Seasonal unit root tests for the monthly container transshipment of the port of Hamburg

Peter M. Schulze

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Institut für Statistik und Ökonometrie
Johannes Gutenberg-Universität Mainz
Fachbereich Rechts- und Wirtschafts-
wissenschaften
Haus Recht und Wirtschaft II

D 55099 Mainz

Herausgeber: Univ.-Prof. Dr. P.M. Schulze

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Contents

Zusammenfassung

Die Analyse betrachtet das saisonale Muster des monatlichen Containerumschlags im Hamburger Hafen von 1993 bis 2008.

Dabei werden die Tests von Franses und Beaulieu-Miron zur Prüfung auf multiple Einheitswurzeln und von Canova-Hansen zur Stabilitätsprüfung der saisonalen Schwankungen benutzt.

Es zeigt sich, dass im betrachteten Zeitraum der Containerumschlag nichtstationär bei Frequenz Null ist und keine saisonale Einheitswurzeln vorliegen. Die Daten sind integriert vom Grad Eins (stochastischer Trend), und die saisonalen Variationen lassen sich durch Dummy-Variable modellieren.

Diese Ergebnisse können bei der Analyse und Prognose des Containerumschlags im Hamburger Hafen für Marktteilnehmer, wie z.B. Reedereien oder Hafengesellschaften, nützlich sein.

Summary

This paper investigates the seasonal behaviour of monthly container transshipment data of the port of Hamburg. The test procedures of Franses and Beaulieu-Miron are used to examine the presence of multiple unit roots in the monthly seasonal frequencies. This is followed by the Canova-Hansen procedure for testing the stability of the seasonal patterns.

Evidence suggests that these monthly transshipment data are non-stationary at frequency zero and have no seasonal unit roots. The analysis shows that the process is in the long run integrated of order one and that the seasonal variations can be modelled by dummy variables.

Using the deterministic seasonality found here, further analysis and forecasting of container throughput of the port of Hamburg can be improved for market participants like containership lines.

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* E-Mail: STATOEK@uni-mainz.de

1 Introduction

In economic time series data reported in periods less than a year one major characteristic is - apart from a trend - the presence of seasonal movements.

The seasonal fluctuations can be of stable shape because of natural effects like weather conditions, but they also may be caused by the behaviour of economic agents and may therefore have a variable course. So, the nature of seasonality can either be deterministic or stochastic (Hylleberg et al., 1995, p. 216). A purely deterministic process may be modelled by Holt-Winters' exponential smoothing methods or regression models with seasonal dummy variables. A stochastic process can, in turn, be either stationary over time or a non-stationary integrated process (seasonal unit root process). In the case of stationarity, the underlying seasonal pattern is constant over time and a shock has only temporary effects. In the non-stationary case shocks have permanent effects on seasonal evolution.

These issues have important implications for the modelling of these variables: Treating stochastic seasonality as deterministic, or vice versa, leads to a misspecification of the time series model and has harmful effects on its forecasting performance.

In applications of seasonal unit root tests to monthly data there is no conclusive evidence whether one should treat seasonality as stochastic or deterministic, see for example Beaulieu and Miron (1993), Osborn, Harevi and Birchenhall (1999), Kim (1999), Kim and Moosa (2001). Therefore, the study of seasonal behaviour in the analysed data is important for model evaluation and forecasting.

The objective of this paper is to examine the nature of seasonal behaviour of monthly container transshipment data of the port of Hamburg. Three different tests are used: The procedures of Franses (1991) and Beaulieu and Miron (1993) for testing multiple unit roots at the monthly seasonal frequencies. This is followed by the procedure of Canova and Hansen (1995) to test for the stability of seasonal patterns.

This paper is organized as follows: Section 2 presents empirical observations of the data base. Section 3 introduces the test procedures that will be used for analysis. Section 4 illustrates the empirical application of the tests to the Hamburg container throughput. Finally, Section 5 presents some conclusions.

2 Empirical Observations

Worldwide ninety percent of the carriage of goods is transported by ship, and especially the rapidly increasing container transport is an important indicator for the dynamics of world trade.

