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PPP despite real shocks: An empirical analysis of the Norwegian real exchange rate.

by

Qaisar Farooq Akram

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PPP despite real shocks: An empirical analysis of the Norwegian real exchange rate

Qaisar Farooq Akram*

Research Department, Norges Bank

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Abstract

Despite the emerging consensus on the validity of purchasing power parity (PPP) between trading countries in the long run, empirical evidence in favour of the PPP theory is scarce in data predominantly exposed to real shocks. This paper tests for PPP between Norway and its trading partners using quarterly observations from the post Bretton Woods period, in which the Norwegian economy has been exposed to numerous real shocks such as frequent revaluations of oil and gas resources through new discoveries and price fluctuations. The paper undertakes an extensive examination of the behaviour of the Norwegian real and nominal exchange rates and shows that it is remarkably consistent with the PPP theory. Moreover, convergence towards the equilibrium level appears relatively fast; our estimate of the half life of a deviation from the equilibrium level is just six quarters. This is partly attributed to the Norwegian government's policies aimed at preserving the competitiveness of the economy and the system of centralised wage bargaining.

Key words: *PPP; real exchange rate; oil prices; Dutch disease; centralised wage bargaining; exchange rate policy; Cointegration analysis.*

JEL Classification: *C22, C32, C51, E31. E58, F41, J51.*

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1. Introduction

A number of recent empirical studies observe convergence towards purchasing power parity (PPP) in the long run, see e.g. Froot and Rogoff (1994), Rogoff (1996), Isard (1995) and MacDonald (1995) and the references therein. Accordingly, changes in nominal exchange rates outweigh changes in domestic prices relative to foreign prices in the long run, and real exchange rates exhibit reversion towards their constant equilibrium rates. The speed of reversion is however relatively low. Consensus estimates of the half life of a deviation from an equilibrium level vary in the range of 2.5 to 6 years for industrial countries. Another common finding is that the support for long run PPP is stronger in data samples dominated by monetary shocks, e.g. in samples from high inflation periods, than in samples presumedly dominated by real shocks such as productivity changes and discovery of natural resources, see e.g. Patel (1990) and Cheung and Lai (2000). In the latter type of samples, real exchange rate behaviour is often indistinguishable from a random walk. Moreover, the support for PPP is often stronger in studies that employ wholesale prices, with a larger share of prices on tradables, rather than consumer prices. Against such a background, this study presents results which would seem to be exceptions within the literature.

This paper tests for PPP between Norway and its trading partners using consumer price indices. It employs quarterly data from the post Bretton Woods era over the period 1972:1-1997:4. This period covers numerous real shocks to the Norwegian economy such as revaluations of Norwegian oil and gas reserves through discoveries of new fields and fluctuations in (real) oil prices. Nevertheless, it finds strong support for PPP, upheld by e.g. a remarkably stable equilibrium real exchange rate over the sample period. Moreover, it is discovered that the half life of a given deviation from the equilibrium rate is only about 1 1/2 years!

The paper argues, however, that the Norwegian government's policies and the system of centralised wage bargaining need to be taken into account when explaining these findings rather than interpreting them as mere indications of relatively strong arbitrage pressure between Norway and its trading partners.

To underpin the PPP theory while taking into consideration the nature of shocks that have hit the Norwegian economy, the paper draws on the "Dutch disease" literature where the effects of revaluations of natural resources on nominal and real exchange rates are among the main issues, see e.g. Corden and Neary (1982) and Bruno and Sachs (1982). Accordingly, the PPP theory can be founded on an intertemporal optimising model that allows for shocks as e.g. revaluations of national wealth. It appears that such shocks, in theory, do not pose a greater challenge to the PPP theory than the Balassa-Samuelson theorem, which has received little support in tests of PPP between industrialised countries at comparable levels of income, see Balassa (1964), Samuelson (1964) and Froot and Rogoff (1994) *inter alia* for an overview of the empirical evidence.

This paper also considers factors that are likely to affect the adjustment of a real exchange rate towards its equilibrium level. In particular, it argues that centralised wage bargaining, which is a feature of a number of small and open industrialised economies, may speed up the adjustment of a real exchange rate towards its equilibrium rate, see e.g. Calmfors and Driffill (1988). For instance, the central wage bargainers may lower their wage claims to absorb adverse shocks to the profitability of the sector for tradables, and thereby restore its competitiveness relative to the abroad and the domestic sector for non-tradables. This contribution of centralised wage bargaining is well known in the literature on wage formation, cf. Aukrust (1977) and Rødseth and Holden (1990), but seems to have escaped attention in the PPP literature. For example, cross country differences in the persistence of real exchange rates do not seem to be classified along this dimension, see e.g. Cheung and Lai (2000).

By considering several factors that may affect the adjustment of a real exchange rate towards its equilibrium level, this paper also sheds light on the commonly observed non-neutrality of nominal exchange rate regimes with respect to the behaviour of real exchange rates, see e.g. Mussa (1986) and Stockman (1983). For instance, real exchange rates often follow random walks in samples from floating regimes, but tend to display mean reverting behaviour in samples from stable exchange rate regimes. This empirical regularity is often regarded as an anomaly and is rarely explained. Mussa (1986), however, suggests that economic policies conducted in conjunction with a fixed exchange rate regime can neutralise the effects from real shocks and might explain their failure to have permanent effects on real exchange rates. This paper elaborates further on how fiscal and exchange rate policies can be, or are, used to affect real exchange rates, but adds that such policies are more likely to be adopted by small and open economies that are more exposed to international arbitrage pressure, which itself is likely to speed up the convergence. Moreover, wages may be set through centralised or coordinated bargaining in small and open economies which may also contribute to mean reversion in real exchange rates. It follows that such additional attributes of an economy need to be controlled for when assessing the partial effect of a nominal exchange rate regime on the behaviour of a real exchange rate.

This paper tests the PPP theory by examining its implications for the behaviour of both the real and nominal exchange rates, see subsection 2.1. More specifically, it tests whether: (i) the Norwegian real exchange rate is a stationary process with a constant equilibrium rate, (ii) domestic and foreign prices have symmetrical and proportional effects on the Norwegian nominal exchange rate in the long run while (iii), any other variable does not affect the nominal exchange rate. The paper also addresses the contentious issue of whether the PPP theory is for the nominal exchange rate or for prices or for both. That is to say that it is concerned with the issue of whether it is the nominal exchange rate that adjusts to deviations from the parity and brings about the convergence or whether it is prices, or both. If the theory is applied to e.g. domestic prices, implications similar to (ii) and (iii) apply to them as well.

To undertake the empirical analysis, we employ a wide range of univariate and multivariate models. Implication (i) is examined within the framework of a univariate model of the real exchange rate whilst implications (ii) and (iii) are tested within a multivariate system framework. The variable set in the system analysis includes the nominal exchange rate, domestic and foreign consumer prices, domestic and foreign interest rates, Norwegian financial investment abroad and oil prices. Most of these variables are commonly used to model nominal exchange rates and to test the PPP theory, see e.g. Frankel and Rose (1995), Juselius (1992) and Johansen and Juselius (1992). In the system framework, the empirical analysis is based on a full system where all of the variables are regarded as endogenous, and on a partial system where a subset of the variables are considered as given for the purpose of analysis. The system analysis (full and partial) applies the multivariate cointegration procedure developed by Johansen (1988, 1995), and previously used by e.g. Juselius (1992) and Johansen and Juselius (1992) in their investigations of PPP with reference to Denmark and the UK, respectively. The test for whether the PPP theory is a theory for the exchange rate and/or for prices can be carried out as an integrated part of this procedure.

Since the system framework treats both prices and the nominal exchange rate as endogenous variables, it avoids possible bias in the results due to invalid *a priori* assumptions, see Isard (1995) and Krugman (1978) *inter alia.* Beside that, if the prices and the exchange rate adjust to a given deviation from the parity, the real exchange rate may adjust faster towards its equilibrium level than if only one of them adjusts. Thus additional insight into the adjustment process of the real exchange rate can be gained by regarding these variables as endogenous. Furthermore, if both the domestic prices and the nominal exchange rate adjust to a deviation from the parity, the nominal exchange rate process cannot be considered as super exogenous for (the long run parameters of) the price process, see Engle, Hendry and Richard (1983) and Johansen (1995, ch. 8). That is, the price process may not be invariant to a possible change from a stable to a floating exchange rate policy. The question of whether or not the Norwegian price process will withstand a switch to a floating exchange rate regime has been a subject of the Norwegian debate on the choice of a monetary policy target, albeit on theoretical grounds, see the articles in Christiansen and Qvigstad (1997), in particular Holden (1997) and Rødseth (1997a).

The paper proceeds as follows: Section 2 outlines the PPP theory and considers factors that may affect the adjustment towards the long run equilibrium. In particular, subsection 2.1 defines the absolute and the relative version of the PPP theory and specifies its implications. Section 3 presents a brief overview of the Norwegian economy focusing on factors that seem relevant for the interpretations of results.

Section 4 undertakes the analysis in the univariate framework. However, it starts with a graphical analysis of the Norwegian consumer prices, the consumer prices in the trading countries and the trade weighted nominal exchange rate in the light of the PPP theory.[1]

Section 5 contains the analysis in the system framework. Subsection 5.1 introduces the variables and investigates their time series properties. Subsection 5.2 discusses the choice between a vector autoregressive (VAR) model and a conditional VAR model which is not obvious given the possible stationarity of oil prices (and hence a cointegrating relation by itself).[2] Subsection 5.3 employs a VAR model to determine the number of long run relations between the variables, their identification and to test the validity of using a conditional VAR model in the further analysis. Subsection 5.4 derives a conditional VAR model and evaluates the robustness of the results obtained from the VAR model. In addition, possible endogeneity of prices is formally tested.

Section 6 reiterates the main conclusions and the appendix presents definitions and sources of variables and offers a sensitivity analysis of the main results in section 5.

