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An empirical examination of the purchasing-power-parity hypothesis for Denmark 1875-2002

Abstract

The paper reviews the empirical evidence regarding long-run relative purchasing-power-parity (PPP) convergence in the case of Denmark using simple unit-root tests and cointegration tests on new historical time-series indices for the effective krone rate since 1875. The results based on a real effective krone rate index with wholesale prices as deflators support a hypothesis of long-run relative PPP convergence. Half-lives are estimated to around 4 years in the post-1923 period and 2 years in the pre-1914 Classical Gold Standard period. The fastest mean reversions to relative PPP occurred towards the end of the Classical Gold Standard period and towards the end of the Bretton Woods period. The paper does not find support for long-run relative PPP convergence when consumer prices are used as deflators in the real effective krone rate index. This result seems consistent with *a priori* expectations based on theoretical considerations.

Key words: Exchange-rate policy; Danish krone exchange rates; Effective exchange rates; Purchasing-power parity; History of exchange rates.

JEL Classification: E42; F31; N23; N24.

Resumé

I papiret foretages en empirisk undersøgelse af holdbarheden af den relative købekraftsparitetsteori (PPP) på langt sigt for Danmark via simple unit-root tests og cointegrations tests på basis af nye historiske tidsserieindex for effektive kronekurser siden 1875. Resultaterne baseret på en real effektiv kronekurs med engrospriser som deflatorer understøtter en hypotese om relativ PPP konvergens på langt sigt. Halveringstiden for en afvigelse fra relativ PPP estimeres til omkring 4 år i perioden efter 1923 og 2 år i perioden under den Klassiske Guldstandard før 1914. Den hurtigste konvergens mod relativ PPP forekom mod slutningen af den Klassiske Guldstandard periode og mod slutningen af Bretton Woods perioden. I papiret findes ikke støtte for en hypotese om konvergens mod relativ PPP på langt sigt, når der ses på en real effektiv kronekurs med forbrugerpriser som deflatorer. Dette resultat synes at være i overensstemmelse med de a priori forventninger, som man kunne have ud fra teoretiske overvejelser.

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1. Introduction

A tendency towards purchasing-power parity (PPP) – at least in the long run – is a crucial mechanism in many theoretical models on real-exchange-rate determination in open economies.

During most of the period 1875-2002, the Danish economy can be characterised as a small, open economy. On average, both exports and imports of goods have amounted to 25-30 per cent of GDP, cf. chart 1.

In a recent study[2], Taylor tests for long-run relative PPP using data over the period 1870-1996 for 20 countries, including Denmark. Taylor's study is based on a bilateral real krone rate (based on consumer prices) vis-à-vis the U.S. dollar and vis-à-vis a "world" basket constructed as a simple average of a bilateral real krone rate vis-à-vis the 19 other currencies. However, Taylor also notes that ideally one might prefer to use trade-weighted real exchange rates for such an exercise.

This paper examines the empirical evidence regarding long-run relative PPP convergence in the case of Denmark based on new indices for the real effective krone rate[3] covering the period since the introduction of the krone as the Danish currency unit in 1875. In order to study the effect on the results of the choice of deflators, the validity of the PPP hypothesis is evaluated on the basis of real effective krone rate indices with respectively wholesale prices and consumer prices as deflators.

This paper is organised as follows: Section 2 offers a brief summary of the PPP theory followed by a short presentation of the data in section 3. In section 4 the principles behind the basic unit-root approach to assessment of relative PPP is outlined. Using this approach, section 5 explores the empirical evidence regarding a long-run tendency of relative PPP convergence in the case of Denmark during the period 1875-2002. Section 6 introduces briefly a single-equation cointegration test that can further highlight the tendency for long-run relative PPP, whereas section 7 looks at the empirical evidence from such tests in the case of Denmark. Finally, section 8 summarises the main findings of the paper and indicates areas for further research.

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[2] Taylor, A. M., A Century of Purchasing-Power Parity, *The Review of Economics and Statistics*, Vol. 84, 2002, 139-150.

[3] Cf. Abildgren, K., Nominal and real effective krone rate indices for Denmark 1875-2002, *Danmarks Nationalbank Working Paper*, No. 13, April 2004. For a short and fact-oriented chronology of the Danish exchange-rate policy since 1875, cf. Abildgren, K. A chronology of Denmark's exchange-rate policy 1875-2003, *Danmarks Nationalbank Working Paper*, No. 12, April 2004.

2. The Purchasing-Power-Parity (PPP) theory[4]

The idea behind the PPP theory can be traced several centuries back. In "modern times" the origin of studies on PPP is primarily associated with the works of the Swedish economist Gustav Cassel around World War I.[5]

The basic version of the PPP theory assumes a two-country world with homogeneous tradable products, competitive market structures, full information, flexible prices, no transportation costs, no taxes and free trade. Furthermore, it is assumed that the exchange rate is basically determined by demand for cross-border current-account transactions. Here the nominal bilateral exchange rate (defined as the amount of foreign currency per unit of domestic currency) must be equal to the ratio between the aggregated absolute price levels in the two countries (the foreign price level relative to the domestic price level). The argument is the "law of one price": Two identical goods in two different countries should have the same price measured in a common currency. If not, goods-market arbitrage will occur, leading to adjustments in prices and/or the nominal exchange rate. If the law of one price holds true for every commodity, then the relationship must hold for aggregated absolute price levels as well – provided that the same weights are used in the construction of the aggregated absolute price level data. This is termed the "absolute" version (or strong form) of the PPP. The absolute PPP implies that the real exchange rate (defined as the nominal exchange rate multiplied by the ratio between the price level for domestic goods and the price level for foreign goods) will be equal to one on a continuous basis.

If one uses price indices instead of aggregated absolute price levels, the weights and base year in the price indices of the two countries must be identical in order to study the absolute version of PPP. This will normally not be the case. Focus in empirical studies is therefore often on the relative version (or weak form) of the PPP theory. The relative PPP hypothesis states that the rate of depreciation of the nominal bilateral exchange rate between two countries will match the inflation differential between the two countries. This implies that the real exchange rate will be equal to a constant. Furthermore, when studying the relative PPP in

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[4] The research on the Purchasing-Power-Parity theory is very comprehensive. For surveys of the theoretical and empirical literature on PPP, its historical origin and econometric approaches to empirical testing of the theory, cf. e.g. Dornbusch, R., Purchasing power theory, in: Eatwell, J., Milgate, M. & Newman, P. (eds.), *The New Palgrave. A Dictionary of Economics*, Volume 3 K to P, London: Macmillan 1987; Isard, P., *Exchange Rate Economics*, Cambridge: Cambridge University Press 1995; Rogoff, K., The Purchasing Power Parity Puzzle, *Journal of Economic Literature*, Vol. XXXIV, 1996, 647-668; and Sarno, L. & Taylor, M. P., *The economics of exchange rates*, Cambridge: Cambridge University Press 2002.

[5] Cf. Cassel, G., Abnormal Deviations in International Exchanges, *Economic Journal*, Vol. 28, 1918, 413-415. In this article Cassel wrote: "According to the theory of international exchanges which I have tried to develop during the course of the war, the rate of exchange between two countries is primarily determined by the quotient between the internal purchasing power against goods of the money in each country... At every moment the real parity between two countries is represented by this quotient between the purchasing power of the money in the one country and the other. I propose to call this parity 'the purchasing power parity'. As long as anything like free movement of merchandise and a somewhat comprehensive trade between the two countries takes place, the actual rate of exchange cannot deviate very much from this purchasing power parity".

a multi-country environment one can expand the relative PPP hypothesis to cover some kind of real effective exchange rate index.

A broad range of empirical studies seem to indicate that the PPP hypothesis does not hold in the short run and definitely not continuously. There can be many explanations for deviations from PPP: Non-traded goods, price and wage rigidities, product differentiation, transportation costs and insurance costs related to international trade of goods, transportation time, transaction costs in international currency arbitrage, tariffs and non-price trade barriers, index number problems, speculative bubbles, "pricing to market", etc. Furthermore, at least in the short run, exchange rates may be significantly affected by demand for currency as an asset (capital flows as a result of interest-rate differentials between countries) rather than demand for currency for current-account transactions. It has also been argued that for some countries a deterministic trend in the real exchange rate could be expected for longer periods, if one studies price data that includes non-traded goods and services for a country that goes through a catching-up process relative to it's trading partners.[6] Another reason for a temporary deterministic trend in a real effective exchange rate – estimated on the basis of price indices that includes non-traded goods and services – could be a faster and larger build-up of the public sector in a country relative to its trading partners. This could increase the prices and wages in the non-tradable goods and service sector at home relative to abroad, if one assumes that government spending contains a larger element of non-tradable goods and services relative to private consumption.