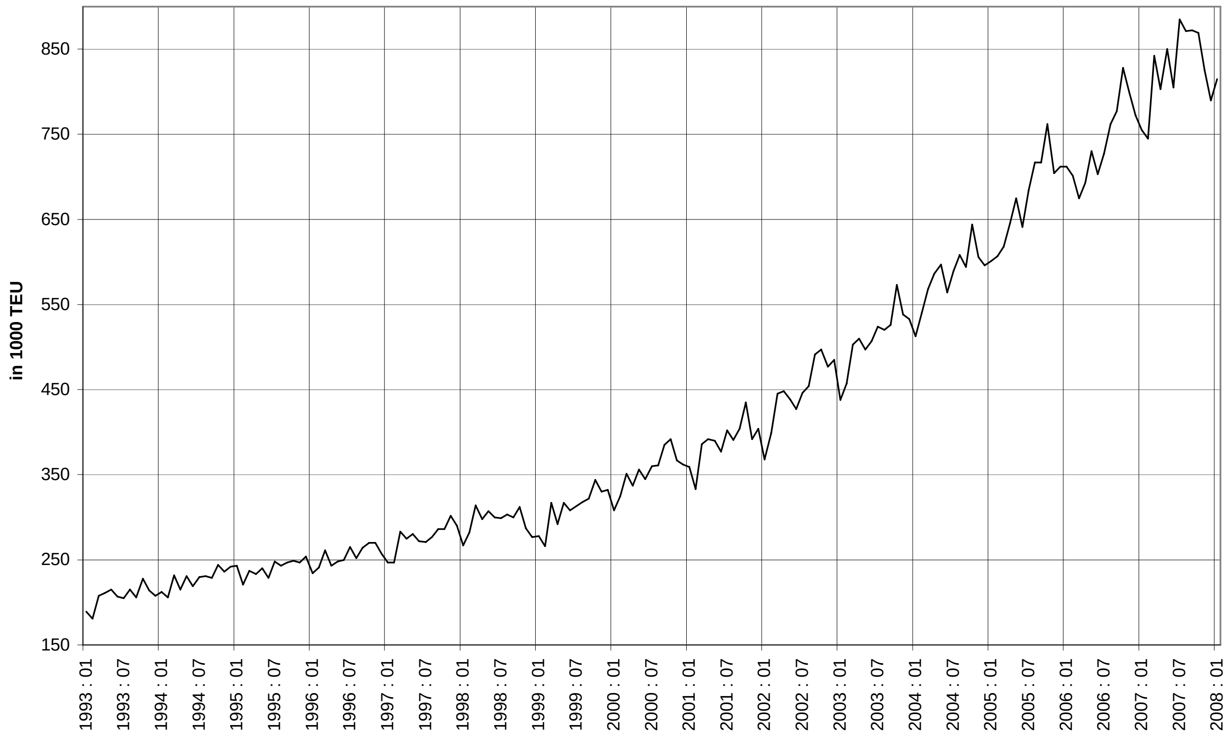
Germany controls about one third of the worlds' container fleet, and the port of Hamburg is No. 9 world wide concerning the container throughput (UN Conference on Trade and Development, 2007, p. 88).

Monthly time series data of the container transshipment of the port of Hamburg to the world are published by the Federal Agency for Merchant Shipping and Hydrography (Bundesamt für Seeschifffahrt und Hydrographie) and, since 2000 by the Federal Statistical Office of Germany (Statistisches Bundesamt), respectively.

In this paper, the number of containers in 1000 TEU (Twenty Foot Equivalent Unit, data transformed to natural logarithms) of the main German harbour, Hamburg, is considered, covering the period from 1993:1 to 2008:1. Figure 1 shows the evolution of the time series and reveals an upward trend and some sort of seasonality.