2. Purchasing power parity (PPP)

Subsection 2.1 defines the absolute and the relative versions of the PPP theory and lays out its implications for the behaviour of real and nominal exchange rates. Subsection 2.2 presents the economic rationale for the PPP theory together with a brief review of the empirical evidence on the different approaches to justify the theory. Next, subsection 2.3 considers factors that may influence how fast a real exchange rate converges towards its equilibrium level. Factors brought into focus are centralised wage bargaining and fiscal and exchange rate policies that can be adopted by small and open economies to preserve their competitiveness, especially upon discovery of a natural resource. It is argued that such factors are likely to speed up the adjustment of the real exchange rate

[1] All empirical results and graphs are obtained using PcGive 9.10, PcFiml 9.10 and GiveWin 1.24, see Hendry and Doornik (1996) and Doornik and Hendry (1996, 1997).

[2] In this paper, a variable is considered non-stationary if it is integrated; otherwise it is considered stationary although its process may have changed due to deterministic shifts.

towards its equilibrium, through their effects on domestic prices and the nominal exchange rate. This elaboration offers a framework to assess the possible influence of the Norwegian wage and price setting system and that of the government's policies on the real exchange rate behaviour.

2.1. Definitions and implications

The absolute version of the PPP theory relates the nominal exchange rate to the ratio between the domestic and foreign price levels as

$$E = P/P^f. \tag{2.1}$$

Here E is the nominal exchange rate, that is the price of domestic currency per unit of foreign currency, P is the domestic general price level and P^f is the foreign general price level. In the Casselian view of PPP the nominal exchange rate exhibits a tendency to converge towards the relative price level (P/P^f), see Cassel (1922) and e.g. MacDonald (1995). Thus the relative price level can be interpreted as the equilibrium nominal exchange rate, the rate to which the actual exchange rate (E) reverts in the long run.[3] The actual exchange rate may however be frequently away from its equilibrium level, for short and long periods, owing to changes in numerous economic and political factors.

The relative version of the PPP theory allows for a multiplicative term γ in equation (2.1):

$$E = \gamma P/P^f. \tag{2.2}$$

γ can also be interpreted as the equilibrium level of the real exchange rate. The relative version is defined by a constant equilibrium real exchange rate different from 1, opposed to the absolute version of the theory,

$$R \equiv EP^f/P = \gamma. \tag{2.3}$$

The PPP theory, in both versions, implies a constant real exchange rate in the long run. In Cassel's view, the nominal exchange rate adjusts to outweigh changes in the relative price level (P/P^f) and thereby maintains the level of the real exchange rate. Specifically, a change in e.g. P is not outweighed by a change in P^f alone or by a combination of changes in P^f and E, but only

[3] "...the point of balance towards which, in spite of all temporary fluctuations, the exchange rate will always tend. This parity I call *purchasing power parity.* (Italics original), Cassel (1922, pp. 140).

by a change in E. The opposing view is that the PPP relation determines domestic prices (P) for a given level of foreign prices and nominal exchange rate, especially for a relatively small economy with a fixed exchange rate, cf. Edison and Klovland (1987) and Giovannini (1988). Another view is that both the nominal exchange rate and the domestic prices are simultaneously determined in the PPP equation, see Isard (1995, pp. 59) and MacDonald (1995).

The PPP theory also implies a symmetry and a proportionality restriction on domestic and foreign prices in a nominal exchange rate equation, or alternatively on the nominal exchange rate and foreign prices in an equation for domestic prices. These restrictions follow from the implied constancy of the real exchange rate. These can be defined using equation (2.4), which is formulated by a slight generalisation of equation (2.2) and taking logs denoted by small letters.

$$e = \ln \gamma + \pi_1 p - \pi_2 p^f. \tag{2.4}$$

π_1 and π_2 denote constant elasticities; Greek letters without subscript t are used to denote constant parameters, throughout the paper. The symmetry restriction is defined by $\pi_1 = \pi_2 = \pi$, and the proportionality restriction by adding $\pi = 1$.

Obviously, the PPP theory also implies the absence of any other variable, say w, from a long run relation between the nominal exchange rate and domestic and foreign prices. For example, the coefficient of w should be zero if it is added to equation (2.4), though w may have short run effects on e.g. the nominal exchange rate.

This paper tests the PPP theory by examining each of its implications. Section 4 sheds light on the empirical validity of equations (2.1)-(2.3). There, equation (2.3) provides the foundation of the univariate analysis of the real exchange rate. Section 5 is concerned with testing the symmetry and proportionality restrictions, see equation (2.4), and the absence of long run effects of variables that are commonly regarded as important determinants of the Norwegian nominal and real exchange rates. Moreover, section 5 formally tests whether or not both the nominal exchange rate and prices respond to deviations from the PPP and contribute to re-establish the parity.

2.2. Economic rationale

This subsection outlines three different but complementary foundations of the PPP theory. First, it reviews the two main and oldest justifications for the PPP, namely the PPP as a long run neutrality proposition and the commodity arbitrage view. The neutrality proposition view does not address the effects of real shocks while the commodity arbitrage view can be criticised for an unsatisfactory treatment of non-tradables goods and services. These shortcomings are explicitly addressed by the third approach, here called "the structural approach", which divides the economy into a sector for tradables and a sector for non-tradables and examines the short run and long run effects of real shocks, as e.g. productivity shocks and discovery of natural resources. Presentation of the latter approach draws extensively on the "Dutch disease" literature.

A long run neutrality proposition: Within the classical quantity theory of money, the PPP theory is regarded as a long run neutrality proposition, see e.g. Samuelson (1964), Officer (1976) and McCallum (1996, pp. 32). Accordingly, an increase in e.g. the domestic money supply ultimately lead to an equiproportionate change in nominal variables leaving real prices such as the real exchange rate unchanged.

This view suggests a broad measure of the general price level to be used in tests of the PPP theory, see e.g. Officer (1977). This, because the nominal exchange rate is interpreted as the relative price of domestic and foreign money, which is defined by the broadest measure of the domestic and foreign general price levels.

The neutrality proposition view is often supported by empirical evidence, since the PPP theory is seldom rejected in data samples from high inflation periods when monetary shocks are likely to be predominant, see e.g. Froot and Rogoff (1994), Rogoff (1996) and MacDonald (1995).

The commodity arbitrage view: The PPP theory is commonly underpinned by assuming commodity arbitrage between open economies. Following this view, prices of tradables tend to equalise across countries when measured in the same currency:

$$P_i = EP_i^f, \qquad \forall\ i. \tag{2.5}$$

P_i and P_i^f denote the price of good i in the domestic and foreign currency, respectively. Equations like (2.5) are commonly referred to as the law of one price. The absolute version of the PPP theory is derived by assuming that P and P^f are aggregates of the same set of prices with equal weights, see e.g. Rogoff (1996).

A host of issues are often raised against the validity of the law of one price. For instance, (i) all goods are not traded, hence the possibility of arbitrage does not exist for nontraded goods, (ii) even traded goods are not homogenous, thus they need not command the same price, (iii) there are transaction costs that lead to a wedge between prices across countries and (iv), prices are set in accordance with the market conditions within a given economy (pricing to market) and are therefore likely to differ across markets, see e.g. Rogoff (1996), Krugman (1987) and Goldberg and Knetter (1997) and the references therein. Actually, numerous empirical studies find persistent deviations from the law of one price, even for highly traded commodities, see e.g. Engle and Roger (1996) and Goldberg and Knetter (1997).

Aggregation from prices at the micro level to general price levels is also subject to criticism. It is pointed out that aggregate prices, in general, are not composed of the same set of prices at micro levels due to variations in consumption and production patterns across countries. For a similar reason, even prices of the same set of goods need not enter the aggregates with constant weights over time. Therefore, aggregate price levels often measure the prices of different baskets of goods across countries and over time. Consequently, they are likely to differ from each other when measured in the same currency, even when the law of one price holds at the micro level.

Empirical studies that subscribe to the commodity arbitrage view employ price aggregates that contains a relatively large number of prices on tradables, for instance export prices, import prices or wholesale prices. Moreover, they use the relative PPP theory by (implicitly) assuming constant transaction costs, constant mark-ups and constant differences in commodity baskets across countries. The adoption of the relative PPP theory can also be justified by the lack of updated series for price levels while indices for general price levels are published regularly by governments. A few recent empirical studies have also allowed for non-linear adjustment in real exchange rates due to presumably large transaction costs, see e.g. Dumas (1992) and Taylor, Peel and Sarno (2000).

The commodity arbitrage view is supported by empirical studies that employ e.g. wholesale price indices and/or long samples of data, as they often reports results in favour of the PPP theory. These studies, however, suggest that arbitrage pressure is too weak to bring about rapid price convergence. Moreover, non-linear models suggest that the arbitrage may be effectively absent at small deviations from the equilibrium level due to large transaction costs.

The structural approach: Balassa (1964) and Samuelson (1964) take into account the effects of prices on non-tradable goods and services and point out that productivity differences between countries may induce persistent deviations from PPP between these countries. They show that prices of internationally non-traded goods (and services) and hence aggregate prices rise with an increase in productivity. Thus, higher domestic productivity growth lead to appreciation of the real exchange rate. Also, it follows that any other real shock that raises the growth in domestic prices on non-tradables relative to the foreign prices on non-tradables will initially have a similar effect on the real exchange rate.

For instance, a discovery of natural resources or any other real shock, which increases the consumption opportunities of an economy, will normally increase the demand for both traded and non-traded goods. The demand for traded goods can be satisfied by import at given international prices while non-traded goods have to be produced at home, at higher prices in general. As a result, the real exchange rate will appreciate, see e.g. Corden (1984). A rise in government expenditures is another popular example, since they are believed to be biased towards non-traded goods and services. Accordingly, an increase in government expenditures raises their price and thereby bring about a real appreciation.

However, real shocks other than shocks to the production technology only cause temporary changes in the real exchange rate under fairly standard conditions. Bruno and Sachs (1982), among others, show within an intertemporal optimising framework that discovery of natural resources or their revaluation leave the long run real exchange rate unaffected, if: (i) there are constant returns to scale in the sector for tradables and non-tradables, (ii) the labour force is mobile between the two sectors and (iii), capital is mobile between the sectors and between countries. Under these conditions, the supply of non-tradables is perfectly elastic, thus, all demand shocks are absorbed by output changes at unchanged prices of non-tradables, see also Corden (1984). As a result, the ratio between the prices of non-tradables and tradables, say P_{nt}/P_{tr}, remains constant, and consequently the real exchange rate R too.

