0.887
BFL1		-0.172	-0.861	-0.344	-0.344	-0.344	-0.689	-0.172	-0.344
BFL2			-0.516	-0.516	-0.689	-0.689	-0.516	-0.689	-0.689
CHO1				-0.172	0.000	-0.516	-0.689	-0.172	-0.516
CHO2					-0.344	-0.516	-0.172	-0.344	-0.516
DEN2						-0.689	-0.172	-0.344	-0.689
DEN3							-1.033	-0.172	-0.609
DEN4								-0.516	-0.861
FER									-0.259

Greece									
LISM	-0.177	0.000	-0.532	-0.710	-0.710	-1.420	-1.420	-0.710	-1.420
BFL1		-0.344	-0.344	-0.689	-0.689	-0.861	-1.033	-0.689	-0.861
BFL2			-0.516	-0.516	-0.516	-0.516	-0.344	-0.516	-0.516
CHO1				-1.033	-0.861	-0.861	-0.861	-0.861	-0.861
CHO2					-0.344	-0.516	-0.516	-1.033	-0.516
DEN2						-0.344	-0.516	-1.033	-0.344
DEN3							0.000	-0.172	-0.689
DEN4								-0.344	0.000
FER									-0.172
Ireland									
LISM	-0.532	-0.532	-0.887	-0.355	-0.355	0.000	-0.355	-0.177	-0.355
BFL1		-0.344	-0.516	-0.516	-0.516	-0.344	-0.344	-0.172	-0.516
BFL2			-0.516	-0.344	-0.172	0.000	-0.344	-0.861	0.000
CHO1				-0.689	-0.344	-0.516	-0.516	-0.689	-0.516
CHO2					-0.689	-0.172	0.000	-0.689	0.000
DEN2						-0.172	0.000	-0.516	0.000
DEN3							0.000	-0.344	-0.172
DEN4								-0.516	0.000
FER									0.000
Italy									
LISM	-0.183	0.000	-0.550	-0.367	-0.367	-0.917	-0.550	-0.367	-0.917
BFL1		0.000	-0.532	0.000	0.000	-0.710	-0.355	0.000	-0.887
BFL2			-0.532	-0.177	-0.177	-0.177	-0.177	-0.177	-0.177
CHO1				-0.532	-0.532	-0.710	-0.710	-0.710	-0.710
CHO2					0.000	0.000	-0.355	0.000	0.000
DEN2						0.000	-0.532	0.000	0.000
DEN3							-0.532	-0.355	-0.089
DEN4								-0.710	-0.532
FER									-0.355
Japan									
LISM	0.000	-0.532	-1.597	0.000	0.000	-0.355	0.000	0.000	-0.355
BFL1		-0.344	-1.549	-0.861	-0.861	0.000	-0.861	-1.033	0.000
BFL2			-1.205	0.000	-0.172	-4.648**	-1.033	-0.172	-3.959**
CHO1				-1.377	-1.377	-1.205	-1.377	-1.721*	-1.205
CHO2					-0.861	-0.172	0.000	-0.861	-0.172
DEN2						0.000	0.000	-0.861	0.000
DEN3							-0.689	-0.172	-0.435
DEN4								0.000	-0.516
FER									-0.172

					the Netherlands				
LISM	-0.759	0.000	0.000	-0.569	-0.569	-0.759	-0.569	-0.569	-0.759
BFL1		-0.550	0.000	-1.100	-1.100	-1.100	-1.100	-0.733	-1.100
BFL2			0.000	-1.467	-1.467	-1.650	-1.467	-0.917	-1.650
CHO1				0.000	0.000	0.000	-0.183	-0.183	0.000
CHO2					-1.283	-0.367	-0.367	-0.367	-0.367
DEN2						-0.183	-0.367	-0.183	0.000
DEN3							-0.550	-0.550	-1.100
DEN4								-0.367	0.000
FER									-0.550
					Portugal				
LISM	0.000	-0.201	0.000	0.000	-0.201	-0.402	-0.603	-0.804	0.000
BFL1		-0.193	0.000	-0.387	0.000	-0.387	-0.967	-1.160	-0.773
BFL2			0.000	-0.580	-0.580	-0.193	-0.773	-0.773	-1.547
CHO1				-0.193	0.000	0.000	0.000	-0.580	0.000
CHO2					-0.580	-0.580	-0.580	-0.387	-0.773
DEN2						-0.580	-0.773	-0.193	-0.773
DEN3							0.000	-0.967	-1.160
DEN4								-0.773	-1.353
FER									-0.193
					Spain				
LISM	-0.367	0.000	-0.367	-0.550	-0.367	-0.367	-0.367	-0.367	-0.367
BFL1		-0.710	0.000	0.000	0.000	0.000	-0.177	0.000	0.000
BFL2			-0.177	-0.177	-0.177	0.000	-0.177	0.000	0.000
CHO1				-0.177	0.000	0.000	0.000	-0.177	0.000
CHO2					0.000	-0.532	-0.355	0.000	-0.532
DEN2						-0.532	-0.532	0.000	-0.532
DEN3							-0.355	0.000	-0.089
DEN4								-0.532	-0.710
FER									0.000
					the United Kingdom				
LISM	0.000	-0.355	-1.420	-0.532	-0.355	0.000	-0.355	-0.355	0.000
BFL1		-0.172	-1.205	-1.205	-1.205	-0.861	-1.033	-1.205	-0.861
BFL2			-1.205	-0.689	-0.689	-0.689	-0.689	-0.689	-0.689
CHO1				-0.516	-0.689	-0.861	-1.205	-0.861	-0.861
CHO2					-1.377	-0.861	-0.172	-1.377	-0.861
DEN2						-0.689	0.000	-1.205	-0.689
DEN3							-0.172	-0.689	-0.689
DEN4								-0.172	0.000
FER									-0.689