Despite the mixed empirical findings, many still consider the PPP hypothesis relevant as a long-run fundamental tendency, and especially in the last decade or so there has been a revival in the literature on testing the validity of PPP as a long-run parity condition.[7]

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[6] I.e. the so-called Balassa-Samuelson effect. The argument is the following: Assume that the nominal exchange rate is determined by PPP for tradable goods, and that productivity in the tradable goods sector initially is lower in the home country than abroad whereas productivity in the non-tradable goods sectors are the same at home and abroad. Under the assumption of full mobility of labour between sectors within a country, but not between countries, the wage level is initially highest abroad due to the higher productivity level in the tradable goods sector. This also means that the level of consumer prices (which includes both tradable and non-tradable goods) initially is highest abroad due to the higher price level for non-tradable goods abroad. When the home country catches up through productivity increases in its tradable goods sector, the domestic wage level will increase relative to abroad leading to a relative increase in the prices of non-tradable goods at home relative to foreign goods. If one measures the real effective exchange rate via consumer prices (including both tradable and non-tradable goods), a trend increase in the home country real effective exchange rate should be expected.

[7] Cf.. Abuaf, N. & Jorion, P., Purchasing Power Parity in the Long Run, *Journal of Finance*, Vol. XLV, 1990, 157-174; Lothian, J. R., A Century Plus of Yen Exchange Rate Behavior, *Japan and the World Economy*, Vol. 2, 1990, 47-70; Diebold, F. X., Husted, S. & Rush, M., Real Exchange Rates under the Gold Standard, *Journal of Political Economy*, Vol. 99, 1991, 1252-1271; Froot, K. A. & Rogoff, K., Perspectives on PPP and Long-Run Real Exchange Rates, *NBER Working Paper*, No. 4952, December 1994; Engel, C., Long-Run PPP May Not Hold After All, *NBER Working Paper*, No. 5646, July 1996; Taylor, A. M., International Capital Mobility in History: Purchasing-Power Parity in the Long Run, *NBER Working Paper*, No. 5742, September 1996; Lothian, J. R. & Taylor, M. P., Real Exchange Rate Behavior: The Recent Float from the Perspective of the Past Two Centuries, *Journal of Political Economy*, Vol. 104, 1996, 488-509; Engel, C. & Kim, C.J., The Long-Run U.S./U.K. Real Exchange Rate, *Journal of Money, Credit, and Banking*, Vol. 31, 1999, 335-356; Cuddington, J. T. & Liang, H., Purchasing power parity over two centuries?, *Journal of International Money and Finance*, Vol. 19, 2000, 753-757; Lothian, J. R. & Taylor, M. P., Purchasing power parity over two centuries: strengthening the case for real

Furthermore, empirical studies on deviations from long-run PPP and the speed of mean reversion in different periods with different exchange-rate regimes, different degrees of cross-border mobility in goods and financial assets, variations in the rate of real or monetary shocks to the economy, etc. can in themselves be of interest from a pure historical perspective.

3. The data set

The data set behind this study consists of annual average observations of the following variables for Denmark 1875-2002 (all indices with 1980=100)[8]:

NEKR	The nominal effective krone rate index. An increase in the index reflects an overall nominal appreciation of the krone vis-à-vis the currencies of Denmark's 15 main trading partners.
$CPI^{Denmark}$	Consumer price index for Denmark.
CPI^{Abroad}	Consumer price index abroad (geometrically weighted average for Denmark's 15 main trading partners).
REKRCPI	The real effective krone rate index based on consumer prices, i.e.: $REKRCPI = NEKR * CPI^{Denmark} / CPI^{Abroad}$. An increase in the index reflects an overall real appreciation of the krone vis-à-vis the currencies of Denmark's 15 main trading partners.
$WPI^{Denmark}$	Wholesale price index for Denmark.
WPI^{Abroad}	Wholesale price index abroad (geometrically weighted average for Denmark's 15 main trading partners).
REKRWPI	The real effective krone rate index based on wholesale prices, i.e.: $REKRWPI = NEKR * WPI^{Denmark} / WPI^{Abroad}$. An increase in the index reflects an overall real appreciation of the krone vis-à-vis the currencies of Denmark's 15 main trading partners.

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exchange rate stability. A reply to Cuddington and Liang, *Journal of International Money and Finance*, Vol. 19, 2000, 759-764; Froot, K. A., Kim, M. & Rogoff, K., The Law of One Price Over 700 Years, *IMF Working Paper*, No. 174, 2001; Cecchetti, S. G., Mark, N. C. & Sonora, R. J., Price Index Convergence Among United States Cities, *International Economic Review*, Vol. 43, 2002, 1081-1099; Lothian, J. R. & McCarthy, C. H., *Real Exchange Rate Behaviour Under Fixed and Floating Exchange Rate Regimes*, *The Manchester School*, Vol. 70, 2002, 229-245; Hegewood, N. D. & Papell, D. H., Purchasing Power Parity under the Gold Standard, *Southern Economic Journal*, Vol. 69, 2002, 72-91; Taylor, A. M., A Century of Purchasing-Power Parity, *The Review of Economics and Statistics*, Vol. 84, 2002, 139-150; Gadea, M. D., Sabaté, M. & Serrano, J. M., PPP and structural breaks. The peseta-sterling rate, 50 years of a floating regime, *Journal of International Money and Finance*, Vol. 22, 2003, 613-527; Chen, L. L. & Devereux, J., What can US city price data tell us about purchasing power parity, *Journal of International Money and Finance*, Vol. 22, 2003, 213-222; Calderón, C. & Ducan, R., Purchasing Power Parity in an Emerging Market Economy: A Long-Span Study for Chile, *Estudios de Economia*, Vol. 30, 2003, 102-132; and Murray, C. J. & Papell, D. H., The Purchasing Power Parity Puzzle is Worse Than You Think, *University of Houston Working Paper*, January 2004.

[8] For a detailed description of the sources and methods used to construct the data series as well as a full listing of data, cf. Abildgren, K., Nominal and real effective krone rate indices for Denmark 1875-2002, *Danmarks Nationalbank Working Paper*, No. 13, April 2004.

The nominal effective krone rate index is constructed as a geometrically weighted chain index with current trade weights based on Denmark's foreign trade in goods[9] with 15 of its largest trading partners (Germany, the U.K., Ireland, Sweden, Norway, the U.S.A., France, Spain, Italy, Portugal, Belgium-Luxembourg, the Netherlands, Japan, Finland, and Switzerland). During each year in the period 1875-2001 these 15 countries accounted for at least 78 per cent of Denmark's total foreign trade in goods. The weighted price indices for Denmark's trading partners (and thus implicitly the real effective krone rates) have been compiled following the same methodology.

Even though the methodology used to compile historical CPI data (or private consumption deflators) are by no means harmonised across countries, they are probably among the best historical statistics available due to the intensive research in historical cost-of-living conditions and national-income accounting. There are, however, several problems related to the use of consumer price indices as deflators in the real effective exchange rate index if the aim is to assess the validity of the purchasing-power-parity hypothesis. Firstly, the CPI includes a substantial amount of goods and services that are not traded internationally, and secondly the development in the CPI is influenced by changes in indirect taxes and subsidies.

The coverage of historical wholesale price indices[10] probably differs even more across countries than that of consumer price indices. However, they are conceptually more interesting in relation to studies of the purchasing-power-parity hypothesis since they normally include relatively few non-traded goods. Furthermore, wholesale price indices normally also exclude most indirect taxes (apart from custom duties) and subsidies.

In this paper the validity of the PPP hypothesis is evaluated on the basis of real effective krone rate indices with respectively wholesale prices and consumer prices as deflators, in order to study the effect on the results of the choice of deflators.

Chart 2 shows the development in the real effective krone rate index based on consumer prices as well as on wholesale prices for the whole period 1875-2002. The two indices show a marked drop followed by a sharp increase around the period with hyperinflation in Germany at the beginning of the 1920s. The reason is that German inflation began to rise before the German exchange rate depreciated (at least in these series based on annual averages). The long-term developments in the two real effective krone rate indices are roughly parallel. However, for the post-1950 period the index based on consumer prices shows the largest appreciation. The reason is that the ratio between consumer prices and wholesale prices for this period has increased more in Denmark than abroad.