The implied constancy of the equilibrium real exchange rate, as in the relative version of the PPP theory, can be exposited as follow. Suppose that $P_{nt}/P_{tr} = \tau$, in the long run, where τ is determined by the production technology in both sectors. Assume that the general price levels at home and abroad are homogenous in sectoral price levels, as e.g. the domestic price level in equation (2.6), where ν is the weight of the price on tradables. Furthermore, assume that foreign countries have a similar economic structure such that $P^f_{nt}/P^f_{tr} = \tau_f$.

$$P = P_{tr}^{\nu} P_{nt}^{1-\nu} \tag{2.6}$$

Then, the equilibrium real exchange rate can be defined as the constant $\tau_f^{1-\nu^f}/\tau^{1-\nu}$ in equation

(2.7) which can be interpreted as γ in equation (2.3).[4]

$$R \equiv EP^f/P = EP^f_{tr}\tau_f^{1-\nu^f}/P_{tr}\tau^{1-\nu} = EP^f_{tr}\tau_f^{1-\nu^f}/EP^f_{tr}\tau^{1-\nu} = \tau_f^{1-\nu^f}/\tau^{1-\nu} \equiv \gamma \qquad (2.7)$$

Note that the equilibrium real exchange rate is equal to 1, as in the absolute version of the PPP theory, in the absence of cross country differences in production technologies and in the construction of general price levels, i.e. $\nu^f = \nu$. In the short run, the real exchange rate will appreciate or depreciate depending on whether $P_{nt}/P_{tr} > \tau$ or $P_{nt}/P_{tr} < \tau$.

The derived equilibrium real exchange rate is not inconsistent with long run current account balance. A rise in consumption opportunities, due to e.g. discovery of oil, and the ensuing rise in P_{nt}/P_{tr}, will lead to a transfer of production factors from the sector for (non-oil) tradables to the sector for non-tradables, and thereby to a decline in the sector for tradables, which is termed as the "Dutch disease", see e.g. Corden and Neary (1982). As a result, the non-oil trade surplus will fall but the total trade surplus need not deteriorate since the export of oil can make up for the fall in the non-oil trade surplus. Intertemporal optimising behaviour by consumers implies that P_{nt}/P_{tr} is above τ, only as long as the sector for tradables is larger than required to ensure long run current account balance. P_{nt}/P_{tr} will return to its long run level τ and R will return to $\tau_f^{1-\nu^f}/\tau^{1-\nu} \equiv \gamma$, when the sector for (non-oil) tradables has reached a level that does not compromise the economy's ability to pay for its imports, cf. Bruno and Sachs (1982).

The next subsection elaborates on the adjustment towards the long run equilibrium. In particular it focuses on the role of centralised or coordinated wage bargaining and of fiscal and exchange rate policies in counteracting a deviation from the equilibrium to e.g. avoid the "Dutch disease". Section 3 suggests that the features discussed below may have played an important role in determining the course of the Norwegian nominal and real exchange rates in the post Bretton Woods era.

2.3. Speed of adjustment towards the long run equilibrium

Beside the nature of a shock, market imperfections play an important role in determining how fast a real exchange rate (R) adjusts towards its equilibrium level. After an unexpected monetary shock, for example, the adjustment is commonly expected to take from 1 to 2 years because of

[4] The denominator in the term after the second identity follows from the assumption of the law of one price in the sector for tradables: $P_{tr} = EP^f_{tr}$.

menu costs and wage contracts of different lengths. Generally, the adjustment time will also depend upon the degree of international competition and on how fast production factors are transferred from sectors that are adversely affected by a shock to those that are experiencing a boom following the shock.

As noted earlier, international competition is believed to be weak due to tariff and non-tariff costs and, according to some accounts, effectively absent at small deviations from the equilibrium level due to large transaction costs. The intra-country reallocation of resources is also believed to be slow, e.g. because of slow labour mobility across sectors. Thus, the product prices in these sectors can deviate from their equilibrium levels for a long period and prevent the real exchange rate reaching its equilibrium rate for the same period. Note that a sluggish adjustment of the prices of non-tradables can delay the adjustment of the real exchange rate, even when the law of one price holds continuously in the sector for tradables.

Sluggish adjustment to the equilibrium level of the real exchange rate can be formalised by equilibrium correction models of domestic prices and the nominal exchange rate, as:

$$\Delta p_t = +\alpha_p(e - (p - p^f))_{t-1} + \textit{residual}, \qquad (2.8)$$

$$\Delta e_t = -\alpha_e(e - (p - p^f))_{t-1} + \textit{residual}. \qquad (2.9)$$

Where Δ defines the first difference operator. These models are derived under the assumption of no cross country differences in production technologies and in the construction of general price levels, cf. equation (2.7). Consequently, the law of one price holds for aggregate prices in the long run, i.e. absolute PPP. The term $(e - (p - p^f))$ represents the deviation from the absolute PPP, while α_p and α_e denote to what extent Δp_t and Δe_t respond to the deviation in the subsequent period. In general, foreign prices may also adjust, but for simplicity they are assumed to be unresponsive, which is not unlikely in the case of a small domestic economy. The residuals represents lagged and contemporaneous effects of Δe_t, Δp_t^f and of other relevant factors.

2.3.1. Centralised wage setting and government policies

Centralised or coordinated wage bargaining between labour and employer unions is a market imperfection that may nevertheless contribute to fast adjustment towards the equilibrium level. It has often been pointed out that centralised wage bargainings tend to take into account the effects of adverse shocks to the overall economy by e.g. wage moderation, see e.g. Calmfors and Driffill (1988) and Jackman (1990). Especially, effects of shocks that may affect the viability of the sector for tradables given its limited opportunities, due to the arbitrage pressure, to offset higher factor costs by raising product prices. Such restraints on wages are built into the Scandinavian model of inflation, see Aukrust (1977) and Calmfors (1977). This model offers a blueprint to preserve international competitiveness and to avoid a transfer of resources from the sector for tradables to the sector for non-tradables following a shock. Accordingly, the wage settlement in the sector for tradables is adopted by the sector for non-tradables. An exposition of this model may be useful in clarifying its implications for the behaviour of prices and the real exchange rate.

The Scandinavian model of inflation is a two-sector model derived under conditions similar to those in e.g. Bruno and Sachs (1982), noted above. Consequently, the wage share, or alternatively the return on capital, is the same across sectors over time. If we add the condition that the aggregate price level is defined as above by equation (2.6), the model can be presented in the growth form as follows:

$$\Delta p_{tr,\,t} = \Delta e_t + \Delta p^f_{tr,\,t} \tag{2.10}$$

$$\Delta w_{tr,\,t} = \Delta p_{tr,\,t} + \Delta q_{tr,\,t} \tag{2.11}$$

$$\Delta w_{nt,\,t} = \Delta w_{tr,\,t} \tag{2.12}$$

$$\Delta p_{nt,\,t} = \Delta w_{nt,\,t} - \Delta q_{nt,\,t} \tag{2.13}$$

$$\Delta p_t = \nu \Delta p_{tr,\,t} + (1-\nu)\Delta p_{nt,\,t} \tag{2.14}$$

Equation (2.10) follows from the law of one price in the sector for tradables, while (2.11) states that wage growth in this sector equals the sum of growth in prices ($\Delta p_{tr,\,t}$) and labour productivity ($\Delta q_{tr,\,t}$). This sum is referred to as the "main course" or the "Scandinavian path" of wage growth. Equation (2.12) indicates that the wage growth in the sector for non-tradables follows the wage growth in the sector for tradables. This property is often considered the hallmark of this model, see e.g. Nymoen (1991). Prices in the sector for non-tradables are set as a constant mark up on unit labour costs, hence their growth equals wage growth in excess of productivity growth, see equation (2.13). Finally, equation (2.14) defines the growth rate in aggregate prices (inflation).

The model implies that domestic inflation depends on nominal exchange rate depreciation (Δe_t), growth rate in international prices on tradables ($\Delta p^f_{tr,\,t}$) and the productivity difference between the sector for tradables and non-tradables. The effect of the productivity difference is influenced by the share of prices of non-tradables in aggregate prices, since productivity growth in the sector for tradables affects the wage growth and thereby the price growth in the sector for non-tradables. In a relatively open economy, defined by a large ν, the effects of productivity differences on Δp_t can be negligible.

$$\Delta p_t = \Delta e_t + \Delta p^f_{tr,\,t} + (1-\nu)(\Delta q_{tr,\,t} - \Delta q_{nt,\,t}) \tag{2.15}$$

The Balassa-Samuelson theorem follows directly from this model if we assume a similar inflation process in foreign countries. Consider the real exchange rate in growth rate terms:

$$\begin{aligned}
\Delta r_t &\equiv \Delta e_t + \Delta p^f_t - \Delta p_t \\
&= \Delta e_t + \{\Delta p^f_{tr,\,t} + (1-\nu^f)(\Delta q^f_{tr,\,t} - \Delta q^f_{nt,\,t})\} - \{\Delta e_t + \Delta p^f_{tr,\,t} + \\
&\quad (1-\nu)(\Delta q_{tr,\,t} - \Delta q_{nt,\,t})\} \\
&= (1-\nu^f)(\Delta q^f_{tr,\,t} - \Delta q^f_{nt,\,t}) - (1-\nu)(\Delta q_{tr,\,t} - \Delta q_{nt,\,t}) \equiv \xi_t
\end{aligned} \tag{2.16}$$

Equation (2.16) suggests that the real exchange rate appreciates if the difference in the productivity growth between the domestic sectors for tradables and non-tradables is higher than that in abroad. In the absence of such differences across countries and $\nu^f = \nu$, the real exchange rate will be constant, i.e. $\xi_t = 0$. The real exchange rate may be constant for a number of other reasons too, as evident from equation (2.16).