the United States									
LISM	-0.569	-0.380	0.000	-0.569	-0.380	-0.759	-1.139	-0.380	-0.949
BFL1		-0.183	0.000	0.000	0.000	-0.367	-0.183	0.000	-0.367
BFL2			0.000	-0.550	0.000	-0.183	-0.183	-0.183	-0.367
CHO1				-0.367	-0.550	-0.550	-0.367	-0.550	-0.550
CHO2					-0.183	-0.367	0.000	0.000	-0.183
DEN2						-0.183	0.000	0.000	0.000
DEN3							-0.092	0.000	0.092
DEN4								-0.183	0.000
FER									-0.183

Note: The 5% critical values for this two sided test are -1.96 and 1.96, whereas the 10% critical values are -1.645 and 1.645. Hence, the values with one asterisk * reject the null hypothesis of a zero median difference at the 10% level and those with two asterisks ** even at the 5% level.

Table A.3: The z-values of the Wilcoxon signed ranks test

	BFL1	BFL2	CHO1	CHO2	DEN2	DEN3	DEN4	FER	LIT
Belgium									
LISM	-0.122	-0.029	-0.060	0.055	0.065	0.113	0.140	0.099	0.118
BFL1		-0.496	-0.051	0.245	0.242	0.334	0.398	0.272	0.334
BFL2			-0.022	0.303	0.305	0.389	0.409	0.275	0.383
CHO1				0.031	0.063	0.015	0.070	0.037	0.023
CHO2					-0.437	-0.051	0.135	-0.489	-0.053
DEN2						0.051	0.112	-0.519	0.049
DEN3							0.128	-0.161	0.184
DEN4								-0.029	-0.125
FER									0.184
Canada									
LISM	-0.356	0.124	0.079	0.000	-0.053	-0.097	-0.050	-0.059	-0.100
BFL1		-0.241	-0.151	-0.209	-0.255	-0.324	-0.366	-0.273	-0.324
BFL2			-0.095	-0.134	0.045	0.016	-0.032	-0.013	0.016
CHO1				0.202	0.313	0.263	0.239	0.252	0.263
CHO2					0.080	0.109	0.077	0.095	0.114
DEN2						0.056	0.073	-0.114	0.041
DEN3							-0.032	-0.156	0.041
DEN4								-0.095	0.034
FER									0.170
France									
LISM	-0.282	0.061	-0.436	-0.147	-0.176	-0.154	-0.140	-0.178	-0.136
BFL1		-0.723	-0.337	-0.121	-0.127	-0.275	-0.404	-0.134	-0.261
BFL2			-0.261	-0.051	-0.041	0.071	0.031	-0.024	0.064
CHO1				0.270	0.246	0.272	0.268	0.259	0.270
CHO2					0.114	0.102	0.086	0.099	0.103
DEN2						0.088	0.075	0.091	0.094
DEN3							-0.110	-0.035	-0.160
DEN4								0.000	0.101
FER									0.030
Germany									
LISM	-0.116	-0.072	-0.036	-0.022	-0.005	0.078	0.079	0.019	0.075
BFL1		-0.454	0.130	0.243	0.237	0.191	0.195	0.222	0.188
BFL2			0.167	0.204	0.200	0.230	0.237	0.202	0.231
CHO1				0.099	0.088	-0.007	0.011	0.013	-0.004
CHO2					-0.226	-0.163	-0.138	-0.167	-0.165
DEN2						-0.158	-0.128	-0.145	-0.160
DEN3							0.078	0.096	0.469
DEN4								-0.031	0.019
FER									-0.099