Figure 1:

Monthly container transshipment of the port of Hamburg (in 1000 TEU, data in logs)



3 Test Procedures

For time series modelling, non-stationary data with stochastic trend and seasonality can be differenced until stationarity is achieved. Using monthly and annual difference operators B should remove trend and seasonality so that

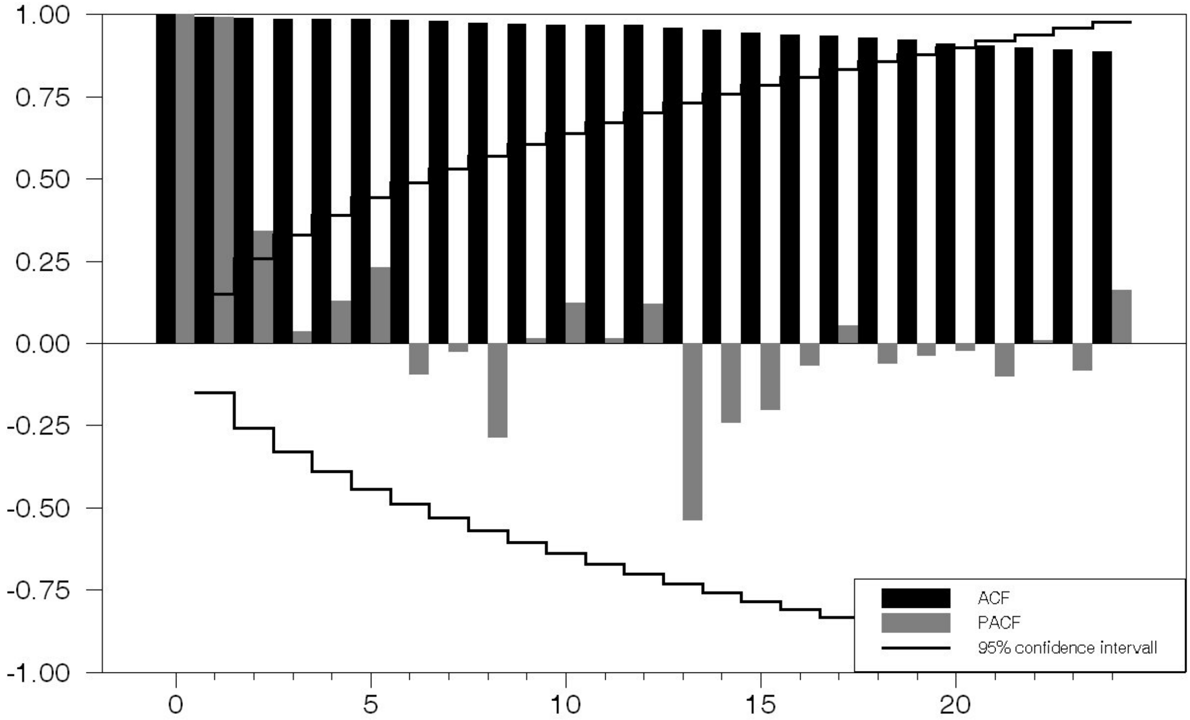
$$x_t = \Delta_1^d \Delta_{12}^D y_t = (1-B)^d \left(1-B^{12}\right)^D y_t \tag{1}$$

is a stationary process.