The Scandinavian model of inflation describes the long run growth in wages and prices, or alternatively, offers a normative account of wage behaviour. Actual growth in wages and prices is however unlikely to accord with this model in the short run. Among others, cyclical factors and wage-wage effects across sectors may be present in the short run, cf. Rødseth and Holden (1990) and Nymoen (1991). Nevertheless, the model suggests that aggregate prices tend to adjust such that the real exchange rate converges towards its equilibrium level. Thus the real exchange rate is likely to adjust faster towards the equilibrium level if wage and price setters adhere to this model.

Appropriate fiscal policies have been mentioned among mechanisms that can encourage adherence to the wage and price behaviour suggested by the Scandinavian model, see e.g. Aukrust (1977). In this regard, tax cuts, subsidies, selective increase in government expenditures, can be traded for wage and price moderation in the face of e.g. demand shocks, see also Corden (1982). Such measures, denoted as income policies, have been employed in e.g. the Nordic countries in addition to legislative actions to counteract wage and price growth in excess of the Scandinavian path, see Calmfors (1990).

The additional parameters α_b and α_g in the equilibrium correction model recognise, respectively, the possible contribution of centralised wage bargaining itself, and of income policies in increasing the speed of adjustment towards the equilibrium.

$$\Delta p_t = +(\alpha_p + \alpha_b + \alpha_g)(e - (p - p^f))_{t-1} + residual \tag{2.17}$$

Nominal exchange rate policy can also contribute to maintain the competitiveness of the sector for tradables by affecting the behaviour of the nominal exchange rate. The Dutch disease literature discusses frequent devaluations, or prevention of appreciations that would otherwise have taken place in the face of revaluation of natural resources, as measures to avoid large fluctuations in the real exchange rate, see e.g. Corden (1982). A stable nominal exchange rate policy may itself have similar effects on the real exchange rate, even in the absence of such "exchange rate protection" policies, as they are termed.

The influence of a stable nominal exchange rate policy can be recognised by the additional term in the nominal exchange rate process:

$$\Delta e_t = -\alpha_e(e - (p - p^f))_{t-1} - \alpha_c(e - \overline{e})_{t-1} + residual \tag{2.18}$$

Here α_c indicates how fast the central bank eliminates a deviation from the central parity, which is usually set equal to the perceived equilibrium nominal exchange rate.

There is ample evidence to suggest that central banks quite often define the equilibrium nominal exchange rate in the light of the PPP theory, either by using aggregate consumer prices, wholesale prices, unit labour costs or other related measures, see e.g. Cassel (1922), Officer (1976), Isard (1995) and Hinkle and Montiel (1999). If $\overline{e}$ is set equal to $p - p^f$, presumed to be fixed for the sake of argument, the authorities can speed up the convergence of the nominal exchange rate to its equilibrium level, $p - p^f$, and thereby also the adjustment of the real exchange rate towards its equilibrium.

It is, however, more realistic to assume that $\overline{e}$ is set equal to e.g. $(p - p^f)$ in a chosen base period t^*. Thus, the actual nominal exchange rate e_t will be directed towards the central parity $\overline{e} \equiv$

$(p-p^f)_{t^*}$, which can lead to persistent deviations from its time varying equilibrium $(p-p^f)_t$. But, if $\overline{e}$ is adjusted frequently, $\overline{e}$ and hence e_t will track $(p-p^f)_t$ more closely. Nevertheless, even if $\overline{e}$ is not adjusted frequently, a stable exchange rate policy is likely to contain excessive fluctuations in the nominal exchange rate and keep it close to, if not equal to, its equilibrium level. A choice of another measure related to $p-p^f$ is likely to have a similar effect on the nominal and real exchange rates, but probably with less strength.

Exchange rate protection policies can be interpreted as frequent changes in $\overline{e}$, and/or as avoidance of short term deviations between e and $\overline{e}$ in the face of appreciation pressure.

The effects on the real exchange rate behaviour of e.g. centralised wage bargaining, fiscal and exchange rate policies are summarised below.

The real exchange rate process To avoid more notation, assume that $\Delta p_t^f = 0$, then a change in the real exchange rate Δr_t depends on the level of the real exchange rate in the following way:

$$\begin{aligned} \Delta r_t &\equiv \Delta e_t - \Delta p_t - \Delta p_t^f = -(\alpha_e + \alpha_p + \alpha_b + \alpha_g + \alpha_c)(e - (p - p^f))_{t-1} + \text{residual} \\ \Delta r_t &= -(\alpha_e + \alpha_p + \alpha_b + \alpha_g + \alpha_c) r_{t-1} + \text{residual} \qquad (2.19) \end{aligned}$$

Equation (2.19), which is obtained by using (2.17) and (2.18), suggests that the real exchange rate is a stationary process when $(\alpha_e + \alpha_p) > 0$, i.e. when arbitrage pressure exists. The adjustment towards the long run equilibrium will be slow, however, if $(\alpha_e + \alpha_p)$ is small, unless the country has a fixed exchange rate regime, centralised wage bargaining and/or active government policies aimed at maintaining the competitiveness. Such features speed up the adjustment towards the long run equilibrium. If $(\alpha_e + \alpha_p)$ is small, the nominal exchange rate is floating and neither the labour market nor the government are concerned about the competitiveness of the economy, i.e. $\alpha_c = \alpha_b = \alpha_g = 0$, the real exchange rate may appear to follow a random walk in small samples of data.

The implied effects of the nominal exchange rate regime on the real exchange rate behaviour are consistent with the observations that real exchange rates tend to display stationary behaviour within fixed exchange rate regimes and appear to follow random walks under floating regimes, see e.g. Mussa (1986) and Stockman (1983). It has been argued that a stable exchange rate regime has a stabilising effect on expectations about the future course of a nominal exchange rate, see Mussa (1986). Moreover, a stable exchange rate policy is often backed up by fiscal policies that have stabilising effects on the nominal exchange rate and prices.

The analysis in this section, however, has focused on the role of centralised or coordinated wage setting and income policies in affecting the real exchange rate behaviour through their influence on domestic prices. In addition, a stable nominal exchange rate policy can influence the real exchange rate behaviour by the choice of an appropriate central parity, or through rapid elimination of deviations from the parity. In general, centralised wage bargaining, income policies and stable exchange rate policies are all features of relatively small (industrialised) economies that takes international prices as given and have relatively large sectors for tradables, i.e. economies that are exposed to relative large arbitrage pressure. It follows that such additional features need to be taken into account when assessing the partial effect of a nominal exchange rate regime on the real exchange rate behaviour.

The next section sketches some of the main features of the Norwegian economy, focusing on the wage and price setting behaviour, income and exchange rate policies. It appears that these factors have contributed to preserve the competitiveness of the economy in the face of considerable demand shocks. This overview will be helpful when interpreting the empirical results. For example, it may be misleading to ascribe our evidence in favour of the PPP theory to the Norwegian stable exchange rate policies and/or the arbitrage pressure.

3. The Norwegian economy

The Norwegian economy is relatively small, open and commodity based relatively to most of the other (western) European economies. The sum of its export and import is more than 1/3 of its GDP, which is almost the twice of that for e.g. France, Germany and Italy, see Haldane (1997). Around 1/2 of the total export is commodity based which is sold at fluctuating world prices, while imports are mainly manufactured goods with more stable prices. It is therefore exposed to considerable terms of trade shocks. The economy's openness is also testified by the relatively large weight, about 40%, in the Norwegian consumer price index (CPI) of prices on imported goods and domestically produced goods exposed to foreign competition.

Norway fully dismantled regulations on capital flows between Norway and abroad in July 1990; the deregulation process started in the early 1980s, see Olsen (1990). Domestic financial markets were also deregulated in about the same period, see Bårdsen and Klovland (2000). These structural changes have contributed to large fluctuations in the saving rate and financial investments abroad. Moreover, they have amplified the effects of other monetary, fiscal and external shocks to the economy and thereby increased fluctuations in the activity level, see e.g. Rødseth (1997b).

Norway has been a net exporter of crude oil since 1975 and of natural gas since 1977. Oil and gas production has constituted a fairly large share of its GDP, roughly 10-20% since the mid 1970s, see Aslaksen and Bjerkholt (1986) and Statistics Norway (1998). Oil and gas exports make up a large share of Norway's total export of goods and services; more than 1/3 of it in the period 1991-97, when oil production rose from about 1.7 to 3 million barrels a day, see Statistics Norway (1998). The petroleum wealth has been revalued several times due to large oil price fluctuations and discovery of new oil and gas fields. Its size can be gauged by the government's share of permanent income, which was estimated at between 48 and 66 billions krone in 1997, see Olsen (1997). Oil (and gas) revenues have been mainly used to finance non-oil fiscal deficits, on average 36 billion krone a year over the period 1980-96. The excess revenues have been used to cover non-oil current account deficits and to acquire financial assets abroad. The latter in order to mitigate the adverse shocks to the sector for non-oil tradables and as precautionary saving, see e.g. Olsen (1997). Positive net effects of a rise in oil prices on the Norwegian GDP, i.e. after taking account of the negative effects on traditional export industries due to lower demand abroad, are documented in e.g. Eika and Magnussen (2000) and Mork, Olsen and Mysen (1994).

The wage setting process is relatively centralised and to a large extent guided by the Scandinavian model of inflation, which also offers a quite good first approximation to the actual wage and price behaviour, see e.g. Rødseth and Holden (1990), Johansen, K. (1995) and Nymoen (1991). The central wage negotiations usually take place every second year but allows for local wage adjustment in the intermediate year. These adjustments are often small compared with the centrally determined wage growth and, arguably, to some extent accounted for in the central accord, see Rødseth and Holden (1990) and Holden (1990) for details. It has however been pointed out that the total wage growth, and even the centrally set wages, have often been above the main course. Nevertheless, the wage share in both sectors has been fairly stable over time. This has been partly ascribed to government interventions aimed at dampening the wage and price growth, see e.g. Calmfors (1990) and Rødseth and Holden (1990). Direct government interventions have mostly occurred since the early 1970s, which can be interpreted as a reflection of large pressure on wages due to the effects from oil wealth and revenues, see the history of wage bargainings since 1946 in Rødseth and Holden (1990, pp. 240).

Figure 4.2.b shows that (quarterly) inflation in Norway has largely been comparable to inflation in its trading partners in the post Bretton Woods period, except during the 1980s. During this decade, the Norwegian inflation was generally above that of its trading partners. However, neither in Norway nor in its trading partners has the inflation rate been at sufficiently high levels to be termed hyperinflation, which would have indicated the predominance of monetary shocks.