[9] I.e. sum of imports and exports of goods.
[10] I.e. indices for domestic producer prices and import prices excluding indirect taxes and subsidies.

Chart 3 shows the development in the nominal effective krone rate and the price development abroad relative to Denmark in the pre-1914 period, while Chart 4 covers the post-1923 period. In the pre-1914 period, where Denmark and all its main trading partners were on the Gold Standard, the variation in both the nominal effective krone rate and the relative price development was very limited, implying only modest fluctuations in the real effective krone rate indices, cf. also chart 2. The post-1923 period has shown much larger fluctuations in both the nominal effective krone rate and the relative price development, and the real effective krone rate.

4. Unit-root tests of PPP - methodology

A rough assessment of the validity of the relative PPP hypothesis for Denmark can be made by a range of unit-root tests for stationarity of the real effective krone rate index (REKR). The basic idea is to test whether the behaviour of the REKR is indistinguishable from a random walk[11] (a non-stationary process), or whether there is a tendency for mean reversion towards a constant long-run level.

The alternative hypothesis of the unit-root test in its basic form can be formulated as equation [1], where $b_1<1$, b_0 is a constant, and the error term (e) is assumed to be independently normally distributed with a zero mean and a constant variance:

$$[1]\ REKR_t = b_0 + b_1 \cdot REKR_{t-1} + e_t$$

Under the alternative hypothesis, the REKR follows a first-order autoregressive process (AR(1)) with non-zero mean, i.e. the REKR is a stationary process which is consistent with long-run PPP convergence. Equation [1] can be rewritten as [2]:

[11] Or more generally an autoregressive process with a unit root. A simple argument for random walk behaviour in the real exchange rate has e.g. been put forward by the efficient market (or ex ante) view of PPP. The starting point of this asset price approach to exchange rate determination is the Uncovered Interest-rate Parity (UIP). The UIP states that the expected depreciation of a currency is equal to the spread between the domestic and foreign interest rate. If one assumes that real interest rates are equalised between countries – due to international arbitrage in capital goods – then the expected rate of depreciation of a currency is equal to the difference between the expected inflation home and abroad. Furthermore, if one assume rational expectations the actual nominal exchange rate, the domestic inflation and the foreign inflation will all be equal to their expected values apart from white noise. This implies that the real exchange rate will follow a random walk, cf. e.g. page 125-126 in Hallwood, C. P. & MacDonald, R., *International Money and Finance*, 3rd Edition, Oxford: Blackwell 2000.

$$[2]\ REKR_t = REKR_{t-1} + (1 - b_1)\cdot\left(\frac{b_0}{1 - b_1} - REKR_{t-1}\right) + e_t$$

$$= \frac{b_0}{1 - b_1} + b_1 \cdot \left(REKR_{t-1} - \frac{b_0}{1 - b_1}\right) + e_t$$

The alternative hypothesis thus implies that the REKR evolves around a constant long-run level given by $b_0/(1-b_1)$. If the REKR in year t-1 is below (above) the long-run level there will be a tendency for the REKR in year t to appreciate (depreciate). The parameter b_1 determines the speed of mean reversion, since $(1 - b_1)$ per cent of the absolute deviation from the long-run level is expected to close each year.

The number of years before one-half of a deviation from the long-run level of the real effective exchange rate is extinguished (the so-called "half-life") can be found as [3]:

$$[3]\ \text{Half} - \text{life in } [1] = \frac{\ln(0.5)}{\ln(b_1)}$$

where ln denotes the natural logarithmic function.

The null hypothesis of the test is that $b_1=1$, i.e. that the REKR follows a random walk (with drift if the constant b_0 differs from zero). Under the null hypothesis, the REKR is a non-stationary process, which is inconsistent with the existence of long-run PPP convergence.

Under the alternative hypothesis in the above-mentioned basic version of the unit-root test, the REKR evolves around a constant long-run level. This rules out the presence of a deterministic trend in the real effective exchange rate. A deterministic trend could be formalised in a unit-root test where the alternative hypothesis in its basic version is given by equation [4]:

$$[4]\ REKR_t = b_0 + b_1 \cdot REKR_{t-1} + d \cdot t + e_t$$

This alternative hypothesis, where $b_1<1$, thus implies that the REKR evolves around a deterministic time trend (i.e. a trend-stationary process). The forces of the relative PPP ensure a long-run mean reversion towards the trend. The null hypothesis of the test is that $b_1=1$, i.e. that the REKR follows a random walk (with drift if the constant b_0 differs from zero) around a deterministic trend.

A test of the null hypothesis ($b_1=1$) based on [1] can be made via the basic Dickey-Fuller test (DF test) for the presence of a unit root (without a trend included). The test is based on the auxiliary regression in [5]:

$$[5]\ D\_REKR_t = b_0 + (b_1 - 1)\cdot REKR_{t-1} + e_t$$

where D_ denotes the first difference operator (i.e. $D\_REKR_t = REKR_t - REKR_{t-1}$). The null hypothesis ($b_1$=1) corresponds to $g = b_1$-1 = 0, and the test-statistic is the usual t value for g. However, under the null hypothesis the distribution of this statistic does not follow the usual Student's t distribution, but a special distribution with larger (absolute) critical values.

An appropriate number (p) of lags of D_REKR_t may have to be added on the right hand side of [5] in order to remove any autocorrelation in the residuals. This gives the Augmented Dickey Fuller test (ADF(p) test). The ADF(1) test is e.g. based on the auxiliary regression in [6]:

$$[6]\ D\_REKR_t = b_0 + \left(\sum_{j=1}^{2} b_j - 1\right)\cdot REKR_{t-1} - b_2 \cdot D\_REKR_{t-1} + e_t$$

whereas the ADF(p) test is based on the auxiliary regression in [7]:

$$[7]\ D\_REKR_t = b_0 + \left(\sum_{j=1}^{p+1} b_j - 1\right)\cdot REKR_{t-1} + \sum_{j=1}^{p} b_j^* \cdot D\_REKR_{t-j} + e_t$$

where b^*_j are functions of $b_2,...,b_{p+1}$.The null hypothesis of non-stationarity of the ADF(p) test is that $g = \Sigma b_j - 1 = 0$ and the test-statistic is the usual t value for g. However - as it was the case in the DF-test - the distribution of this statistic is non-standard.

With no significant lags, the ADF(0) test is identical to the DF test. With p significant lags in an ADF(p) test, the REKR follows an (p+1)-order autoregressive path under the alternative hypothesis ($\Sigma b_j < 1$), cf. [8]:

$$[8]\ REKR_t = b_0 + \sum_{j=1}^{p+1} b_j \cdot REKR_{t-j} + e_t$$

[8] can be rewritten as [9]:

$$[9]\ REKR_t = \frac{b_0}{1 - \sum_{j=1}^{p+1} b_j} + \sum_{j=1}^{p+1} \left(b_j \cdot \left[REKR_{t-j} - \frac{b_0}{1 - \sum_{j=1}^{p+1} b_j} \right] \right) + e_t$$

The alternative hypothesis thus implies that the REKR evolves around a constant long-run level given by $b_0/(1-\Sigma b_j)$. A commonly used approximate formula for the number of years before one half of a shock to the real effective exchange rate is extinguished (the half-life) is given by [10][12]:

$$[10]\ \text{Half} - \text{life in } [8] = \frac{\ln(0.5)}{\ln\left(\sum_{j=1}^{p+1} b_j \right)}$$

The ADF test has become the "standard" test for stationarity in the literature. However, it should be noted that the power of ADF tests is not very strong. It can therefore be difficult to reject the null hypothesis of non-stationarity even when it is false, especially if the stationary alternative has a sum of autoregressive parameters (Σb_j) close to one (i.e. in cases where convergence towards PPP is slow).[13] It has been demonstrated that ADF tests have higher power for data sets covering long time spans than for data sets covering short time spans.[14] Finally, it should be mentioned that the failure to reject a null hypothesis of non-stationarity could be the result of structural breaks caused by e.g. large shocks to the real economy rather than lack of relative PPP convergence *per se*.[15]

Even when the REKR is stationary, Ordinary Least Squares (OLS) estimates of the parameters to the lagged dependent variables in [1] and [8] will be downward biased in finite

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[12] Half-lives can only be considered as a simple "summary measure" characterising the process of mean reversion. A more complete picture of the adjustment dynamics of the real effective exchange rate may be achieved by the use of impulse response analysis. For a discussion of half-life measures, impulse responses and the construction of confidence intervals related to half-lives and impulse responses, cf. e.g. Cheung, Y.-W. & Lai, K. S., On the purchasing power parity puzzle, *Journal of International Economics*, Vol. 52, 2000, 321-330; and Rossi, B., Confidence intervals for half-life deviations from Purchasing Power Parity, *Duke Economics Working Paper*, No. 02-08, 2002.