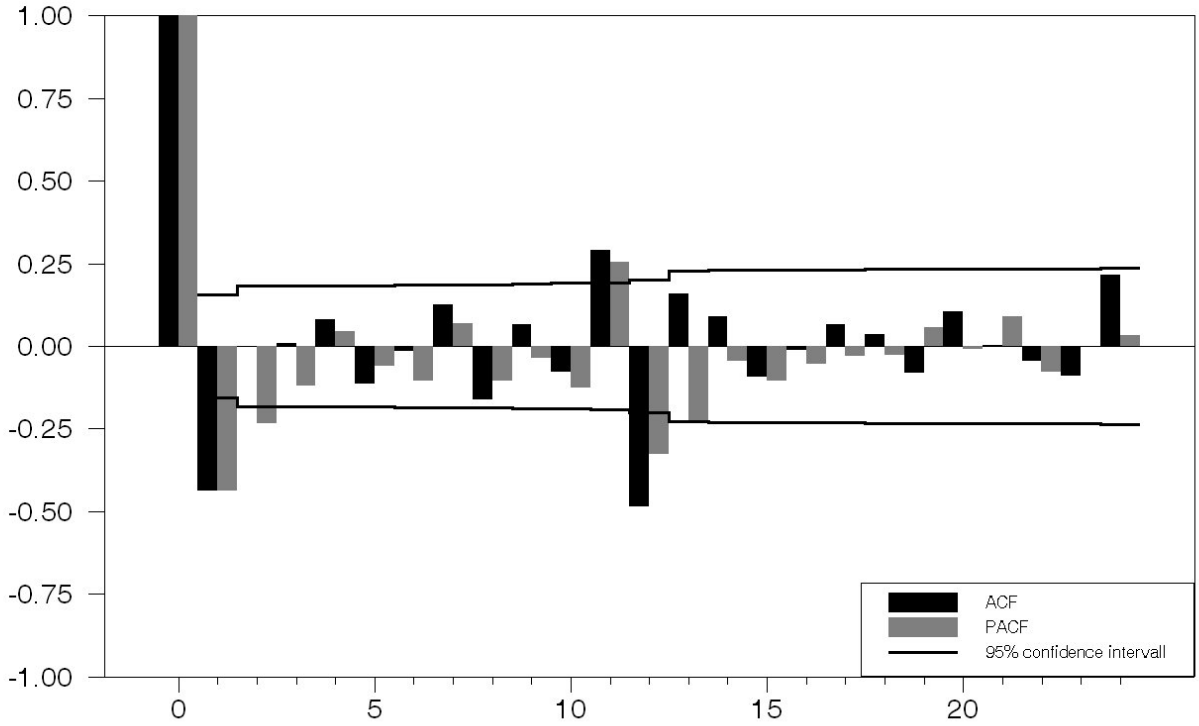
Time series requiring d annual and D monthly differences to achieve stationarity are denoted as I(d, D). Mostly for economic time series, the values of d and D are 0 or 1, respectively. Preliminary data analysis for the time series analysed in this paper showed that $\Delta_1 \Delta_{12} y_t$ has the properties of stationarity because the values of the sample autocorrelation function (ACF) are declining rapidly to zero. [See Figure 2 for the ACF and partial autocorrelation functions (PACF) of the original transshipment data of Hamburg (2a) and of the first and twelfth differences (2b) (in logarithm).] If the filter Δ_1 is not relevant, the test can be applied to the original data.

Figure 2:

2a: ACF and PACF of the original transshipment data of the port of Hamburg (data in logs)



2b: ACF and PACF of $\Delta_1\Delta_{12}$ transshipment data of the port of Hamburg (data in logs)



A test for seasonal unit roots is developed by Hylleberg et al. (1990) for quarterly data and extended by Franses (1991) and Beaulieu and Miron (1993) for monthly data. These procedures propose to test the null hypothesis of unit roots at the zero and monthly seasonal frequencies against the alternative of stationarity.

Franses considers the following model

$$\begin{aligned}\Delta_{12}y_t &= \beta_0 + \beta_1 t + \sum_{i=1}^{11}\gamma_i d_{it} + \pi_1 z_{1,t-1} + \pi_2 z_{2,t-1} \\ &\quad + \pi_3 z_{3,t-1} + \pi_4 z_{3,t-2} + \pi_5 z_{4,t-1} + \pi_6 z_{4,t-2} + \pi_7 z_{5,t-1} \\ &\quad + \pi_8 z_{5,t-2} + \pi_9 z_{6,t-1} + \pi_{10} z_{6,t-2} + \pi_{11} z_{7,t-1} + \pi_{12} z_{7,t-2} + \sum_{j=1}^{p}\delta_j \Delta_{12} y_{t-j} + \varepsilon_{1t}\end{aligned} \tag{2}$$

and estimates the coefficients β, γ, π and δ by applying OLS. In equation (2) β_0 is the constant, t is the deterministic trend and d_i represents seasonal dummies, where $d_{it} = 1$ if t corresponds to month i and 0 otherwise. The z_i's cover non-singular linear transformations of lagged values of y_t (for details see Franses, 1991, p. 202). In empirical implementation of the above equation, the value of p should be determined so that ε_{1t} is a white noise process.