Concern for the viability of the sector for tradables is not only reflected in the choice of the wage setting system, but seems to have been the guiding principle for the governments involvement in wage setting and for the Norwegian exchange rate policy, at least since the discovery of North Sea oil. The government plays an active role in the wage and price setting processes to maintain the competitiveness of the non-oil sector for tradables. A permanent government commission serves the central wage bargainers by providing background information and outlining the consequences of different wage settlements. As noted above, the government has also intervened directly in the wage setting process whenever the wage growth has been far in excess of the main course. In 1973 and 1975-80, tax cuts and/or increases in government expenditures were traded for wage moderation. The government has also reduced taxes in advance of wage bargainings in order to influence their outcomes.

Since the end of the 1970s, the government involvement in wage negotiations has been less direct and it has to a large extent resorted to legal actions or voluntarily agreements to contain growth in wages and prices. In the period September 1978-December 1979, 1981 and later in 1988-89, growth in wages and prices was regulated through legislative actions, see Rødseth and Holden (1990). These wage and price controls had a significant effect on the wage growth during these years, though their initial effects were to some extent outweighed by compensatory wage growth in the subsequent wage settlements, see e.g. Nymoen (1989). Since 1992 the government has entered an agreement with the largest confederation of workers union (LO) to provide nominal exchange rate stability in exchange for wage moderation which is termed “the solidarity alternative”. Its success in terms of wage moderation is contended, however, see e.g. Evjen and Nymoen (1997) and Alexander et al. (1997).

Norway has mainly pursued a policy of exchange rate stabilisation against western European countries since the end of Bretton Woods system in 1971. Norway participated in the European “snake agreement” until 1978, but linked the krone to a trade weighted basket of currencies, mainly composed of western European currencies, when the ERM was established. Since October 1990, the krone has been stabilised against the ECU. Despite the stated aim of currency stabilisation, the value of the Norwegian krone has shown relatively large fluctuations however. The fluctuations have been allowed by changes in the currency basket and in the fluctuation margins across time. In addition, the krone has been devalued about 10 times since 1972, mostly during the 1970s. During the 1980s, the 9.2% devaluation of the krone in May 1986 stands out. This also marks a switch to a no-devaluation stance, since the krone has not been devalued since then. The devaluations were mainly carried out to correct for the weakening of the competitiveness of the economy due to excessive wage and price growth, see e.g. Norges Bank (1987), Skånland (1983) and Rødseth and Holden (1990).

Major changes in the value of the krone have often coincided with large fluctuations in oil prices. The devaluation in May 1986, was also preceded by a fall in oil prices. The krone was allowed to float in January 1997 and in the autumn of 1998 following appreciation and depreciation pressure, respectively. The value of the krone changed by about 10% relative to the ECU on both occasions, which coincided with unusually high and low oil prices, respectively, see Norges Bank (1997, 1998). In addition to these possibly oil price related currency crises, the krone was also allowed to float against the ECU in December 1992, following strong depreciation pressure triggered by the crisis in the ERM. The practice of exchange rate stabilisation against the ECU was resumed briefly afterwards, but without formal fluctuation margins, see Norges Bank (1995) and Alexander et al. (1997).

To summarise, the Norwegian economy is small and open with a large export share of commodities and hence exposed to large fluctuations in the terms of trade. However, the Norwegian wage setting system, the fiscal and exchange rate policies have been aimed at preserving the international competitiveness of the sector for non-oil tradables and to avoid growth in the sector for non-tradables at the expense of the former, especially since the discovery of relatively large oil resources. Therefore, these and other possible real shocks to the economy may not have affected the real exchange rate beyond the short run. Indeed, if wage and price setters adhere to the Scandinavian model of inflation, real shocks affecting prices through demand are not expected to last beyond the contract period of two years, as for monetary shocks, see subsection 2.3. The next section, however, draws a more nuanced picture of the real exchange rate behaviour.

4. Testing PPP in a univariate framework

The next subsection describes the data series for the nominal exchange rate and domestic and foreign consumer prices, focusing on their relation to each other in the light of the PPP theory. Thereafter, subsection 4.2 formalises the PPP theory in a univariate framework and employs an augmented Dickey Fuller (ADF) test to examine whether the real exchange rate behaviour is consistent with the PPP theory. This subsection also plots the implied equilibrium real exchange rate over time together with a 95% confidence interval to expose possible changes over time. The speed of adjustment towards the equilibrium rate is another main issue in this subsection.

4.1. Prices, the nominal and the real exchange rate

Figure 4.1 displays the value of the Norwegian trade weighted (effective) nominal exchange rate (E) and the Norwegian consumer price index (CPI) relative to a trade weighted index of foreign consumer prices (CPI^f) over the period 1972:1-1997:4. The trade weights are tabulated in Appendix A and suggest that Norwegian trade is not confined to a single dominant trading partner. This makes it more relevant to focus on the trade weighted exchange rate and prices rather than on bilateral exchange rates and prices.

Figure 4.1: *Trade weighted nominal exchange rate, E, (solid line) and relative consumer prices between Norway and trading partners, CPI/CPI^f, (boxed line).*

The overall impression from Figure 4.1 is that the actual exchange rate (E) does not evolve independently of the relative consumer prices (CPI/CPI^f), though it is more volatile than the relative consumer prices. One noticeable exception from this tendency is the relatively strong exchange rate appreciation until 1976/77, which is not matched by a comparable fall in the relative consumer prices in this period. From the late 1970s to about 1992, however, changes in the relative consumer prices appear to precede fluctuations in the exchange rate fluctuations. The large devaluation in May 1986 is commonly ascribed to the fall in oil prices in 1985/86, but the figure shows that it was also preceded by a rise in the relative consumer prices. The exchange rate fluctuations since 1992, in particular, seem to be driven by other factors than the relative consumer prices, since the latter are relatively stable in this period, see also Figure 4.2.d. However, the nominal exchange rate evolves around the relative consumer prices, which may be considered as the equilibrium level of the nominal exchange rate in the PPP framework, see subsection 2.1.

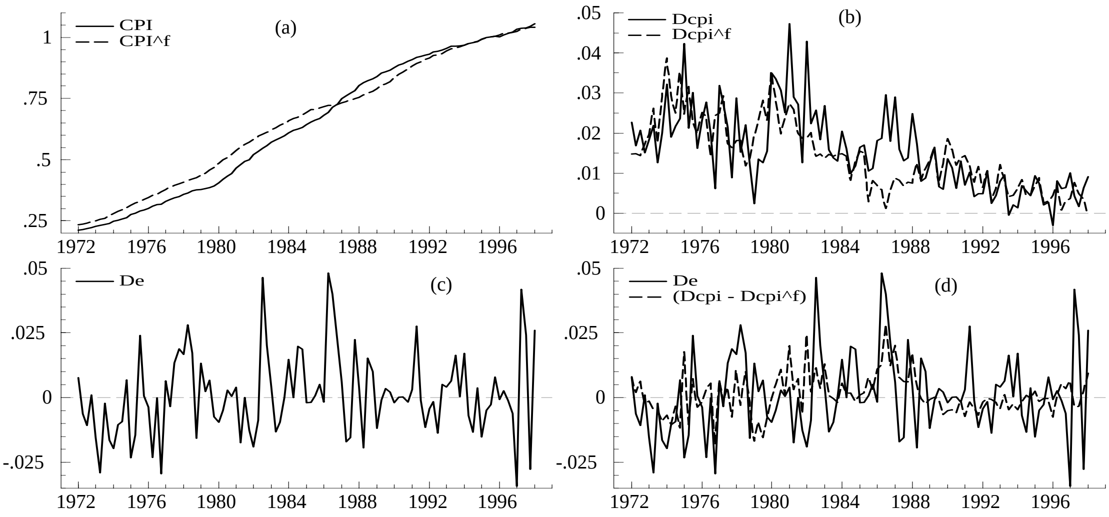

Figure 4.2: *The graphs display quarterly observations of different variables over period 1972:1-1997:4. (a) Consumer price indices for Norway and its trading partners, CPI and CPI^f, respectively. (b) Quarterly inflation rates, denoted by Dcpi and $Dcpi^f$. The prefix "D" denotes the first difference Δ. (c) Quarterly depreciation rate, De. (d) The depreciation rate and inflation differences.*

Figure 4.3 shows that changes in the nominal exchange rate (E) and the (redefined) relative consumer prices (CPI^f/CPI) tend to outweigh each other, especially before the 1990s. Thus fluctuations in the real exchange rate, $R \equiv E(CPI^f/CPI)$, have a smaller range compared with the fluctuations in the nominal exchange rate and the relative consumer price level. In the late 1980s and early 1990s movements in the real exchange rate are mainly driven by the relative consumer prices since the nominal exchange rate is relatively stable in this period. The case is the opposite after 1992/93 when fluctuations in the real exchange rate can be almost entirely ascribed to fluctuations in the nominal exchange rate, as the relative consumer prices are quite stable. Figure 4.3 also indicates that the tendency of the nominal exchange rate and the relative consumer prices to outweigh each other is stronger when the fluctuations are large compared with when they are small. This is apparent when the period before e.g. 1987 is compared with the period afterwards.