Greece									
LISM	-0.683	-0.538	0.067	-0.051	-0.046	-0.079	-0.113	-0.058	-0.077
BFL1		0.754	0.057	0.002	-0.004	0.055	0.167	-0.035	0.048
BFL2			0.048	-0.022	-0.029	0.007	0.123	-0.048	0.009
CHO1				0.332	0.232	0.035	0.081	0.051	0.038
CHO2					-0.144	0.048	0.119	-0.108	0.046
DEN2						0.081	0.154	-0.083	0.066
DEN3							0.158	-0.268	-0.067
DEN4								-0.273	-0.167
FER									0.270
Ireland									
LISM	0.025	-0.128	0.060	0.137	0.144	0.149	-0.037	0.096	0.225
BFL1		-0.035	0.105	0.158	0.145	-0.101	-0.200	0.011	0.040
BFL2			0.160	0.180	0.189	0.259	0.081	0.220	0.244
CHO1				0.109	0.015	-0.154	-0.209	-0.152	-0.141
CHO2					-0.214	-0.191	-0.239	-0.237	-0.193
DEN2						-0.211	-0.239	-0.202	-0.175
DEN3							-0.316	0.114	0.233
DEN4								0.228	0.299
FER									0.066
Italy									
LISM	-0.180	-0.103	0.159	-0.225	-0.225	-0.443	-0.453	-0.247	-0.438
BFL1		0.030	0.072	-0.036	-0.036	-0.060	0.055	-0.075	-0.060
BFL2			0.161	-0.061	-0.055	-0.077	-0.051	-0.072	-0.079
CHO1				-0.051	-0.070	-0.089	-0.103	-0.065	-0.091
CHO2					-0.233	0.089	0.171	-0.207	0.101
DEN2						0.084	0.200	-0.209	0.099
DEN3							0.476	-0.119	-0.156
DEN4								-0.242	-0.461
FER									0.125
Japan									
LISM	-0.436	-0.274	-0.864	-0.166	-0.156	-0.065	-0.284	-0.245	-0.082
BFL1		0.166	-0.729	0.237	0.217	0.631	0.762	0.074	0.637
BFL2			-0.617	0.683	0.623	4.478**	0.671	0.321	4.152**
CHO1				0.698	0.703	0.651	0.597	0.706	0.654
CHO2					-0.353	-0.167	-0.037	-0.377	-0.167
DEN2						-0.083	-0.020	-0.374	-0.082
DEN3							-0.025	0.088	0.182
DEN4								0.085	0.023
FER									-0.083

the Netherlands									
LISM	-0.165	-0.168	0.271	0.444	0.435	0.341	0.341	0.460	0.347
BFL1		-0.544	0.156	0.345	0.345	0.255	0.255	0.335	0.265
BFL2			0.231	0.546	0.541	0.557	0.560	0.546	0.567
CHO1				-0.077	-0.106	-0.101	-0.095	-0.109	-0.093
CHO2					-0.518	-0.411	-0.278	-0.379	-0.414
DEN2						-0.382	-0.278	-0.363	-0.377
DEN3							0.158	0.252	0.383
DEN4								0.267	-0.129
FER									-0.264
Portugal									
LISM	-0.405	-0.206	-0.195	-0.623	-0.565	0.003	0.084	-0.586	0.195
BFL1		-0.246	-0.106	-0.354	-0.407	0.382	0.538	-0.507	0.323
BFL2			-0.087	-0.339	-0.423	0.671	0.761	-0.329	0.628
CHO1				-0.242	-0.183	0.140	0.146	-0.044	0.214
CHO2					0.326	0.367	0.385	0.168	0.426
DEN2						0.500	0.569	0.143	0.491
DEN3							0.289	-0.432	0.564
DEN4								-0.507	0.267
FER									0.466
Spain									
LISM	-0.430	-0.117	0.517	0.236	0.220	0.109	0.077	0.270	0.114
BFL1		-0.582	0.380	0.296	0.324	0.318	0.245	0.322	0.318
BFL2			0.499	0.354	0.351	0.517	0.475	0.349	0.504
CHO1				0.014	-0.024	-0.322	-0.351	-0.144	-0.315
CHO2					-0.502	-0.325	-0.308	-0.438	-0.330
DEN2						-0.325	-0.285	-0.427	-0.322
DEN3							-0.043	0.238	0.279
DEN4								0.229	0.106
FER									-0.229
the United Kingdom									
LISM	-0.147	-0.067	0.806	0.359	0.349	0.325	0.349	0.354	0.322
BFL1		-0.661	0.510	0.338	0.336	0.248	0.231	0.332	0.246
BFL2			0.523	0.426	0.415	0.376	0.378	0.384	0.373
CHO1				-0.318	-0.340	-0.461	-0.503	-0.433	-0.455
CHO2					-0.533	-0.446	-0.460	-0.566	-0.428
DEN2						-0.413	-0.425	-0.581	-0.400
DEN3							-0.127	0.395	0.413
DEN4								0.393	0.152
FER									-0.380

the United States									
LISM	-0.230	0.090	-0.206	0.021	-0.094	0.024	0.000	-0.047	0.009
BFL1		-0.219	-0.244	-0.188	-0.403	-0.577	-0.564	-0.520	-0.607
BFL2			0.017	0.008	0.033	-0.098	-0.281	0.021	-0.040
CHO1				0.027	0.188	0.138	0.119	0.164	0.183
CHO2					-0.058	-0.072	-0.030	-0.125	-0.088
DEN2						0.013	0.114	-0.057	0.003
DEN3							0.073	-0.093	-0.273
DEN4								-0.228	-0.152
FER									0.072

Note: The 5% critical values for this two sided test are -1.96 and 1.96, whereas the 10% critical values are -1.645 and 1.645. Hence, the values with one asterisk * reject the null hypothesis of samples of the same population at the 10% level and those with two asterisks ** even at the 5% level.