[13] In the ADF test, non-stationarity is the null hypothesis. A null hypothesis is always accepted unless there is strong evidence against it. One the other hand, if the null hypothesis of non-stationarity in an ADF test is rejected, there is a strong case for stationarity. Alternative tests with stationarity as the null hypothesis have been developed, cf. e.g. chapter 7 in Patterson, K., *An Introduction to Applied Econometrics. A Time Series Approach*, New York: Palgrave 2000. However, Augmented Dickey-Fuller tests still serve as the starting point or "benchmark" in the empirical literature on PPP.

[14] For a detailed treatment of the various types of unit-root tests, cf. e.g. Hamilton, J. D., *Time Series Analysis*, Princeton: Princeton University Press 1994; Mills, T. C., *The Econometric Modelling of Financial Time Series*, Second edition, Cambridge: Cambridge University Press 1999; and Patterson, K., *An Introduction to Applied Econometrics. A Time Series Approach*, New York: Palgrave 2000.

samples. A downward bias in the parameters implies that point estimates for half-lives will be too low when calculated from the OLS estimates.[16] In the case of the AR(1)-model for REKR, a bias-adjusted half-life may be calculated from the OLS estimate as [11][17]:

$$[11]\ \text{Bias adjusted OLS estimate for half}-\text{life in AR(1) model for REKR} = \frac{\ln(0.5)}{\ln\left(\frac{b_1 \cdot N}{N-3} + \frac{1}{N-3}\right)}$$

where N denotes the number of observations. In the case of an AR(2)-model for the REKR, a bias-adjusted approximate half-life may be calculated from the OLS estimates as [12]:

$$[12]\ \text{Bias adjusted OLS estimate for half}-\text{life in AR(2) model for REKR} = \frac{\ln(0.5)}{\ln\left(\frac{b_1 \cdot N}{N-1} + \frac{1}{N-1} + \left(\frac{1}{N-1}+1\right)\cdot\left(\frac{b_2 \cdot N}{N-4} + \frac{2}{N-4}\right)\right)}$$

5. Unit-root tests of PPP - empirical findings

Table 1.a-1.b show the results of a range of ADF tests on respectively the real effective krone rate index based on wholesale prices (REKRWPI) and the real effective krone rate index based on consumer prices (REKRCPI) for Denmark 1875-2002. To avoid the possibility of bias in the test results due to outliers around the German hyperinflation, separate test statistics for two subperiods (1875-1913 and 1924-2002) are also reported.[18]

The results support long-run relative PPP convergence in case of the real effective krone rate index based on wholesale prices, cf. table 1.a. Non-stationarity is rejected by the ADF test (without a trend) at a 5-per-cent significance level for both the total period 1875-2002 and

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[15] For a treatment of structural breaks and unit-root tests, cf. e.g. chapter 3 in Harris, R. & Sollis, R., *Applied Time Series Modelling and Forecasting*, West Sussex: Wiley 2003.

[16] Cf. e.g. Cashin, P. & McDermott, C. J., An Unbiased Appraisal of Purchasing Power Parity, *IMF Staff Papers*, Vol. 50, 2003, 321-351. However, other factors (e.g. application of low frequency data, linear model specification and the use of aggregated price indices) may imply that conventionally estimated half-lives tend to be too high, cf. e.g. Taylor, A. M., Potential pitfalls for the purchasing-power-parity puzzle? Sampling and specification biases in mean-reversion tests of the law of one price, *Econometrica*, Vol. 69, 2001, 473-498; and Imbs, J., Mumtaz, H., Ravn, M. & Rey, H., PPP strikes back: Aggregation and the real exchange rate, *CEPR Discussion Paper*, No. 3715, January 2003.

[17] Cf. e.g. page 577 in Patterson, K., *An Introduction to Applied Econometrics. A Time Series Approach*, New York: Palgrave 2000.

[18] All test results in this paper have been obtained by the use of PcGive except for the 10-per-cent critical values for the ADF tests. The critical values for the latter statistics are calculated from the MacKinnon response surface table reproduced on page 372 in Patterson, K., *An Introduction to Applied Econometrics. A Time Series Approach*,

for the post-1923 period. However, it is hardly relevant to consider the period 1875-2002 as a whole due to the outliers around the German hyperinflation. For the pre-1914 period non-stationarity cannot be rejected at a 5-per-cent level, which should be viewed in the light of the relatively short sample period (1875-1913). At a 10-per-cent significance level non-stationarity is rejected.

The diagnostics show no trace of autocorrelation in the residuals, but there is evidence of heteroscedasticity and non-normality due to some outliers. However, taking the results from the estimations without a trend at face value they show an average half-life of 4.2 years (bias adjusted 5.3 years) in the post-1923 period. In the pre-1914 period, where Denmark and most of its trading partners followed the Gold Standard, the average speed of adjustment towards the long-run equilibrium is about twice as fast (half-life is 1.9 years – bias adjusted 2.8 years). The underlying univariate autoregressive models explain around 50 per cent of the linear variation in the real effective exchange rate in the pre-1914 period and around 85 per cent in the post-1923 period.

In chart 5 and 6 the half-lives for the REKRWPI are explored further via 20-year rolling-window regressions of the AR-models from table 1.a. During the last 10 years of the Gold Standard period, half-lives reached an average level of only around 0.5 years, compared to an average of 2.4 years in the period 1895-1903. Immediately after World War II, half-lives are estimated to around 3 years. Towards the end of the Bretton Woods period in the late 1960s, half-lives had once again reached a low level around 1 year. The breakdown of the Bretton Woods system caused a marked slowdown of the speed of PPP convergence with half-lives of more than 10 years. In 2002, half-lives had decreased to a level of around 3 years.

The euro area – towards which the current Danish fixed-exchange-rate policy is oriented – accounted for 56 per cent of the weighting basis of the REKRWPI in 2002. Even though this is a substantial part of the Danish foreign trade, it is less than the share of the countries that like Denmark followed the Gold Standard in the pre-1914 period, or the share of the countries that like Denmark participated in the Bretton Woods system at the end of the 1960s. The above results thus seem to indicate that the fastest mean reversion towards PPP has occurred in those periods where Denmark pursued a fixed-exchange-rate policy vis-à-vis the majority of its trading partners and thereby had the lowest volatility in the nominal effective krone rate.

In the case of the real effective krone rate based on consumer prices, non-stationarity cannot be rejected in any period when no trend is included in the unit-root tests, cf. table 1.b. The lack of support for relative PPP convergence when consumer prices rather than wholesale prices are used as deflators seems consistent with *a priori* expectations based on theoretical

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New York: Palgrave 2000. The numbers of lags included in the ADF tests have been chosen so that no autocorrelation was evident in the residuals from the auxiliary regression.

considerations due to the fact that consumer prices include non-traded goods and indirect taxes. However, the results of the test where a trend is included suggest that the REKRCPI may be trend stationary. The positive trend in the post-1923 period could partly be the result of a faster and larger increase in indirect taxes in Denmark than abroad during this period. A "catching up" hypothesis hardly seems relevant for Denmark for the period, but the average annual growth in real GDP per capita has been slightly higher in Denmark than abroad in the post-1913 period, cf. table 2. For the period 1875-1913 the autoregressive parameter (b_1) is not significant and the trend is estimated to be negative – despite faster economic growth in Denmark than abroad – so further analysis seems required if the presence of such a trend should have a plausible explanation.

6. Single-equation cointegration tests of PPP – methodology

An alternative way to make a rough assessment of the validity of the relative PPP hypothesis for Denmark is to use the Engle-Granger single-equation cointegration test.[19]

The relative PPP hypothesis implies that the real effective krone rate (REKR) will be equal to a constant (K), i.e.:

$$[13]\ REKR_t = \frac{NEKR_t \cdot PI_t^{Denmark}}{PI_t^{Abroad}} = \frac{NEKR_t}{\frac{PI_t^{Abroad}}{PI_t^{Denmark}}} = \frac{NEKR_t}{RELPI_t} = K$$

where NEKR is a nominal effective krone rate index and RELPI is the ratio between the price index abroad and in Denmark ($PI^{Abroad}/PI^{Denmark}$).