Figure 4.3 gives the impression that the real exchange rate is likely to have evolved around a

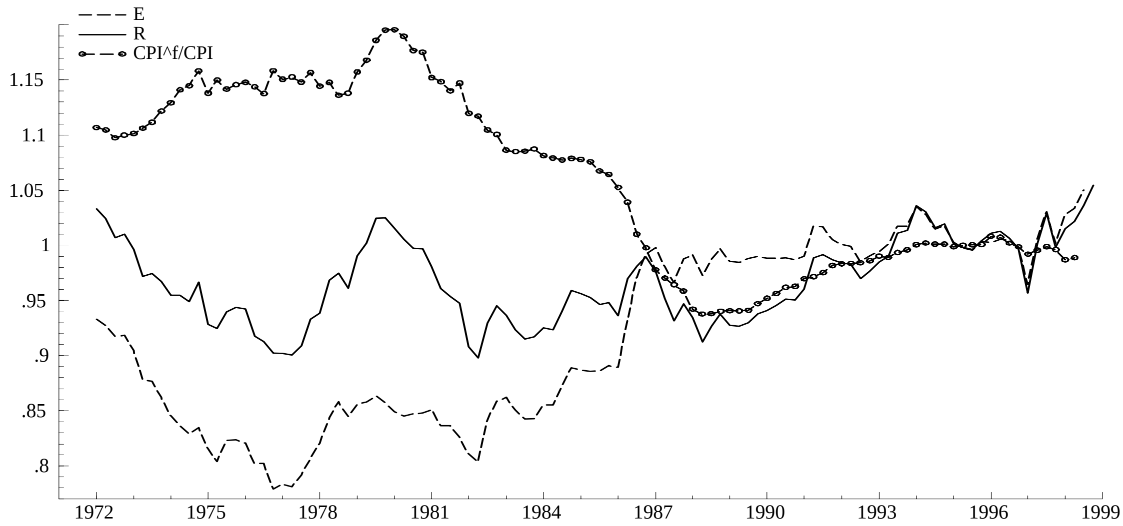

Figure 4.3: *Nominal exchange rate, E, (dashed line), real exchange rate, R, (solid line) and relative consumer prices between trading partners and Norway, CPI^f/CPI (circled line).*

constant level and that the range of its fluctuations have possibly declined over time. At least, it is not obvious that the range has steadily increased over time, as implied by the random walk hypothesis of real exchange rate, cf. Mark (1990). Indeed, the behaviour of the real exchange rate resembles that of a (weak) stationary time series that displays fluctuations within a given range and reversion towards a constant mean level. The next subsection tests this impression formally.

4.2. Augmented Dickey Fuller (ADF) test

The PPP theory implies that the real exchange rate (R) evolves around a constant mean or equilibrium level, γ, over time, see equation (2.3). This proposition can be formalised as follows:

$$R_t = \gamma + \sum_{i=1}^{p} \psi_i (R_{t-i} - \gamma) + \varepsilon_t. \tag{4.1}$$

Here ε_t is the error term, assumed to be identically, independently normally distributed with zero mean and constant variance, σ^2, i.e. IIDN(0, σ^2).

Under the PPP theory, the (absolute) value of $\sum_{i=1}^{p} \psi_i$, hereafter denoted as ϱ, should be less than 1. Otherwise R will not revert to its equilibrium level γ, i.e. not be a stationary process. The speed of adjustment towards the equilibrium level is inversely related to the (absolute) value of ϱ. R follows a random walk process if $\varrho = 1$, in which case every shock has a permanent effect on R, making it drift away randomly from any level. If $\varrho = 0$, every shock has a transitory effect on R and it will fluctuate randomly around γ. This case can be interpreted as a formalisation of the PPP theory if it holds continuously. But, even Cassel recognised that purchasing power parity is frequently violated and a given violation can persist for long time periods, see Cassel (1922).[5] This notion of the PPP theory corresponds to a value of $\varrho \in (0,\, 1)$.

Restrictions on ϱ can be tested by employing the ADF test, see e.g. Banerjee, Dolado, Galbraith and Hendry (1993, ch. 4) for details. The null hypothesis under the ADF test is that the real exchange rate is a random walk process, i.e. $\varrho = 1$. The alternative hypothesis is that ϱ is less than 1 in absolute value.[6] In order to separate out the unobservable γ from the actual rate R, equation (4.1) is rephrased in the ADF framework as follow, with the constant term α defined as $\gamma(1-\varrho)$:

$$\Delta R_t = \alpha - (1-\varrho)R_{t-1} + \sum_{i=1}^{\mathrm{p}-1} \psi_i \Delta R_{t-i} + \varepsilon_t. \tag{4.2}$$

This equation was estimated by OLS for a value of p equal to 6, which appeared sufficiently high to avoid any structure, e.g. autocorrelation, in the residuals. The coefficients of ΔR_{t-4}, ΔR_{t-5} and also of ΔR_{t-2}, however, appeared to be insignificantly different from zero with p-values, 0.84, 0.27 and 0.28, respectively. Joint zero restrictions on these coefficients were accepted by a F-test at a p-value of 0.44. Table 4.1 sets out a parsimonious version of the general model, obtained by (sequential) omission of these terms.

The diagnostics of the estimated equation do not indicate systematic structure in the residuals, increasing the reliability of the coefficient estimates. Due to some outliers, however, the normality assumption is violated at the 1% level of significance, cf. Figure 4.5.

The null hypothesis of, $\varrho = 1$, or equivalently of $1 - \varrho = 0$ is rejected at the 5% level when using the Dickey-Fuller critical values. Since both the ADF model (4.2) and the presumed data generating process (4.1) contain the same type of deterministic term, a constant, one may argue for the use of critical values from the normal distribution. West (1988) shows that the t-statistic, e.g. $(1-\widehat{\varrho})/SE(\widehat{\varrho})$, will be asymptotically normally distributed under the null hypothesis of unit root, if both the model employed to test for unit root and the data generating process contain same type of deterministic terms, constant term and/or trend. Accordingly, the observed t-value -3.057

[5] For instance, "...this restoring of the equilibrium may take a long time, especially if the forces which keep the rate down are powerful and are continually at work." Cassel (1922, pp.158).

[6] The case with $-1 < \varrho < 0$, implies cyclical convergence towards $\overline{R}$, which seems implausible. This because it implies a systematic overshooting and undershooting of R relative to $\overline{R}$, as in the well known cobweb model.

Table 4.1: A univariate model for the real exchange rate.

$$\Delta\widehat{R}_t = \underset{(3.048)}{0.126} - \underset{(-3.057)}{0.131} R_{t-1} - \underset{(1.824)}{0.183} \Delta R_{t-1} + \underset{(1.266)}{0.134} \Delta R_{t-3}$$

Sample: 1972(2) -1997(4), 103 Quarterly observations.

$t - ADF = -3.057$, DF-*Critical values:* $5\% = -2.887$, $1\% = -3.489$

Diagnostics

R^2	=	0.101
Standard error of residuals: $\widehat{\sigma}$	=	0.015
Durbin Watson statistic: DW	=	1.95
Autocorrelation 1-5: $F_{ar,1-5}(5,94)$	=	0.51[0.77]
ARCH 5: $F_{arch,1-5}(5,89)$	=	1.11[0.36]
Normality: $\chi^2_{nd}(2)$	=	9.1[0.011]*
Heteroscedasticity: $F_{het,\mathrm{Xi}^2}\ (6,92)$	=	1.86[0.10]
Heteroscedasticity: $F_{het,\mathrm{XiXj}}\ ,(9,89)$	=	1.27[0.26]
Model specification: RESET $F(1,98)$	=	0.13[0.72]

Note: $F_{ar,1-5}$(df1, df2) tests for autocorrelation in the residuals up to 5 lags. df1 and df2 denote degrees of freedom. $F_{arch,1-5}$(df1, df2) tests for autoregressive conditional heteroscedasticity (ARCH) up to order 5, see Engel (1982). The normality test with chi-square distribution is that by Jarque and Bera (1980). $F_{het,\mathrm{XiXj}}$(df1,df2) and F_{het,Xi^2}(df1, df2) are tests for residual heteroscedasticity due to omission of cross products of regressors and/or squares of regressors, see White (1980). RESET F(df1, df2) is a regression specification test. It tests the null hypothesis of correct model specification against the alternative hypothesis of misspecification, indicated by the significance of the square of the fitted value of the dependent variable in the model, see Ramsey (1969). The results in this table are based on the implementation of these tests in PcGive 9.10, see Hendry and Doornik (1996). Here and elsewhere in this study, a raised star * indicates rejection of the null hypothesis at 5% level of significance, while two stars** indicate rejection of the null hypothesis at 1% level of significance. Furthermore, p-values in square brackets.

should be compared with the 95% critical value of -1.95 from the normal distribution. Banerjee et al. (1993, pp. 105), however, recommend the use of Dickey-Fuller distribution in finite samples to avoid overrejection of a possibly true null hypothesis.

The outcome of the ADF-test is consistent with the PPP theory. The real exchange rate does not seem to be a random walk process, but an equilibrium reverting process. The derived estimate of the equilibrium level is $0.126/0.131 \approx 0.96$, see Table 4.1. The speed of adjustment towards the long run equilibrium is 0.131, which is relatively fast. The half life of a given deviation from the equilibrium real exchange rate is about 6 quarters, while about 2/3 of a deviation is eliminated within a period of 10 quarters, see Figure 4.4.[7] We elaborate on the adjustment process towards

[7] The estimate depends on whether one employs the commonly used formula for half life, i.e. $\ln(1/2)/\ln(\widehat{\varrho})$ where $\widehat{\varrho}$ is the estimated value of ϱ, or impulse response analysis, see e.g. MacDonald and Hallwood (1994, pp. 133). In the first case the half life is 4.94 or 5 quarters since $\widehat{\varrho} = -0.131 + 1 = 0.869$. However, if one takes into account the distribution of e.g. $\widehat{\varrho}$ on the different lags of R by impulse response analysis, the estimate of half life increases by 1.4 quarters in this case, see Figure 4.4. The figure is based on an AR(4) model for the real exchange rate, a

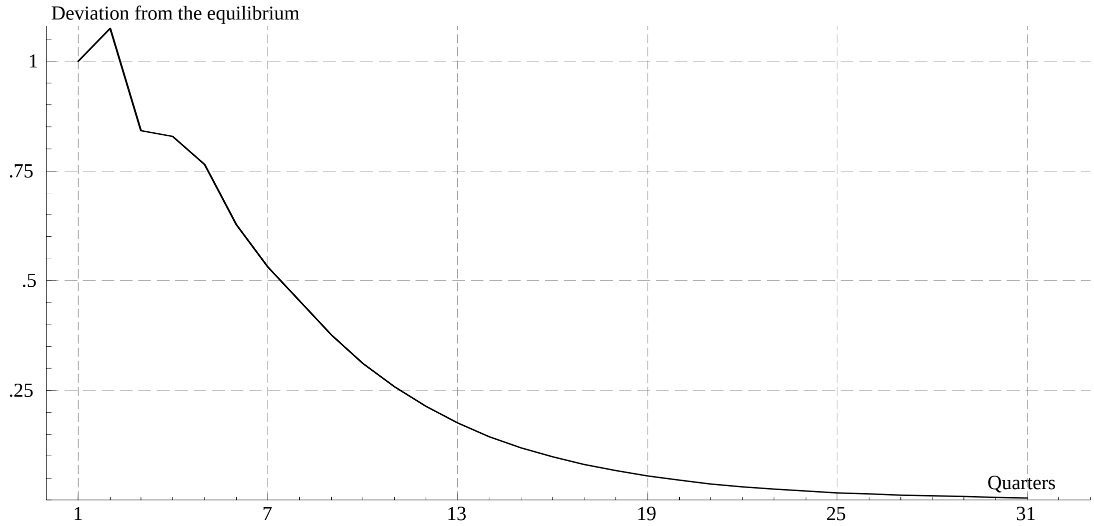

Figure 4.4: *Real exchange response when exposed to a shock of size 1 in quarter 1, when the real exchange rate is at its equilibrium level.*

the long run equilibrium after examining the constancy of the equilibrium real exchange rate.