To test for unit roots at 0 and π frequencies, the null hypotheses $H_{k0}: \pi_k = 0$ for $k = 1, 2$ (annual and semi-annual) against the alternative hypotheses $H_{k1}: \pi_k < 0$ are tested using a special t-statistic. For testing unit roots at other frequencies, the following steps are used: (1) To test for the presence of all complex unit roots, a joint F-test is used for testing $H_0: \pi_3 = \pi_4 = \ldots = \pi_{12} = 0$ against $H_1:$ at least one of the π's is not equal to zero; (2) to test for the presence of pairs of complex unit roots, an F-test is used for testing $H_{k0}: \pi_{k-1} = \pi_k = 0$ for $k = 4, 6, 8, 10, 12$ against $H_{k1}:$ at least one π_{k-1} and π_k is not equal to zero; (3) to test for the presence of separate complex unit roots a t-test is used for testing $H_{k0}: \pi_k = 0$ for $k = 3, 4, \ldots, 12$ against $H_{k1}: \pi_k < 0$. The critical values of the above t- and F-statistics are tabulated in Franses (1990, pp. 12-18). The seasonal unit roots are only present when pairs of π's are equal to zero simultaneously (Franses, 1991, p. 202).

Beaulieu and Miron derive the test equation as

$$\Delta_{12} y_t = \beta_0 + \beta_1 t + \sum_{i=1}^{11} \gamma_i d_{it} + \sum_{k=1}^{12} \pi_k z_{k,t-1} + \sum_{j=1}^{p} \delta_j \Delta_{12} y_{t-j} + \varepsilon_{2t} \qquad (3)$$

where $z_{k,t-1}$ are again linear transformations of lagged values of y_t (for details see Beaulieu and Miron, 1993, Appendix A).

In order to test for the presence of unit roots at 0 and π frequencies, the null hypotheses $H_{k0}: \pi_k = 0$ for $k = 1, 2$ are tested against the alternative hypotheses $H_{k1}: \pi_k < 0$ using t-statistics. To test for complex unit roots, the joint null hypotheses $H_{k0}: \pi_{k-1} = \pi_k = 0$ for $k = 4, 6, 8, 10, 12$ against the alternative hypotheses $H_{k1}:$ at least one of the π_{k-1} and π_k is not equal to zero, are tested by F-statistics. Alternatively, the null hypotheses of $H_{k0}: \pi_k = 0$ for $k = 3, 4, \ldots, 12$ are tested against the alternative hypotheses $H_{k1}: \pi_k < 0$ using a t-statistic. (The corresponding critical values are tabulated in Beaulieu and Miron, 1993, pp. 325-326.)

The Canova and Hansen procedure on the other hand tests for the null hypothesis of stability of deterministic seasonal intercepts against the alternative of seasonal unit roots and/or non-constant seasonal intercepts. Canova and Hansen (1995) consider equation (4) in trigonometric representation

$$y_t = \beta_0 + \beta_1 t + S_t + \varepsilon_{3t} \tag{4}$$

with $S_t = \sum_{j=1}^{q} f_{jt}^{'} \delta_j$, where $q = s/2$ ($s = 12$ for monthly data) and, for $j < q$, $f_{jt}^{'} = [\cos(j/q)\pi t, \sin(j/q)\pi t]$, with $j = q$, $f_{qt} = \cos(\pi t)$.

It is required that y_t not have a unit root at the zero frequency, in order to distinguish non-stationarity at the seasonal and at the zero frequency. If a unit root at the zero frequency exists, $\Delta y_t = y_t - y_{t-1}$ is considered as the dependent variable (Silvapulle, 2004, p. 98).

Changing seasonal pattern can lead to a varying coefficient δ over time as a random walk $\delta_t = \delta_{t-1} + u_t$. The autocovariance of u is zero under the null hypothesis of deterministic seasonality and greater than zero under the alternative of stochastic seasonality. To obtain an estimator of the autocovariance u, Canova and Hansen propose the consistent Newey-West procedure (1987). If it is allowed that the number of estimated autocovariances increases as $T \to \infty$ but controls the rate of increase so that a number $m \approx T^{\frac{1}{4}}$. This choice is an empirical matter (Maddala and Kim, 2004, p. 80).