Using lower case letters to denote natural logarithms of the corresponding upper case letter variables and adding an error term (e), which is assumed to be independently normally distributed with a zero mean and a constant variance, [13] can be written as [14]:

$$[14]\ nekr_t - relpi_t = k + e_t$$

If nekr and relpi are both integrated of first order (I(1)), they are cointegrated if the natural logarithm to the real effective krone rate (rekr = nekr – relpi) is stationary. This can be evaluated via ADF tests on nekr, relpi and rekr. If nekr and relpi are I(1) and the rekr is stationary, the results support a hypothesis of long-run relative PPP convergence, and the

cointegrating relation implied by [14] can be viewed as the long-term relationship between nekr and relpi. If nekr and relpi both are stationary, then the rekr is also stationary. This also gives support for long-run relative PPP. If stationarity of rekr is rejected, there is no support for relative PPP.

7. Single-equation cointegration tests of PPP - empirical findings

In this section the results from a number of single-equation cointegration tests are reviewed in order to explore the robustness of the results from the unit-root tests in section 5. The findings from the tests related to equation [14] are summarised in table 3.a-3.b.

For the index based on wholesale prices, the results confirm the support for long-run PPP convergence for the two subperiods (1875-1913 and 1924-2002) by a rejection of the non-stationarity hypothesis for rekrwpi. In both subperiods this is a result of both nekr and relwpi being stationary. For the period 1875-2002 as a whole, a unit-root hypothesis for nekr and relwpi in levels could not be rejected while the unit-root hypothesis was rejected for the first differences of the series. This indicates that the two variables are I(1), and the stationarity of rekrwpi suggests that nekr and relwpi are cointegrated. Thus also for the period 1875-2002 as a whole the results are consistent with long-run relative PPP convergence. However, as in section 5 it is hardly relevant to consider the period 1875-2002 as a whole due to the outliers around the German hyperinflation.

Using consumer prices as deflators, the tests do not find support for long-run relative PPP convergence since non-stationarity of the rekrcpi can not be rejected. For the period 1875-2002 as a whole nekr and relcpi are I(1) but not cointegrated. For each of the two subperiods the equation [14] is unbalanced due to the different order of integration of nekr and relcpi (nekr is I(0) while relcpi is I(1)).

8. Conclusion and scope for further research

This paper has reviewed the empirical evidence regarding long-run relative PPP convergence in the case of Denmark 1875-2002. The data set consisted of two new effective krone rate indices with respectively wholesale prices and consumer prices as deflators. The real effective exchange rate indices have been constructed as geometrically weighted chain indices with current trade weights based on Denmark's foreign trade in goods with 15 of its largest trading partners. For each of the years during the sample period, the weighting basis covers at least 78

[19] For a detailed treatment of the test, cf. e.g. chapter 8 and 13 in Patterson, K., An Introduction to Applied Econometrics. A Time Series Approach, New York: Palgrave 2000 or chapter 4 in Harris, R. & Sollis, R., *Applied Time Series Modelling and Forecasting*, West Sussex: Wiley 2003.

per cent of Denmark's total foreign trade in goods. To avoid biased results from outliers in the period around the German hyperinflation, the tests were performed both for the period 1875-2002 as a whole and for the two subperiods that emerged when the period 1914-1923 was excluded from the data set.

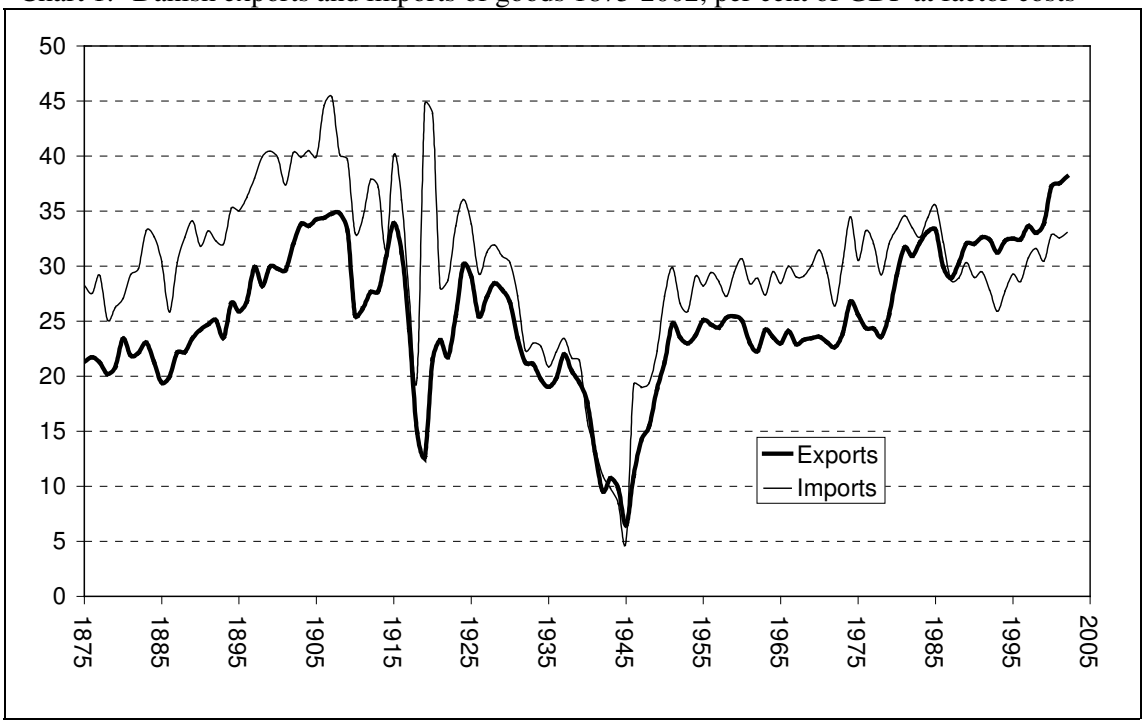
The results from both unit-root rests as well as cointegration tests based on the real effective krone rate index with wholesale prices as the deflator supported a hypothesis of long-run PPP convergence. Half-lives were estimated to around 4 years in the post-1923 period and 2 years in the pre-1914 Classical Gold Standard period. The fastest mean reversions towards relative PPP were found towards the end of the Classical Gold Standard period and towards the end of the Bretton Woods period. These results seem to indicate that the fastest mean reversion towards PPP has occurred in those periods where Denmark has pursued a fixed-exchange-rate policy vis-à-vis the majority of its trading partners and thereby in those periods with the lowest volatility in the nominal effective krone rate.

The paper did not find support for long-run relative PPP convergence when consumer prices were used as deflators. This seems consistent with *a priori* expectations based on theoretical considerations and highlights the importance of choice of deflators for studies of PPP.

The various tests for relative PPP in this paper have been very simple and should be considered as a first explorative examination of the new historical time-series indices for the real effective krone rate. A natural next step could be exploration of the PPP hypothesis within a multivariate system framework to review the robustness of the results in this paper. One could also try to analyse the tendency towards long-run PPP and the speed of mean reversion using regime-switching models that allow for multiple structural mean shifts in the real exchange rate. By such a procedure it will be possible to estimate breakpoints years in the series, and it would be interesting to see whether such breakpoints could be given reasonable economic historical interpretations.