4.3. Testing the constancy of the equilibrium real exchange rate

The real exchange rate model in Table 4.1 has been estimated recursively and subjected to a number of parameter constancy tests in order to evaluate the assumption of parameter constancy, in particular the constancy of γ. The upper panel of Figure 4.5 plots the recursive OLS estimates of α and $-(1-\varrho)$ together with ± 2 times their recursively estimated standard errors. The impression is of parameter stability, which is not contradicted by the Chow tests, used to test the overall stability of the model. However, due to an outlier in 1997, the 1-step up Chow test and the break point (Ndn) Chow tests indicate a parameter change in 1997.[8]

The relatively stable estimates of α and of $-(1-\varrho)$ imply that the recursively derived estimates of γ, the equilibrium real exchange rate, are stable too. Figure 4.6 shows the estimated values of R_Eq $\pm 2SE$, where R_Eq is the estimated value of γ, over the period 1976:1 - 1997:4.[9] The

reformulation of the model in Table 4.1.

[8] A dummy variable, *id97q1* with a value of 1 in 1997:1, -1 in 1997:2 and zero elsewhere was used to take account of the extreme values in 1997. This resulted in no-rejection of the parameter constancy assumption by the tests employed above, including the Chow tests, at the 5% level. Moreover, the dummy also helped to improve the model diagnostic, cf. Table 4.1. In particular, the normality assumption regarding the residuals was not rejected at 10% level. The t-ADF from this model was -3.147.

[9] In fact, R_Eq has been obtained by recursive estimation of an autoregressive model for R with 4 lags, i.e. AR(4), which is just a reparameterisation of the model in Table 4.1 with p = 4. This, for our convenience in deriving the corresponding (asymptotic) standard errors. As noted earlier, the AR(4) model estimated on the full sample was also employed in the impulse response analysis. Recursive estimates of γ obtained by $\widehat{\alpha}/(1-\widehat{\varrho})$ are slightly different from

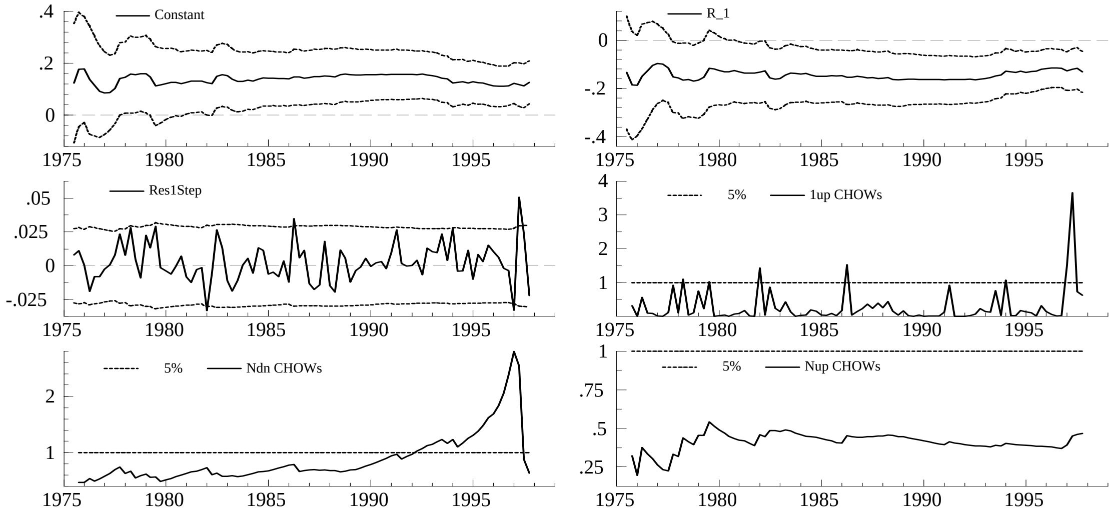

Figure 4.5: *Recursive statistics for the ADF model in table 4.1. Top panel: recursive estimates of the constant term (α) $\pm 2SE$ and of -(1-ϱ) $\pm 2SE$. Middle panel: 1-step ahead residuals $\pm 2SE$ and 1-step ahead Chow test statistics normalized by the critical value at 5% level of significance. Bottom panel: Break point Chow tests and N-step ahead Chow tests. Both test statistics are normalized by the accosiated critical values at 5% level.*

standard errors have been (recursively) estimated by following the procedure suggested in Bårdsen (1989). Figure 4.6 also displays the actual real exchange rate, R, in the same period.

The estimates of γ are remarkably stable around 0.95 over the period 1978:1-1997:4. The γ-estimates before 1978 are relatively less stable, but then they are based on quite few observations. This is also reflected in the relatively large standard errors of the estimates from this period. If we disregard these, an estimate of γ at time $t+n$ where $n>0$, remains well inside the $\pm 2SE$ band of a $\gamma-$estimate at any time t from 1978 and onwards. It follows that the constancy of γ cannot be rejected at the 5% level in this period.

Fluctuations of the (actual) real exchange rate, R, against the estimated equilibrium level in Figure 4.6, provide more information about how fast a given deviation from the equilibrium level is eliminated. In the figure, R fluctuates around the estimated equilibrium rate until about 1990. In this period, most of the deviations from equilibrium seem to be eliminated within 1-2 years. The exception is the late 1970s when the deviation lasts about 3.5 years. R is above its equilibrium rate, i.e. at a depreciated level relative to the equilibrium level, during this period. This may partly owe to a devaluation of the krone by 8% within the "snake" in February 1978 and thereafter, avoidance

R_Eq during the early 1970s owing to few observations, elsewhere they are almost indistinguishable as expected. As suggested by the graphs for the recursive estimates of α and -$(1-\varrho)$, recursive estimates of γ obtained by $\widehat{\alpha}/(1-\widehat{\varrho})$ are relatively more stable than R_Eq in the mid 1970s.

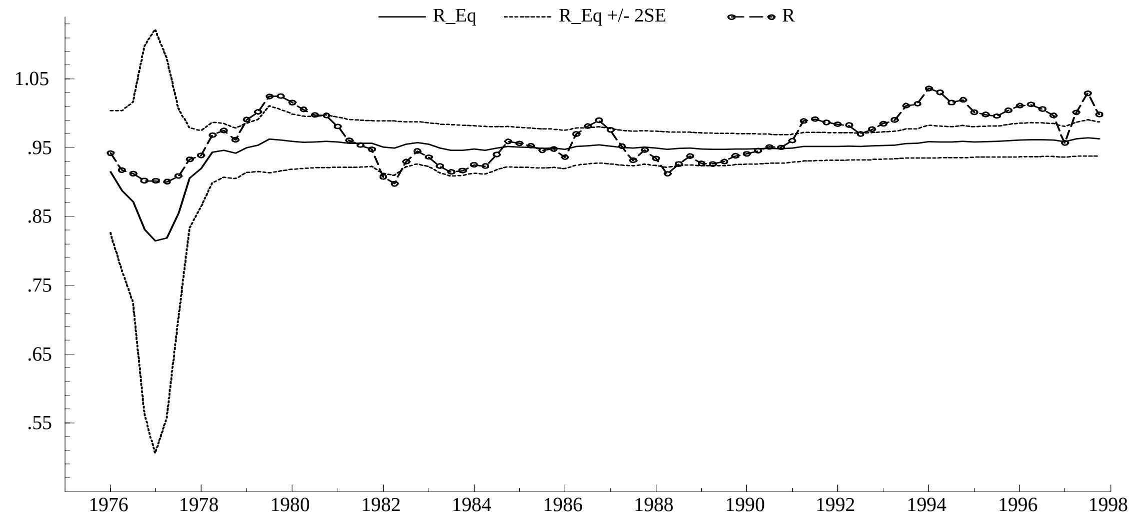

Figure 4.6: *Solid line shows recursive estimates of the equilibrium real exchange rate,* γ, *here denoted by R_Eq. The recursive estimates have been derived for period 1975:2-1997:4. The initial estimate is based on 14 observations from period 1972:2-1975:4. The dashed lines represents the 95% confidence interval for R_Eq. The dashed line with circles shows the actual real exchange rate,* R, *in this period.*

of a revaluation of about 2-4 % within the snake in October 1978, see Norges Bank (1987) and section 3. The wage and price freeze from September 1978 to December 1979 appears to be another factor behind the real exchange rate depreciation during this period.

During the 1990s, R is again mostly above the estimated equilibrium level. The deviation is abruptly eliminated by the relatively large nominal appreciation in 1997:1, but R returns to its previous level shortly afterwards, see Figure 4.3. If we disregard this single quarter, the 1990s can be defined as a 7 years period with R above γ.