Table A.4 The t-values of the t-test of equal means

	BFL1	BFL2	CHO1	CHO2	DEN2	DEN3	DEN4	FER	LIT
Belgium									
LISM	-0.148	-0.091	-0.075	-0.062	-0.060	-0.055	-0.066	-0.055	-0.055
BFL1		-0.953	-0.021	0.028	0.014	-0.007	0.060	-0.026	-0.006
BFL2			0.033	0.157	0.151	0.175	0.212	0.131	0.174
CHO1				0.049	0.039	0.025	0.060	0.017	0.025
CHO2					-0.253	-0.111	0.121	-0.258	-0.110
DEN2						-0.077	0.239	-0.254	-0.076
DEN3							0.354	-0.101	0.126
DEN4								-0.434	-0.360
FER									0.108
Canada									
LISM	-0.043	0.092	-0.044	0.070	0.057	0.082	0.109	0.075	0.081
BFL1		-0.969	-0.185	-0.231	-0.178	-0.260	-0.332	-0.242	-0.257
BFL2			-0.109	-0.123	0.077	0.080	0.007	0.044	0.082
CHO1				0.030	0.157	0.144	0.124	0.140	0.145
CHO2					0.264	0.212	0.174	0.219	0.213
DEN2						-0.067	-0.227	-0.294	-0.060
DEN3							-0.653	-0.133	0.693
DEN4								0.169	0.656
FER									0.148
France									
LISM	-0.129	-0.058	-0.016	0.004	0.005	0.020	0.027	0.013	0.019
BFL1		-1.188	-0.020	-0.000	-0.009	-0.122	-0.151	-0.053	-0.115
BFL2			0.037	0.132	0.131	0.212	0.210	0.124	0.214
CHO1				0.031	0.025	-0.001	-0.005	0.004	-0.000
CHO2					-0.148	-0.080	-0.086	-0.156	-0.077
DEN2						-0.073	-0.080	-0.159	-0.070
DEN3							-0.182	0.025	0.350
DEN4								0.040	0.206
FER									-0.019
LIT									
Germany									
LISM	-0.129	-0.026	0.062	0.087	0.088	0.098	0.102	0.091	0.098
BFL1		-0.912	-0.101	-0.117	-0.124	-0.197	-0.195	-0.161	-0.195
BFL2			0.005	0.095	0.094	0.083	0.074	0.085	0.086
CHO1				0.069	0.065	0.036	0.034	0.047	0.038
CHO2					-0.136	-0.126	-0.159	-0.152	-0.120
DEN2						-0.125	-0.162	-0.156	-0.118
DEN3							-0.125	0.092	0.819
DEN4								0.170	0.181
FER									-0.077

					Greece				
LISM	-0.386	-0.583	-0.095	-0.132	-0.132	-0.166	-0.195	-0.133	-0.164
BFL1		0.304	-0.074	-0.056	-0.061	-0.027	0.026	-0.070	-0.029
BFL2			-0.084	-0.070	-0.075	-0.048	0.004	-0.087	-0.048
CHO1				0.102	0.091	0.114	0.150	0.076	0.114
CHO2					-0.041	0.120	0.193	0.007	0.120
DEN2						0.145	0.222	0.020	0.147
DEN3							0.501	-0.335	-0.107
DEN4								-0.409	-0.455
FER									0.356
					Ireland				
LISM	-0.073	-0.083	-0.098	-0.052	-0.051	-0.031	0.053	-0.084	-0.042
BFL1		-0.577	-0.100	-0.056	-0.064	-0.149	-0.460	-0.155	-0.097
BFL2			-0.079	-0.025	-0.028	0.004	-0.241	-0.062	0.005
CHO1				0.162	0.139	0.091	0.070	0.083	0.099
CHO2					-0.003	0.032	0.006	0.003	0.038
DEN2						0.038	0.008	0.004	0.046
DEN3							-0.146	-0.122	0.006
DEN4								-0.012	0.085
FER									0.172
					Italy				
LISM	-0.463	-0.569	0.044	-0.036	-0.041	-0.141	-0.179	-0.048	-0.139
BFL1		0.532	-0.091	-0.033	-0.047	0.066	0.122	-0.080	0.066
BFL2			-0.131	-0.117	-0.136	-0.068	-0.018	-0.179	-0.067
CHO1				0.127	0.114	0.149	0.166	0.091	0.150
CHO2					-0.164	0.194	0.249	-0.180	0.198
DEN2						0.263	0.316	-0.188	0.268
DEN3							0.592	-0.457	0.055
DEN4								-0.522	-0.546
FER									0.468
					Japan				
LISM	-0.367	-0.524	0.005	-0.095	-0.094	-0.368	-0.452	-0.083	-0.368
BFL1		-0.953	-0.105	-0.042	-0.097	-0.042	0.468	-0.476	-0.042
BFL2			-0.044	0.211	0.176	1.688*	1.311	-0.104	1.681*
CHO1				0.109	0.095	0.104	0.140	0.031	0.104
CHO2					-0.531	0.034	0.168	-0.542	0.034
DEN2						0.091	0.223	-0.545	0.091
DEN3							0.735	-0.479	-0.024
DEN4								-0.622	-0.722
FER									0.482