Charts and tables

Chart 1: Danish exports and imports of goods 1875-2002, per cent of GDP at factor costs

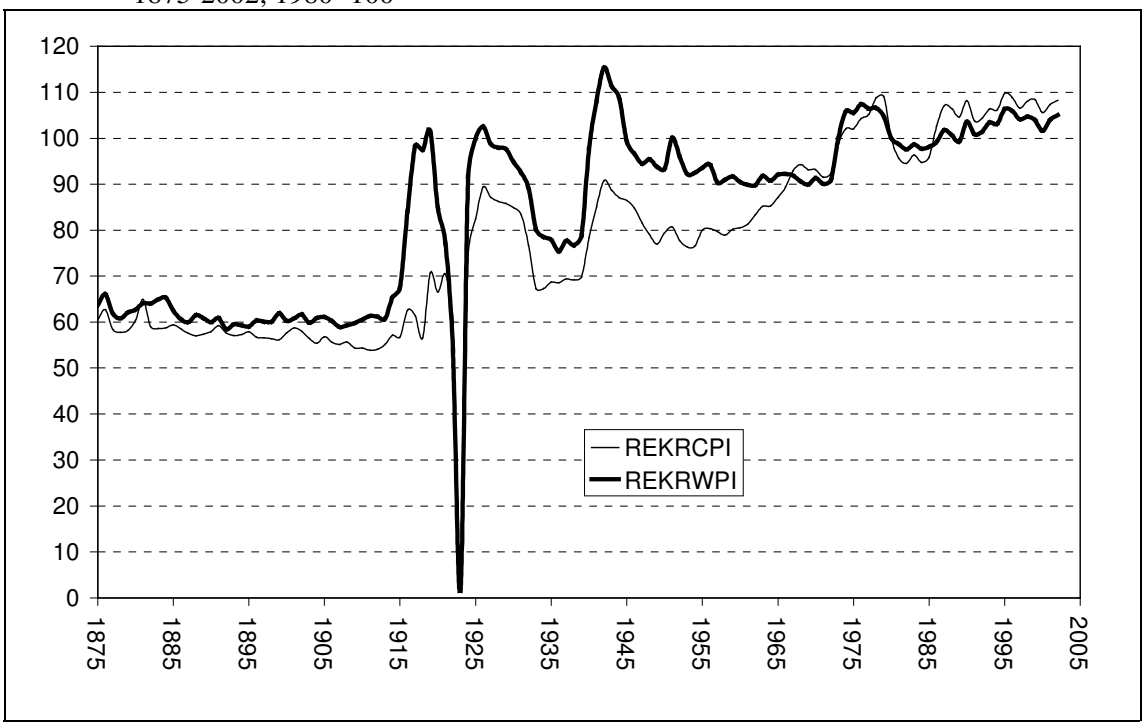


Notes to foreign trade data:
(1) Including transit trade in the periods 1875-1909 and 1959-1977. (2) Change to special trade in 1937. (3) Before 1920 Germany includes the northern part of the old Duchy of Schleswig. (4) Import figures are cif-values. (5) All figures are in current prices.

Notes to GDP data:
(1) After 1920 including the northern part of the old Duchy of Schleswig. (2) Since 1966 based on the methods laid out in the European System of National Accounts 1995 (ESA 95). No adjustment for the break in series in 1966 has been made. (3) All figures are in current prices.

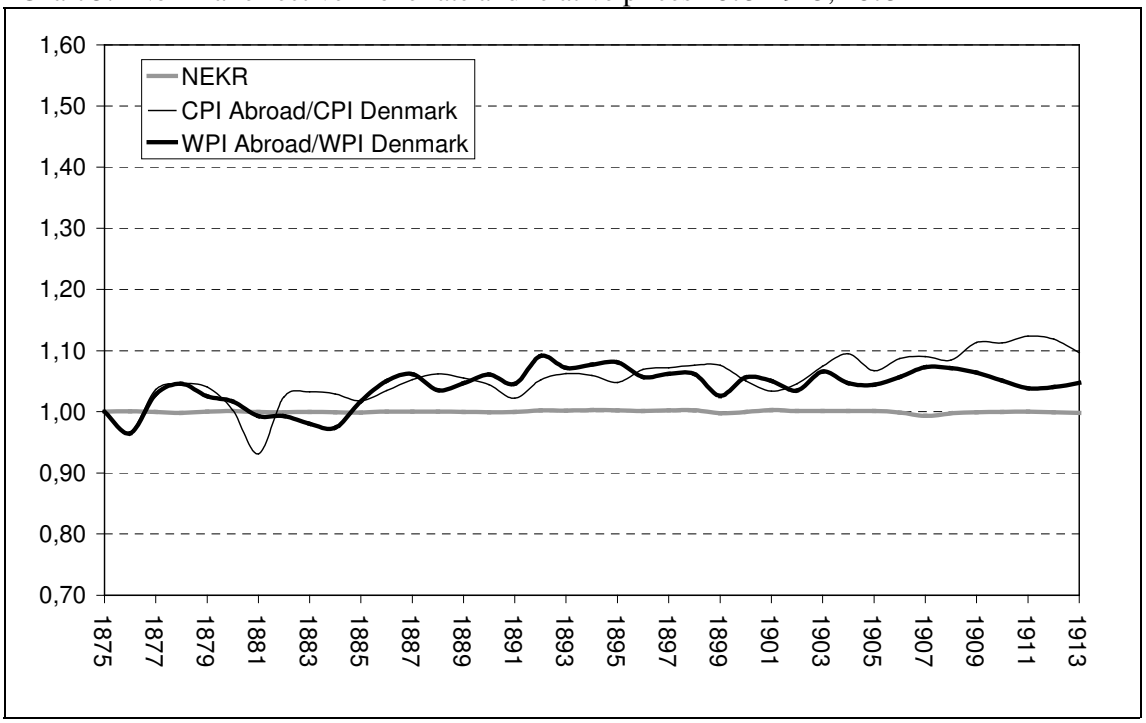
Sources:
Hansen, S. Aa., *Økonomisk vækst i Danmark. Bind II: 1914-1983*, Third Edition, Copenhagen: Akademisk Forlag 1983; Johansen, H. C., *Danish historical statistics 1814-1980*, Copenhagen: Gyldendal 1985; Statistics Denmark, *StatBank Denmark*, Statistics Denmark's website (www.dst.dk); Statistics Denmark, *Statistisk tabelværk*, various issues; Statistics Denmark, *Statistical ten-year review*, various issues; Statistics Denmark, *Statistical Yearbook*, various issues; Statistics Denmark, *50-year review*, Copenhagen: Statistics Denmark 1995; and Statistics Denmark, *50-year review*, 2nd Edition, Copenhagen: Statistics Denmark 2001.

Chart 2: Real effective krone rate indices based on consumer prices and wholesale prices 1875-2002, 1980=100



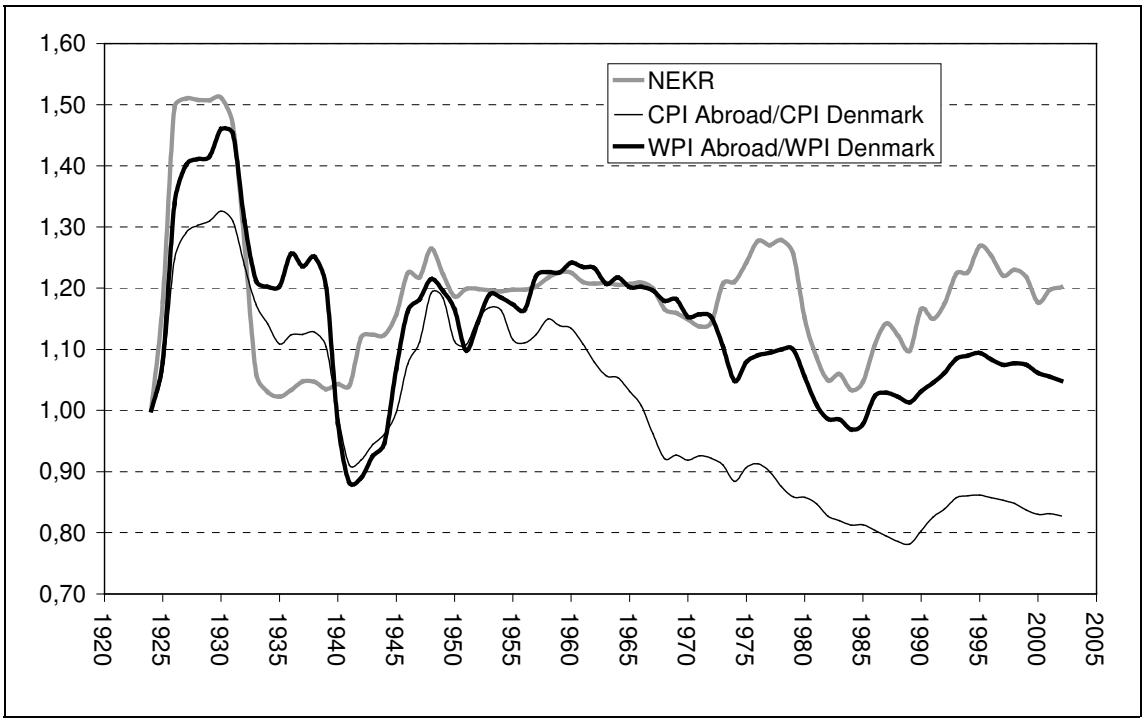
Source: Abildgren, K., Nominal and real effective krone rate indices for Denmark 1875-2002, *Danmarks Nationalbank Working Paper*, No. 13, April 2004.