The distribution of the Lagrange multiplier test statistic L, suggested by Canova and Hansen, is not standard and has p degrees of freedom (Canova and Hansen, 1995, p. 241), where p rises with the number of possible unit roots. For example, if deterministic seasonality is tested, $p-1$ seasonal unit roots are allowed under the alternative hypothesis (an overview on the Canova-Hansen test is given in Ghysels and Osborn, 2001, pp. 31-34).

The test regression (4) of Canova-Hansen also allows for explanatory variables, which should typically include one lagged dependent variable y_{t-1}. In contrast, Hylleberg (1995) states that this term should not be included, because y_{t-1} could absorb some of the impact of the biannual unit root.

A basic test for the presence of deterministic seasonality in time series is to regress the monthly data - here the first differences occur - to twelve seasonal dummies

$$\Delta_1 y_t = \sum_{i=1}^{12} \gamma_i D_{it} + \varepsilon_{4t} \tag{5}$$

If there is no seasonality, the F-test for $\gamma_1 = \gamma_2 = \ldots = \gamma_{12}$ should not be rejected.

If the results of the different tests lead to the same conclusion, one can declare whether the seasonal root is stationary with a high(er) reliability. Applying these tests to the data used in this analysis, the nature of seasonality (deterministic, stationary, non-stationary) of the Hamburg container transshipment should be detected.

4 Empirical Application

In this section, the presence of non-stationarity and the stability of monthly seasonal dummies are investigated applying the testing procedures discussed earlier in this paper.

First the Franses test is used to examine the presence of unit roots in monthly Hamburg container transshipment data. Model (2) is estimated with different sets of deterministic regressors: constant (c), seasonal dummies (d) and trend (tr), no constant (nc) etc. The number of lagged values p included to whiten the latent variable ε_{1t} is selected using Ljung-Box statistics.

The corresponding critical values for $\alpha = 0{,}05$ and $T = 120$ are given in Franses, 1990, pp. 12-18, and also in Franses, 1991, p. 203, Franses and Hobijn, 1997, pp. 29-33.

The null hypothesis for this - and the Beaulieu-Miron test - is that the underlying process is stationary (Rodrigues and Osborn, 1999, p. 986). First computations of the Franses and Beaulieu-Miron test with Δ_{12} values in equations (2) and (3) showed that $\pi_1 = 0$, so the presence of root 1 could not be rejected. In this case the Franses and Beaulieu-Miron tests are applied to the doubly differenced data. The PACF (see Figure 2b) suggests also the $\Delta_1\Delta_{12}$ - filtering. Table 1 contains the results of the Franses tests by OLS - estimation of equation (2), and Table 2 shows the results of the Beaulieu-Miron tests, where equation (3) is estimated by OLS.

Table 1:

The Franses test results in the logarithm of the Hamburg container transshipment model (2)