the Netherlands									
LISM	-0.186	-0.099	0.087	0.088	0.088	0.067	0.052	0.090	0.066
BFL1		-0.945	-0.008	0.001	-0.005	-0.065	-0.067	-0.037	-0.056
BFL2			0.062	0.110	0.108	0.133	0.142	0.108	0.137
CHO1				0.019	0.010	-0.022	-0.020	-0.017	-0.018
CHO2					-0.146	-0.080	-0.072	-0.110	-0.073
DEN2						-0.073	-0.065	-0.102	-0.066
DEN3							0.019	0.036	0.296
DEN4								0.027	0.055
FER									-0.018
Portugal									
LISM	-0.216	-0.238	-0.011	-0.131	-0.136	-0.164	-0.196	-0.092	-0.097
BFL1		-0.605	0.068	0.088	0.021	-0.089	0.063	-0.013	-0.158
BFL2			0.089	0.110	0.068	0.328	0.418	0.059	0.054
CHO1				0.052	-0.098	-0.069	-0.060	-0.100	-0.081
CHO2					-0.149	-0.089	-0.080	-0.130	-0.102
DEN2						-0.029	-0.010	-0.071	-0.051
DEN3							0.564	0.003	-0.114
DEN4								-0.023	-0.204
FER									-0.036
Spain									
LISM	-0.209	-0.032	0.053	-0.067	-0.066	-0.058	-0.069	-0.051	-0.058
BFL1		-0.942	-0.065	-0.132	-0.146	-0.319	-0.293	-0.231	-0.313
BFL2			0.024	0.038	0.033	0.151	0.281	0.010	0.148
CHO1				-0.007	-0.012	0.004	0.021	-0.028	0.004
CHO2					-0.121	0.023	0.060	-0.097	0.023
DEN2						0.036	0.075	-0.092	0.037
DEN3							0.386	-0.131	0.017
DEN4								-0.180	-0.357
FER									0.134
the United Kingdom									
LISM	-0.022	-0.017	0.062	0.127	0.129	0.116	0.127	0.133	0.115
BFL1		-0.904	-0.267	-0.214	-0.222	-0.233	-0.303	-0.242	-0.230
BFL2			-0.222	-0.104	-0.108	-0.069	-0.126	-0.120	-0.067
CHO1				0.254	0.251	0.255	0.232	0.243	0.256
CHO2					-0.037	0.170	0.062	-0.058	0.175
DEN2						0.190	0.070	-0.068	0.196
DEN3							-0.341	-0.252	0.196
DEN4								-0.095	0.336
FER									0.261

the United States									
LISM	-0.011	0.178	-0.023	-0.054	-0.057	0.002	0.055	-0.051	-0.007
BFL1		-1.114	-0.102	-0.148	-0.156	-0.376	-0.510	-0.205	-0.349
BFL2			0.057	0.041	0.179	0.098	-0.027	0.163	0.120
CHO1				-0.038	0.040	-0.030	-0.078	0.019	-0.020
CHO2					0.134	-0.004	-0.073	0.086	0.011
DEN2						-0.327	-0.423	-0.281	-0.294
DEN3							-0.580	0.323	0.687
DEN4								0.435	0.597
FER									-0.280

Note: The 5% critical values for this two sided test are -1.96 and 1.96, whereas the 10% critical values are -1.645 and 1.645. Hence, the values with one asterisk * reject the null hypothesis of a zero mean difference at the 10% level.

Table A.5 The F-values of the null hypothesis of equal variances

	BFL1	BFL2	CHO1	CHO2	DEN2	DEN3	DEN4	FER	LIT
Belgium									
LISM	1.086	1.061	0.066*	0.292*	0.317*	0.456*	0.359*	0.383*	0.452*
BFL1		0.977	0.061*	0.269*	0.292*	0.420*	0.331*	0.353*	0.416*
BFL2			0.062*	0.275*	0.299*	0.430*	0.339*	0.361*	0.426*
CHO1				4.412*	4.795*	6.894*	5.430*	5.798*	6.835*
CHO2					1.087	1.562*	1.231	1.314	1.549*
DEN2						1.438*	1.132	1.209	1.425*
DEN3							0.788	0.841	0.991
DEN4								1.068	1.259
FER									1.179
Canada									
LISM	1.091	1.071	0.102*	0.187*	0.566*	0.722*	0.733*	0.633*	0.721*
BFL1		0.982	0.093*	0.171*	0.519*	0.662*	0.672*	0.580*	0.661*
BFL2			0.095*	0.174*	0.528*	0.674*	0.684*	0.591*	0.673*
CHO1				1.834*	5.555*	7.085*	7.193*	6.213*	7.075*
CHO2					3.030*	3.864*	3.923*	3.388*	3.858*
DEN2						1.275	1.295	1.118	1.274
DEN3							1.015	0.877	0.999
DEN4								0.864	0.984
FER									1.139
France									
LISM	0.994	0.974	0.024*	0.119*	0.132*	0.466*	0.508*	0.195*	0.459*
BFL1		0.980	0.024*	0.120*	0.133*	0.469*	0.511*	0.196*	0.461*
BFL2			0.025*	0.123*	0.136*	0.478*	0.522*	0.200*	0.471*
CHO1				4.940*	5.467*	19.276*	21.035*	8.058*	18.984*
CHO2					1.107	3.902*	4.258*	1.631*	3.843*
DEN2						3.526*	3.848*	1.474*	3.472*
DEN3							1.091	0.418*	0.985
DEN4								0.383*	0.902
FER									2.356*
Germany									
LISM	1.007	0.934	0.106*	0.314*	0.326*	0.448*	0.429*	0.383*	0.448*
BFL1		0.928	0.105*	0.312*	0.323*	0.445*	0.426*	0.380*	0.445*
BFL2			0.113*	0.336*	0.349*	0.480*	0.460*	0.409*	0.480*
CHO1				2.968*	3.081*	4.244*	4.062*	3.620*	4.239*
CHO2					1.038	1.430*	1.369*	1.220	1.428*
DEN2						1.377*	1.318	1.175	1.376*
DEN3							0.957	0.853	0.999
DEN4								0.891	1.044
FER									1.171