Chart 3: Nominal effective krone rate and relative prices 1875-1913, 1875=1



Source: Abildgren, K., Nominal and real effective krone rate indices for Denmark 1875-2002, *Danmarks Nationalbank Working Paper*, No. 13, April 2004.

Chart 4: Nominal effective krone rate and relative prices 1924-2002, 1924=1



Source: Abildgren, K., Nominal and real effective krone rate indices for Denmark 1875-2002, *Danmarks Nationalbank Working Paper*, No. 13, April 2004.

Chart 5: OLS estimates of half-lives measured in years from 20-year rolling-window regressions of AR(1)-model for the REKRWPI in the pre-1914 period

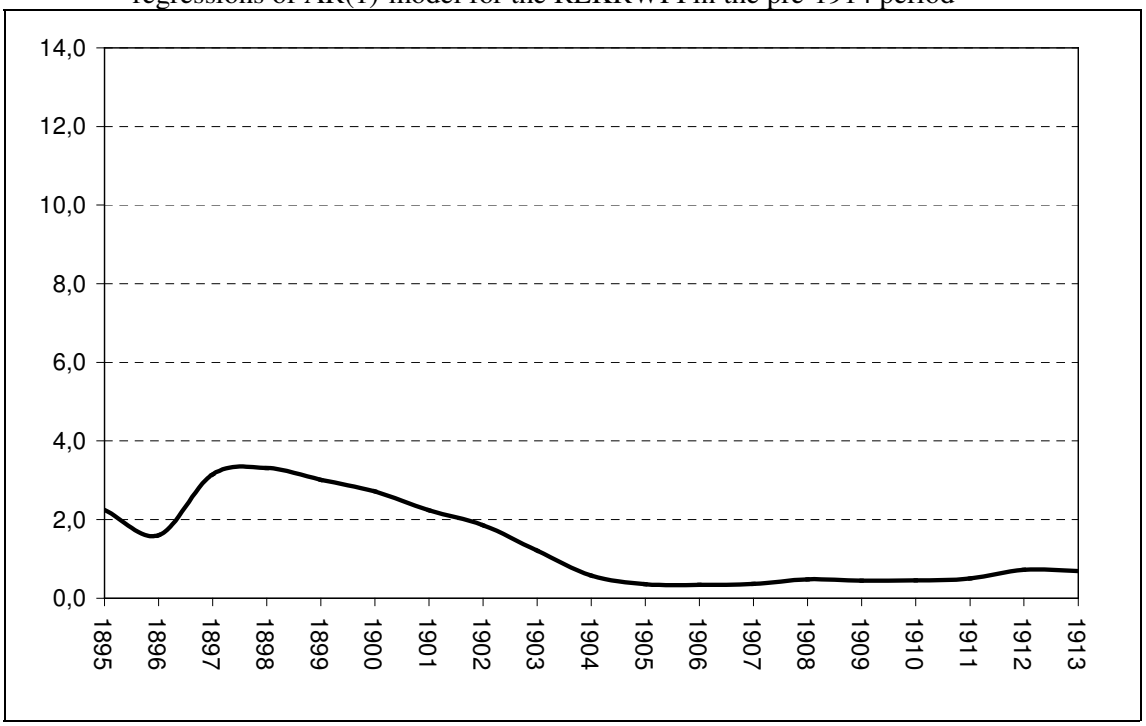


Chart 6: OLS estimates of half-lives measured in years from 20-year rolling-window regressions of AR(2)-model for the REKRWPI in the post-1923 period

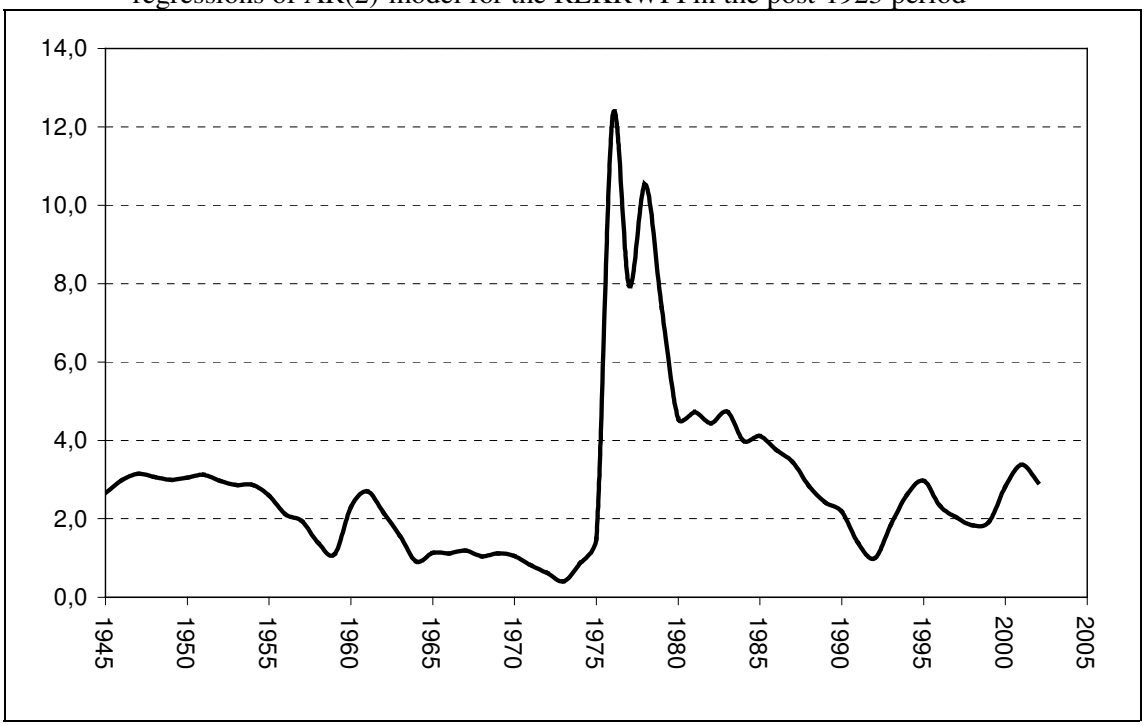


Table 1.a: Unit-root tests - real effective krone rate based on wholesale prices (REKRWPI)

		Sample period					
		1875-2002		1875-1913		1924-2002	
No trend included							
ADF test on REKRWPI							
Number of lags in ADF test		0		0		1	
ADF test statistics	(a)	-3.10	**	-2.67	*	-3.15	**
LM tests for autocorrelated residuals	(b)						
Lag 1		0.58		0.44		0.40	
Lag 1-2		0.53		0.64		0.21	
Lag 1-3		0.41		0.46		0.72	
Lag 1-4		1.31		0.98		0.57	
Test for heteroscedasticity in residuals	(c)						
Levels and squares of regressors		92.2	**	13.0	**	11.1	**
Levels, squares and cross-products of regressors		n.a.		n.a.		13.8	**
Test for nomality of residuals	(d)	347.2	**	0.59		25.6	**
AR-model for REKRWPI							
Parameter estimates (OLS)	(e)						
bo		12.35	**	18.61	**	14.53	**
b1		0.86	**	0.69	**	1.29	**
b2		n.a.		n.a.		-0.45	**
Adjusted R-squared		0.73		0.49		0.84	
OLS estimates of half-life (years)		4.5		1.9		4.2	
Bias adjusted OLS estimates of half-life (years)		5.7		2.8		5.3	
Trend included							
ADF test on REKRWPI							
Number of lags in ADF test		0		0		1	
ADF test statistics	(a)	-5.44	**	-3.02		-4.01	**
LM tests for autocorrelated residuals	(b)						
Lag 1		0.60		0.00		2.07	
Lag 1-2		0.67		0.09		1.26	
Lag 1-3		0.88		0.21		0.99	
Lag 1-4		0.75		0.71		0.74	
Test for heteroscedasticity in residuals	(c)						
Levels and squares of regressors		69.4	**	14.9	**	12.7	**
Levels, squares and cross-products of regressors		73.3	**	17.6	**	15.6	*
Test for nomality of residuals	(d)	524.4	**	0.21		22.7	**
AR-model for REKRWPI							
Parameter estimates (OLS)	(e)						
d		0.16	**	n.a.		0.05	**
bo		22.19	**	n.a.		18.24	**
b1		0.61	**	n.a.		1.26	**
b2		n.a.		n.a.		-0.47	**
Adjusted R-squared		0.76		n.a.		0.85	
OLS estimates of half-life (years)		1.4		n.a.		3.0	
Bias adjusted OLS estimates of half-life (years)		1.5		n.a.		3.4	

Notes:
* (**) denotes rejection of the null hypothesis at a 10-per-cent (5-per-cent) significance level.
(a) Null hypothesis is non-stationarity.
(b) F-tests. Null hypothesis is no autocorrelation.
(c) White Chi-square tests. Null hypothesis is no heteroscedasticity.
(d) Chi-square skewness-kurtosis test with a small-sample correction. Null hypothesis is normality.
(e) Null hypothesis: Coefficient equal to zero.