		Deterministic regressors				
		nc, nd, ntr	c, nd, ntr	c, nd, tr	c, d, ntr	c, d, tr
Lags p		2	0	1	0	0
p-values Ljung-Box statistic		0.45	0.20	0.31	0.92	0.96
Frequencies		t-statistics				
0	π_1	–1.21	–4.82***	–4.26***	–4.19***	–4.44***
π	π_2	–3.58***	–3.89***	–3.53**	–4.96***	–4.97***
$\frac{\pi}{2}$	π_3	1.57	2.64	2.17	3.04	2.99
	π_4	–2.90***	–3.00***	–2.55***	–3.56**	–3.53**
$\frac{2\pi}{3}$	π_5	–0.42	–0.42	–0.41	–1.54	–1.57
	π_6	0.40	0.28	0.33	–2.01	–2.04
$\frac{\pi}{3}$	π_7	1.59	2.47	1.88	3.03	2.73
	π_8	–1.47	–2.45***	–1.69*	–3.69**	–3.37**
$\frac{5\pi}{6}$	π_9	0.74	0.90	0.62	1.29	1.29
	π_{10}	–2.09**	–1.67*	–1.86**	–1.01	–1.02
$\frac{\pi}{6}$	π_{11}	1.90	2.30	2.09	3.39	3.29
	π_{12}	–1.22	–1.38	–1.13	–1.89	–1.80
		F-statistics				
$\frac{\pi}{2}$	π_3, π_4	5.59***	8.53***	5.61***	11.86***	11.60***
$\frac{2\pi}{3}$	π_5, π_6	0.61	0.46	0.50	2.04	2.08
$\frac{\pi}{3}$	π_7, π_8	1.30	3.33**	1.80	6.81**	5.67*
$\frac{5\pi}{6}$	π_9, π_{10}	4.53***	3.58**	3.58**	3.01	3.02
$\frac{\pi}{6}$	π_{11}, π_{12}	1.92	2.69*	2.25*	5.88**	5.49*
	$\pi_3, \ldots, \pi_{12}$	20.62***	28.58***	19.67***	68.36***	63.12***

Note: *** Significant at the 1 percent level, ** significant at the 5 percent level, * significant at the 10 percent level.

Table 2:

The Beaulieu-Miron test results in the logarithm of the Hamburg container transshipment model (3)

		Deterministic regressors				
		nc, nd, ntr	c, nd, ntr	c, nd, tr	c, d, ntr	c, d, tr
Lags p		2	1	1	1	1
p-values Ljung-Box statistic		0.32	0.20	0.31	0.92	0.96
Frequencies		t-statistics				
0	π_1	–1.35	–3.90***	–4.33***	–3.59***	–3.95***
π	π_2	–1.78*	–2.28**	–2.19**	–3.05***	–2.93**
$\frac{\pi}{2}$	π_3	–2.45**	–2.09*	–2.14**	–3.34*	–3.38**
	π_4	2.13	2.84	2.86	3.71	3.72
$\frac{2\pi}{3}$	π_5	–3.54***	–3.22***	–3.20***	–3.76**	–3.72**
	π_6	–1.00	–0.86	–0.93	–1.64**	–1.67*
$\frac{\pi}{3}$	π_7	–1.19	–1.14	–1.08	–3.02*	–3.03*
	π_8	1.41	1.82	1.78	2.61	2.53
$\frac{5\pi}{6}$	π_9	–2.51***	–2.45**	–2.41**	–4.43***	–4.32***
	π_{10}	–2.40***	–2.11**	–2.11**	–3.26***	–3.30***
$\frac{\pi}{6}$	π_{11}	–1.45	–1.77*	–1.62*	–3.60**	–3.50**
	π_{12}	0.96	1.26	1.22	1.85	1.74
		F-statistics				
$\frac{\pi}{2}$	π_3, π_4	5.48***	6.22***	6.35***	12.64***	12.80***
$\frac{2\pi}{3}$	π_5, π_6	6.67***	5.53***	5.51***	8.17***	8.09**
$\frac{\pi}{3}$	π_7, π_8	1.82	2.44*	2.30*	8.37***	8.18**
$\frac{5\pi}{6}$	π_9, π_{10}	5.61***	4.85***	4.76***	13.70***	15.24***
$\frac{\pi}{6}$	π_{11}, π_{12}	1.77	2.86*	2.50*	8.00***	9.47***

Note: *, **, *** are explained in Table 1.

The results in Tables 1 and 2 indicate that overall Franses and Beaulieu-Miron F-tests and the t-tests provide some contrasting conclusions about the validity of the Δ_{12}-filter applied to the first-differenced series. However, in broad terms the results are similar: the rejection of the Δ_{12}-component of the $\Delta_1\Delta_{12}$-filter seems reasonable for the series of the Hamburg container transshipment. Both tests concerning equations (2) and (3) reject the hypotheses of seasonal unit roots as overall F-tests as well as t-tests on individual seasonal unit roots.

Table 3 shows the results of the Canova-Hansen tests of deterministic versus non-stationary stochastic seasonality.