Greece									
LISM	1.117	1.056	0.038*	0.072*	0.079*	0.142*	0.166*	0.113*	0.138*
BFL1		0.945	0.034*	0.065*	0.070*	0.127*	0.148*	0.101*	0.124*
BFL2			0.036*	0.068*	0.074*	0.134*	0.157*	0.107*	0.131*
CHO1				1.891*	2.054*	3.708*	4.335*	2.949*	3.613*
CHO2					1.086	1.960*	2.292*	1.559*	1.910*
DEN2						1.805*	2.111*	1.436*	1.759*
DEN3							1.169	0.795	0.974
DEN4								0.680*	0.833
FER									1.225
Ireland									
LISM	1.123	1.075	0.021*	0.047*	0.060*	0.579*	0.928	0.301*	0.357*
BFL1		0.957	0.018*	0.042*	0.053*	0.516*	0.826	0.268*	0.318*
BFL2			0.019*	0.044*	0.055*	0.539*	0.864	0.280*	0.332*
CHO1				2.305*	2.902*	28.187*	45.172*	14.632*	17.356*
CHO2					1.259	12.231*	19.601*	6.349*	7.531*
DEN2						9.714*	15.567*	5.042*	5.981*
DEN3							1.603*	0.519*	0.616*
DEN4								0.324*	0.384*
FER									1.186
Italy									
LISM	1.157	1.062	0.115*	0.380*	0.416*	0.626*	0.646*	0.488*	0.621*
BFL1		0.918	0.100*	0.328*	0.360*	0.541*	0.559*	0.422*	0.537*
BFL2			0.108*	0.357*	0.392*	0.589*	0.609*	0.460*	0.585*
CHO1				3.295*	3.611*	5.432*	5.612*	4.238*	5.392*
CHO2					1.096	1.649*	1.703*	1.286	1.636*
DEN2						1.504*	1.554*	1.174	1.493*
DEN3							1.033	0.780	0.993
DEN4								0.755	0.961
FER									1.272
Japan									
LISM	1.039	1.016	0.134*	0.743	0.779	1.025	0.978	0.921	1.025
BFL1		0.978	0.129*	0.715*	0.750	0.987	0.942	0.887	0.987
BFL2			0.132*	0.731*	0.767	1.009	0.963	0.907	1.009
CHO1				5.562*	5.829*	7.671*	7.322*	6.896*	7.670*
CHO2					1.048	1.379*	1.317	1.240	1.379*
DEN2						1.316	1.256	1.183	1.316
DEN3							0.955	0.899	1.000
DEN4								0.942	1.048
FER									1.112

the Netherlands									
LISM	1.051	1.030	0.086*	0.187*	0.201*	0.442*	0.472*	0.294*	0.429*
BFL1		0.980	0.081*	0.178*	0.191*	0.420*	0.449*	0.279*	0.408*
BFL2			0.083*	0.181*	0.195*	0.429*	0.458*	0.285*	0.417*
CHO1				2.182*	2.345*	5.166*	5.519*	3.435*	5.020*
CHO2					1.075	2.368*	2.530*	1.574*	2.301*
DEN2						2.202*	2.353*	1.465*	2.140*
DEN3							1.068	0.665*	0.972
DEN4								0.622*	0.910
FER									1.461*
Portugal									
LISM	1.153	1.135	0.050*	0.052*	0.201*	1.084	1.046	0.400*	0.947
BFL1		0.985	0.043*	0.045*	0.174*	0.940	0.908	0.347*	0.822
BFL2			0.044*	0.046*	0.177*	0.955	0.922	0.352*	0.834
CHO1				1.052	4.045*	21.808*	21.046*	8.045*	19.050*
CHO2					3.845*	20.730*	20.006*	7.648*	18.109*
DEN2						5.391*	5.203*	1.989*	4.709*
DEN3							0.965	0.369*	0.874
DEN4								0.382*	0.905
FER									2.368*
Spain									
LISM	0.981	0.952	0.103*	0.293*	0.316*	0.764	0.824	0.463*	0.758
BFL1		0.971	0.105*	0.298*	0.322*	0.779	0.840	0.472*	0.772
BFL2			0.108*	0.307*	0.332*	0.802	0.865	0.486*	0.796
CHO1				2.850*	3.081*	7.443*	8.030*	4.509*	7.382*
CHO2					1.081	2.611*	2.817*	1.582*	2.590*
DEN2						2.416*	2.606*	1.463*	2.396*
DEN3							1.079	0.606*	0.992
DEN4								0.561*	0.919
FER									1.637*
the United Kingdom									
LISM	1.126	1.101	0.081*	0.335*	0.350*	0.549*	0.596*	0.383*	0.545*
BFL1		0.979	0.072*	0.297*	0.311*	0.488*	0.529*	0.340*	0.484*
BFL2			0.073*	0.304*	0.318*	0.498*	0.541*	0.348*	0.495*
CHO1				4.150*	4.342*	6.809*	7.388*	4.753*	6.760*
CHO2					1.046	1.641*	1.780*	1.145	1.629*
DEN2						1.568*	1.702*	1.095	1.557*
DEN3							1.085	0.698*	0.993
DEN4								0.643*	0.915
FER									1.422*