Table 1.b: Unit-root tests - real effective krone rate based on consumer prices (REKRCPI)

		Sample period					
		1875-2002		1875-1913		1924-2002	
No trend included							
ADF test on REKRCPI							
Number of lags in ADF test		4		0		1	
ADF test statistics	(a)	-0.80		-2.57		-1.33	
LM tests for autocorrelated residuals	(b)						
Lag 1		0.02		0.38		0.94	
Lag 1-2		0.12		1.18		1.27	
Lag 1-3		0.62		1.99		0.85	
Lag 1-4		1.03		1.92		0.67	
Test for heteroscedasticity in residuals	(c)						
Levels and squares of regressors		34.3	**	11.2	**	1.2	
Levels, squares and cross-products of regressors		110.4	**	n.a.		1.6	
Test for nomality of residuals	(d)	328.7	**	11.2	**	6.0	**
Trend included							
ADF test on REKRCPI							
Number of lags in ADF test		0		0		5	
ADF test statistics	(a)	-6.27	**	-4.76	**	-4.60	**
LM tests for autocorrelated residuals	(b)						
Lag 1		1.12		3.47	*	0.07	
Lag 1-2		0.81		2.30		0.33	
Lag 1-3		0.60		1.64		0.24	
Lag 1-4		0.91		2.08		0.21	
Test for heteroscedasticity in residuals	(c)						
Levels and squares of regressors		19.2	**	7.9	*	8.4	
Levels, squares and cross-products of regressors		19.7	**	10.5	*	40.5	
Test for nomality of residuals	(d)	168.3	**	14.7	**	1.0	
AR-model for REKRCPI							
Parameter estimates (OLS)	(e)						
d		0.23	**	-0.12	**	0.16	**
bo		22.31	**	47.78	**	20.20	**
b1		0.53	**	0.21		1.24	**
b2		n.a.		n.a.		-0.65	**
b3		n.a.		n.a.		0.33	
b4		n.a.		n.a.		-0.22	
b5		n.a.		n.a.		0.21	
b6		n.a.		n.a.		-0.22	*
Adjusted R-squared		0.84		0.62		0.96	
OLS estimates of half-life (years)		1.1		0.4		1.9	

Notes:
* (**) denotes rejection of the null hypothesis at a 10-per-cent (5-per-cent) significance level.
(a) Null hypothesis is non-stationarity.
(b) F-tests. Null hypothesis is no autocorrelation.
(c) White Chi-square tests. Null hypothesis is no heteroscedasticity.
(d) Chi-square skewness-kurtosis test with a small-sample correction. Null hypothesis is normality.
(e) Null hypothesis: Coefficient equal to zero.

Table 2: Annual average compound growth of real GDP per capita, per cent

	1870-1998	1870-1913	1913-1998	Trade weight (a)
Denmark	1.9	1.6	2.1	n.a.
Trading partners:				
Germany	1.8	1.6	1.9	0.29
U.K.	1.4	1.0	1.6	0.30
Ireland	1.9	1.0	2.3	0.00
Sweden	1.9	1.5	2.1	0.12
Norway	2.2	1.3	2.7	0.05
U.S.A.	1.9	1.8	1.9	0.08
France	1.8	1.5	2.1	0.03
Spain	1.8	1.2	2.2	0.01
Italy	2.0	1.3	2.3	0.02
Portugal	2.0	0.5	2.8	0.00
Belgium	1.6	1.0	1.8	0.02
Netherlands	1.6	0.9	1.9	0.04
Japan	2.6	1.5	3.2	0.01
Finland	2.2	1.4	2.6	0.02
Switzerland	1.8	1.5	1.9	0.01
Total, trade weighted	1.7	1.4	1.9	1.00

Notes:
(a) Average annual weight in the nominal effective krone rate index 1875-2002.

Sources: Maddison, A., *Monitoring the World Economy 1820-1992*, Paris: OECD 1995; Maddison, A., *The World Economy. A Millennial Perspective*, Paris: OECD 2001; and Abildgren, K., Nominal and real effective krone rate indices for Denmark 1875-2002, *Danmarks Nationalbank Working Paper*, No. 13, April 2004.

Table 3.a: Single equation cointegration tests of [14] $rekrwpi_t = nekr_t - relwpi_t = k_t + e_t$

		Sample period					
		1875-2002		1875-1913		1924-2002	
ADF test on nekr (no trend included)							
Number of lags in ADF test		1		0		5	
ADF test statistics	(a)	-1.23		-3.37	**	-5.37	**
ADF test on D_nekr (no trend included)							
Number of lags in ADF test		0		n.a.		n.a.	
ADF test statistics	(a)	-8.55	**	n.a.		n.a.	
ADF test on relwpi (no trend included)							
Number of lags in ADF test		1		0		1	
ADF test statistics	(a)	-1.31		-2.65	*	-3.48	**
ADF test on D_relwpi (no trend included)							
Number of lags in ADF test		0		n.a.		n.a.	
ADF test statistics	(a)	-8.61	**	n.a.		n.a.	
ADF test on rekrwpi (no trend included)							
Number of lags in ADF test		0		0		1	
ADF test statistics	(a)	-7.88	**	-2.67	*	-3.09	**
LM tests for autocorrelated residuals	(b)						
Lag 1		2.61		0.46		0.39	
Lag 1-2		1.85		0.65		0.21	
Lag 1-3		1.24		0.48		1.01	
Lag 1-4		0.93		1.01		0.78	
Test for heteroscedasticity in residuals	(c)						
Levels and squares of regressors		5.9	*	11.9	**	13.1	**
Levels, squares and cross-products of regressors		n.a.		n.a.		16.8	**
Test for nomality of residuals	(d)	858.2	**	0.3		35.0	**

Notes:
* (**) denotes rejection of the null hypothesis at a 10-per-cent (5-per-cent) significance level.
(a) Null hypothesis is non-stationarity.
(b) F-tests. Null hypothesis is no autocorrelation.
(c) White Chi-square tests. Null hypothesis is no heteroscedasticity.
(d) Chi-square skewness-kurtosis test with a small-sample correction. Null hypothesis is normality.

Table 3.b: Single equation cointegration tests of [14] $rekrcpi_t = nekr_t - relcpi_t = k_t + e_t$

		Sample period					
		1875-2002		1875-1913		1924-2002	
ADF test on nekr (no trend included)							
Number of lags in ADF test		1		0		5	
ADF test statistics	(a)	-1.23		-3.37	**	-5.37	**
ADF test on D_nekr (no trend included)							
Number of lags in ADF test		0		n.a.		n.a.	
ADF test statistics	(a)	-8.55	**	n.a.		n.a.	
ADF test on relcpi (no trend included)							
Number of lags in ADF test		1		4		2	
ADF test statistics	(a)	-1.33		0.10		-1.72	
ADF test on D_relcpi (no trend included)							
Number of lags in ADF test		0		3		2	
ADF test statistics	(a)	-8.89	**	-6.42	**	-4.68	**
ADF test on rekrcpi (no trend included)							
Number of lags in ADF test		4		0		1	
ADF test statistics	(a)	-2.55		-2.47		-1.49	
LM tests for autocorrelated residuals	(b)						
Lag 1		1.27		0.31		1.32	
Lag 1-2		1.06		1.16		0.88	
Lag 1-3		1.13		1.97		0.88	
Lag 1-4		1.20		1.93		0.67	
Test for heteroscedasticity in residuals	(c)						
Levels and squares of regressors		40.7	**	12.1	**	2.5	
Levels, squares and cross-products of regressors		105.84	**	n.a.		3.9	
Test for nomality of residuals	(d)	2208.1	**	9.7	**	11.1	**

Notes:
* (**) denotes rejection of the null hypothesis at a 10-per-cent (5-per-cent) significance level.
(a) Null hypothesis is non-stationarity.
(b) F-tests. Null hypothesis is no autocorrelation.
(c) White Chi-square tests. Null hypothesis is no heteroscedasticity.
(d) Chi-square skewness-kurtosis test with a small-sample correction. Null hypothesis is normality.