Table 3:

The Canova-Hansen test results in the logarithm of the Hamburg container transshipment model (4)

Test statistic						
L_{π}	$L_{\frac{\pi}{2}}$	$L_{\frac{2\pi}{3}}$	$L_{\frac{\pi}{3}}$	$L_{\frac{5\pi}{6}}$	$L_{\frac{\pi}{6}}$	L_{joint}
0.20	0.35	0.70	0.51	0.22	0.54	2.18

Note: The 5 percent critical values of $L_{\frac{j\pi}{q}}$ $(j < q)$, L_{π} and L_{joint} are 0.749, 0.470 and 2.750.

These tests are applied to the series in levels when they are I(0) at the zero frequency or when the series is I(1) to the first differences, therefore Δ_1-values are used here. To estimate the autocovariance of u the Newey and West procedure (1987) is used, applicating Bartlett windows and lag truncation with approximately $m = 4$; $p - 1$ is 1, 2 and 11, alternatively.

All computed values are smaller than the corresponding critical values, so it is evident that the series has no seasonal unit roots, which is consistent with the overall results of the Franses and Beaulieu-Miron tests.

As a general result for the series of the port of Hamburg container transhipment, the three tests reveal no seasonal unit roots. For that the data reject the presence of unit roots at all seasonal frequencies; the original series however shows the existence of a unit root at the zero frequency. This indicates that the time series can be regarded as an I(1,0) process. As a consequence, the first difference of this series may be modelled with seasonal dummies by equation (5). The Δ_1-filter is sufficient to remove non-stationarity. There would be a misspecification by the incorrect assumption of the presence of seasonal unit roots. The $\Delta_1\Delta_{12}$-filter would imply an over-differencing, and this misspecification originates from treating deterministic seasonality incorrectly as being stochastic (Franses, 1991, p. 200).

Table 4 shows the results of OLS estimation with seasonal dummy variables according to equation (5), with one endogenous lag variable to whiten the variable ε_{4t}. Except for November and December dummies - and June, near the 10 percent level - all dummies are highly significant. This supports the previous test results.

Table 4:

The OLS results with deterministic dummy variables in the logarithm of the Hamburg container transshipment model (5)

Variable	Coefficient	p-value t-statistic
January	–0.040	0.000
February	0.027	0.036
March	0.134	0.000
April	0.064	0.000
May	0.062	0.000
June	0.021	0.103
July	0.066	0.000
August	0.067	0.000
September	0.059	0.000
October	0.093	0.000
November	0.015	0.238
December	0.009	0.466
$\Delta_1 y_{t-1}$	–0.449	0.000
p-value Ljung-Box statistic	0.16	

To summarize, for most specifications with deterministic regressors in the Franses and Beaulieu-Miron tests we reject unit roots at most frequencies, and we also fail to reject unit roots for at least one of the seasonal frequencies.

These results are confirmed by the results of the Canova-Hansen test, and the monthly estimation with dummies which are mostly significant.

5 Conclusions

This paper examines the seasonal patterns in monthly container transshipment series of the port of Hamburg. The application of the various tests should lead to nearly equal results because single unit root tests can exhibit poor power (Hylleberg, 1995; Rodrigues and Osborn, 1999). The Franses and the Beaulieu-Miron procedures which test the null hypotheses of the zero and seasonal unit roots against the alternative hypotheses of stationarity were applied. The regressions with $\Delta_1\Delta_{12}$-data mostly lead to the rejection of (seasonal) unit roots. The Canova-Hansen tests confirm these results: there are deterministic seasonal patterns in this monthly dataset. The time series has a stochastic trend and deterministic seasonality. It can be modelled by I(1,0) process with one differencing and dummy variables.

These results can improve further analysis and forecasting of container transshipment of the port of Hamburg and may be useful for market participants like containership lines and the Hamburg port authority.

Data sources

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Autor:

Peter M. Schulze, Univ.-Prof. Dr., Leiter des Instituts für Statistik und Ökonometrie, Johannes Gutenberg-Universität Mainz

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