the United States									
LISM	1.149	1.113	0.210*	0.279*	0.585*	0.787	0.814	0.641*	0.780
BFL1		0.969	0.182*	0.243*	0.509*	0.685*	0.709*	0.558*	0.679*
BFL2			0.188*	0.250*	0.526*	0.707*	0.731*	0.576*	0.701*
CHO1				1.330	2.793*	3.757*	3.885*	3.061*	3.723*
CHO2					2.100*	2.824*	2.921*	2.301*	2.799*
DEN2						1.345	1.391*	1.096	1.333
DEN3							1.034	0.815	0.991
DEN4								0.788	0.958
FER									1.216

Notes: ° The rows represent the numerator of the test statistic, while the colums denote the denominator

° The approximate 5% critical values for this one sided test are either 0.74 (for values of the test statistic smaller than 1) or 1.35 (for values of the test statistic larger than 1). The values with an asterisk * reject the null hypothesis of equal variances at the 5% level.

Table A.6 The F_r-values of the null hypothesis of equal variances with correlated observations

	BFL1	BFL2	CHO1	CHO2	DEN2	DEN3	DEN4	FER	LIT
Belgium									
LISM	0.162	0.095	0.881*	0.600*	0.576*	0.456*	0.540*	0.515*	0.459*
BFL1		0.053	0.891*	0.637*	0.615*	0.507*	0.582*	0.560*	0.510*
BFL2			0.890*	0.628*	0.606*	0.497*	0.573*	0.549*	0.500*
CHO1				0.841*	0.852*	0.878*	0.851*	0.878*	0.878*
CHO2					0.841*	0.786*	0.582*	0.786*	0.786*
DEN2						0.764*	0.423*	0.744*	0.764*
DEN3							0.737*	0.537*	0.756*
DEN4								0.202*	0.733*
FER									0.523*
Canada									
LISM	0.146	0.092	0.823*	0.707*	0.352*	0.235*	0.226*	0.302*	0.235*
BFL1		0.036	0.840*	0.737*	0.428*	0.326*	0.316*	0.382*	0.327*
BFL2			0.844*	0.744*	0.427*	0.327*	0.320*	0.384*	0.328*
CHO1				0.406*	0.788*	0.823*	0.824*	0.805*	0.822*
CHO2					0.822*	0.813*	0.805*	0.824*	0.813*
DEN2						0.615*	0.556*	0.608*	0.615*
DEN3							0.117	0.581*	0.308*
DEN4								0.483*	0.124
FER									0.581*
France									
LISM	0.013	0.044	0.954*	0.808*	0.791*	0.470*	0.437*	0.716*	0.475*
BFL1		0.034	0.954*	0.805*	0.788*	0.465*	0.432*	0.711*	0.470*
BFL2			0.953*	0.802*	0.785*	0.459*	0.424*	0.708*	0.464*
CHO1				0.916*	0.924*	0.959*	0.959*	0.944*	0.958*
CHO2					0.933*	0.886*	0.881*	0.919*	0.887*
DEN2						0.878*	0.872*	0.914*	0.879*
DEN3							0.616*	0.842*	0.695*
DEN4								0.832*	0.631*
FER									0.843*
Germany									
LISM	0.010	0.085	0.819*	0.577*	0.566*	0.460*	0.475*	0.515*	0.460*
BFL1		0.114	0.825*	0.595*	0.584*	0.483*	0.498*	0.536*	0.483*
BFL2			0.824*	0.589*	0.578*	0.475*	0.490*	0.529*	0.475*
CHO1				0.761*	0.770*	0.820*	0.814*	0.799*	0.820*
CHO2					0.818*	0.780*	0.772*	0.797*	0.781*
DEN2						0.774*	0.763*	0.792*	0.775*
DEN3							0.690*	0.745*	0.276*
DEN4								0.691*	0.679*
FER									0.747*

Greece									
LISM	0.189*	0.073	0.928*	0.871*	0.862*	0.770*	0.739*	0.811*	0.775*
BFL1		0.164	0.936*	0.885*	0.876*	0.795*	0.768*	0.830*	0.799*
BFL2			0.932*	0.878*	0.869*	0.784*	0.756*	0.820*	0.788*
CHO1				0.849*	0.873*	0.930*	0.932*	0.929*	0.929*
CHO2					0.963*	0.944*	0.928*	0.958*	0.944*
DEN2						0.937*	0.920*	0.956*	0.937*
DEN3							0.784*	0.834*	0.928*
DEN4								0.831*	0.811*
FER									0.815*
Ireland									
LISM	0.167	0.081	0.960*	0.912*	0.892*	0.338*	0.065	0.591*	0.528*
BFL1		0.086	0.965*	0.922*	0.903*	0.429*	0.197*	0.633*	0.588*
BFL2			0.963*	0.918*	0.899*	0.414*	0.212*	0.608*	0.575*
CHO1				0.888*	0.924*	0.968*	0.963*	0.969*	0.968*
CHO2					0.976*	0.941*	0.923*	0.928*	0.949*
DEN2						0.929*	0.906*	0.911*	0.939*
DEN3							0.467*	0.609*	0.762*
DEN4								0.626*	0.624*
FER									0.241*
Italy									
LISM	0.226*	0.075	0.808*	0.518*	0.486*	0.314*	0.297*	0.425*	0.317*
BFL1		0.190*	0.832*	0.579*	0.551*	0.418*	0.408*	0.500*	0.421*
BFL2			0.816*	0.539*	0.508*	0.368*	0.361*	0.450*	0.371*
CHO1				0.812*	0.826*	0.839*	0.834*	0.844*	0.839*
CHO2					0.806*	0.697*	0.661*	0.787*	0.698*
DEN2						0.657*	0.616*	0.775*	0.656*
DEN3							0.276*	0.531*	0.622*
DEN4								0.490*	0.317*
FER									0.526*
Japan									
LISM	0.069	0.023	0.780*	0.235*	0.208*	0.035	0.027	0.091	0.034
BFL1		0.066	0.791*	0.294*	0.268*	0.049	0.148	0.148	0.049
BFL2			0.790*	0.278*	0.252*	0.048	0.098	0.133	0.047
CHO1				0.773*	0.781*	0.791*	0.775*	0.801*	0.791*
CHO2					0.464*	0.291*	0.218*	0.376*	0.293*
DEN2						0.264*	0.188*	0.354*	0.266*
DEN3							0.170	0.137	0.017
DEN4								0.060	0.166
FER									0.137

the Netherlands									
LISM	0.090	0.045	0.850*	0.713*	0.696*	0.463*	0.438*	0.596*	0.474*
BFL1		0.042	0.859*	0.733*	0.717*	0.504*	0.482*	0.625*	0.514*
BFL2			0.858*	0.728*	0.713*	0.497*	0.473*	0.619*	0.506*
CHO1				0.754*	0.779*	0.877*	0.876*	0.863*	0.876*
CHO2					0.902*	0.852*	0.838*	0.851*	0.854*
DEN2						0.844*	0.828*	0.835*	0.846*
DEN3							0.489*	0.740*	0.733*
DEN4								0.722*	0.566*
FER									0.733*
Portugal									
LISM	0.208*	0.150	0.907*	0.903*	0.690*	0.092	0.048	0.493*	0.051
BFL1		0.047	0.921*	0.917*	0.736*	0.120	0.159	0.565*	0.222*
BFL2			0.919*	0.916*	0.733*	0.099	0.146	0.552*	0.205*
CHO1				0.074	0.883*	0.912*	0.909*	0.942*	0.901*
CHO2					0.957*	0.908*	0.905*	0.938*	0.896*
DEN2						0.695*	0.684*	0.784*	0.664*
DEN3							0.241*	0.490*	0.162
DEN4								0.470*	0.117
FER									0.440*
Spain									
LISM	0.041	0.088	0.824*	0.602*	0.579*	0.241*	0.194*	0.457*	0.245*
BFL1		0.054	0.825*	0.605*	0.583*	0.243*	0.199*	0.459*	0.248*
BFL2			0.823*	0.600*	0.578*	0.228*	0.176*	0.455*	0.233*
CHO1				0.699*	0.723*	0.840*	0.841*	0.801*	0.840*
CHO2					0.823*	0.718*	0.697*	0.784*	0.719*
DEN2						0.703*	0.680*	0.773*	0.704*
DEN3							0.372*	0.618*	0.483*
DEN4								0.585*	0.383*
FER									0.619*
the United Kingdom									
LISM	0.175*	0.118	0.856*	0.550*	0.535*	0.365*	0.328*	0.505*	0.368*
BFL1		0.058	0.982*	0.554*	0.590*	0.401*	0.407*	0.627*	0.411*
BFL2			0.873*	0.598*	0.585*	0.440*	0.409*	0.559*	0.442*
CHO1				0.798*	0.806*	0.859*	0.863*	0.822*	0.858*
CHO2					0.824*	0.767*	0.724*	0.813*	0.768*
DEN2						0.757*	0.710*	0.807*	0.758*
DEN3							0.393*	0.729*	0.646*
DEN4								0.677*	0.408*
FER									0.729*

the United States									
LISM	0.204*	0.129	0.677*	0.601*	0.334*	0.180*	0.161	0.291*	0.185*
BFL1		0.053	0.726*	0.660*	0.437*	0.307*	0.286*	0.400*	0.313*
BFL2			0.726*	0.654*	0.415*	0.293*	0.284*	0.379*	0.296*
CHO1				0.262*	0.645*	0.714*	0.713*	0.665*	0.713*
CHO2					0.785*	0.754*	0.721*	0.778*	0.758*
DEN2						0.565*	0.465*	0.567*	0.578*
DEN3							0.139	0.521*	0.230*
DEN4								0.399*	0.152
FER									0.541*

Note: The approximate 5% critical value for this two sided test is 0.174 (except for Portugal, where the 5% critical value is equal to 0.195). The values with an asterisk * reject the null hypothesis of equal variances at the 5% level.

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