The persistent real exchange rate depreciation relative to the equilibrium rate during the 1990s may be related to the no-devaluation stance since the late 1980s and/or the "solidarity alternative" since 1992, according to which nominal exchange rate stability is offered for wage and price moderation, see section 3. A value of $R > \gamma$ suggests that the real exchange rate is likely to appreciate. This can occur through nominal exchange rate appreciation and/or by a rise in CPI/CPI^f. The "solidarity alternative" appears to inhibit the real appreciation by obstructing both of these channels. Even if the wage and price moderation due to this agreement is insignificant, as argued by e.g. Evjen and Nymoen (1997), a stable exchange rate policy entails that the real appreciation has to occur mainly by way of a rise in CPI/CPI^f, which takes a longer time than nominal appreciation in general.

The coincidence of the relatively long period of real exchange rate depreciation with the no devaluation stance and the "solidarity alternative", also lends support to the proposition that the relatively fast adjustment toward the equilibrium before the 1990s, in particular before the late 1980s is to a large extent the result of frequent devaluations until the middle of 1986, cf. Rødseth and Holden (1990) and Calmfors (1990).[10] This is especially true, if the "solidarity alternative" has itself been ineffective in bringing about a wage and price moderation, i.e. the wage and price processes have remained as in the 1970s and 1980s.

Summary and conclusions: Both the graphical analysis and a formal test conducted within a univariate model are consistent with the PPP theory. The test suggests that real exchange rate is a stationary process which converges towards its equilibrium level. Tests for parameter stability, in particular recursive estimates of the equilibrium real exchange rate have not revealed significant changes in the equilibrium rate over time, at least not over a 20 years period from 1978:1 to 1997:4. Theories that imply a change in the equilibrium real exchange rate in the face of a discovery or a revaluation of natural resources, fail to explain this finding.

Deviations from the equilibrium rate are eliminated relatively fast. The half life is about 1.5 years, which is less than the consensus estimates from the PPP literature that vary from 2.5 to 6 years for industrial countries. The measure of half life has been shown to disguise fairly large variation in the periods of deviations from the equilibrium rate, however; periods of deviations from the equilibrium rate has varied in the approximate range of 1-7 years. Since comparable results are not available in the literature, as it usually focuses on the half life measure, it is not possible to assess how typical the observed range is.

It is also difficult to assess the exact contribution of each of the factors that may have played a role in bringing about a rapid adjustment. Yet, if we confine ourselves to the 20 years period for which we have more certain results, our impression is, that the fast adjustment mainly owes to the active use of devaluations until the middle of 1986. This is consistent with the persistent real exchange rate depreciation during the 1990s, when no devaluation did take place. Centralised bargaining itself appear to be another explanation, since most a given deviation from the equilibrium is, on average, eliminated within a 1-2 years period, which coincides with the length of wage contracts. But, given the relative openness of the Norwegian economy, the arbitrage pressure is

[10] A stable exchange rate policy under the prospects of nominal appreciation is also classified as an "exchange rate protection" policy, i.e. competitiveness preserving policy, see section 2.3 and e.g. Corden (1982). This may partly explain why it has been supported by the Norwegian labour and employers unions. Furthermore, why the monetary authorities, whose policies have traditionally been guided by the objective of preserving the competitiveness of the economy, have not needed to retreat from the no-devaluation stance, see the discussion in Section 3.

also likely to be relatively strong. Accordingly, the 1-2 years period can also be interpreted as the time lag in price setting due to menu costs. However, if the arbitrage pressure is assessed in the light of the weak empirical support for the law of one price, suggested by e.g. Goldberg and Knetter (1997), then centralised bargaining seems to have had a stronger influence on the speed of adjustment than arbitrage pressure, see subsection 2.3.

Income policy, interpreted narrowly as changes in fiscal policy to influence the outcome of wage settlements, is unlikely to have played a considerable role in bringing about a rapid convergence towards the equilibrium. This because it has not been actively used during this 20 years period, at least not as often and explicit as before the late 1970s. However, attempts to control growth in wages and prices through legal actions in the late 1970s, or voluntarily through the "solidarity alternative" during the 1990s, have apparently kept the real exchange rate at a depreciated level relative to its equilibrium for a longer period than it would have been otherwise.

5. Testing PPP in a multivariate system framework

The PPP theory implies symmetry and proportionality restrictions on e.g. domestic and foreign prices in a long run nominal exchange rate equation, see equation (2.4). In the previous section, these restrictions were imposed by the definition of the real exchange rate. A number of studies have, however, questioned the plausibility of these restrictions in the light of e.g. possible variation in the construction of aggregate prices across countries and measurement errors, see among others Froot and Rogoff (1994). This criticism finds support in numerous empirical studies that report considerable deviations from both restrictions, see e.g. MacDonald (1995)

The present section employs the multivariate cointegration procedure of Johansen (1988) to test the symmetry and proportionality restrictions, see e.g. Juselius (1992) and Johansen and Juselius (1992). Single equation models as equation (2.4) have been popular in tests of the symmetry and proportionality restrictions, using either the nominal exchange rate or domestic prices as the left hand side variable. Such tests are however potentially biased if conditioning on the right hand side variables is invalid. Traditionally, the criticism has been formulated in terms of a potential simultaneity bias and the suggested remedy has been to use more appropriate estimation methods, maintaining a single equation framework, see e.g. Krugman (1978). A single equation framework is however only justified for the purpose of drawing inference on parameters of interest if the right hand side variables are weakly exogenous for the parameters of interest, see Engle et al. (1983). Hence, joint modelling of the variables is required to avoid biased inference when this assumption is violated.

The multivariate cointegration procedure is employed within vector autoregressive (VAR) models that not only treats the nominal exchange rate and domestic and foreign consumer prices as endogenous variables, but also a number of other variables that are commonly regarded as important determinants of nominal and real exchange rates, in particular the oil price in our case. A well specified VAR model enables one to draw valid inference on e.g. the long run effects of a variable and, in addition, offers a convenient framework to test whether valid inference is feasible by conditioning on a subset of variables, see Engle et al. (1983) and Johansen (1995, ch. 8). We exploit both of these capabilities in the following tasks:

Firstly, we examine the long run relation between the nominal exchange rate and the prices, and test for long run effects of the additional variables on these, especially of oil prices on the nominal exchange rate. The evidence in favour of a constant equilibrium real exchange rate in the previous section suggests that the additional variables are unlikely to have long run effects on the real exchange rate. Tests for their effects on the nominal exchange rate and the prices are not only interesting in their own right, but may also shed light on whether they indirectly affect the real exchange rate through the nominal exchange rate and the prices. For instance, one cannot exclude the possibility that e.g. oil prices have an appreciating effect on the nominal exchange rate which in the long run is cancelled out by a rise in the relative price, CPI^f/CPI, brought about by higher oil prices, leaving the equilibrium real exchange rate constant. If so, oil prices may have considerable influence on the real exchange rate in the short and medium run.

Second, we investigate whether, and to what extent, the consumer prices and the nominal exchange rate adjusts to a deviation from the parity, provided that it holds. The graphical analysis in the previous section has revealed that both the relative price, CPI^f/CPI, and the nominal exchange rate tend to adjust when there is a deviation from the equilibrium real exchange rate. This behaviour can be analysed more rigorously in the VAR framework by testing whether the consumer prices and the nominal exchange rate are weakly exogenous for the parameters defining the long run relation between them. The outcome of these tests may throw light on the speed of adjustment towards the long run relation. In particular, it can provide information on the relative contribution of the nominal exchange rate and the domestic prices in bringing about adjustment towards the long run, although it will not be possible to identify the partial contribution of the factors discussed in subsection 2.3. And secondly, the outcome of the tests may suggest whether shifts in the nominal exchange rate process is likely to affect the long run behaviour of the domestic prices, i.e. whether the nominal exchange rate is super exogenous for the parameters determining the long run behaviour of the prices.[11]

The next subsection motivates the choice of the variables to be included in the information set and examines their time series properties. Subsection 5.2 discusses whether it is necessary to conduct the analysis in a full VAR model or whether a conditional VAR model may be employed and, based on this discussion, it offers a guide to the subsequent analysis.

5.1. Choice of variables

The choice of variables is mainly motivated by earlier studies of PPP, e.g. Juselius (1992) and Johansen and Juselius (1992). In addition to the (natural) log of E, CPI and CPI^f, which have already been defined, the following variables are included in the information set: the log of the oil price ($oilp$), the domestic bond rate (RB), the trade weighted government bond rate (RB^f) and a measure of net financial investment abroad relative to growth in the Norwegian GDP, $FI.Y$, see Appendix B for precise definitions.[12] The data set consists of seasonally non-adjusted quarterly observations and the sample covers the period from 1971:1 to 1997:4.[13] The estimation period however starts in 1972:2 owing to lags in the variables. The variables, including the level of the crude oil price in US dollars ($OILP$), are plotted in Figures 4.1, 4.2, 5.1 and 5.2.

The domestic bond rate was chosen in preference to the money market rates as the latter display quite erratic behaviour until the end of the 1970s, probably because of a thin domestic money market and regulations of international capital flows, see Figures 5.1 and 5.2. The government bond rate of Norway's trading partners is used as the Norwegian exchange rate was stabilised against the currencies of a majority of these countries, see section 3. This policy entails a close link between the domestic and foreign interest rates under free international capital movements. Figure 5.1, however, indicates large gaps between these interest rates in the 1970s and 1980s. These can be partly ascribed to the Norwegian capital regulations which were not fully dismantled before 1990 and were relatively tight during the 1970s, but may also reflect devaluation expectations and risk premia due to the frequent devaluations in this period.

The oil price is included to test for long run effects of oil prices on the exchange rate.[14] Oil prices, closely linked to gas prices, offer an indication of the oil and gas wealth and of their revenues

[11] Weak exogeneity will be defined more precisely in the main text. A variable is super exogenous for parameters of interest if: (i) it is weakly exogenous and (ii), all parameters in the conditional model are invariant to changes in the process for the weakly exogenous variable, see Engle et al. (1983).

[12] Log transformation of E, CPI, CPI^f and $OILP$ will make it possible to interpret all the coefficient estimates as elasticities. Note that RB, RB^f and $FI.Y$ are measured in rates, hence they do not require log transformation.

[13] Initially, RB^f, was not readibly available from 1971:1 but from 1972:1. To avoid losing observations when modelling, it was extended backwards with the same observations as in 1972, for convenience.

[14] This is in contrast to e.g. Johansen and Juselius (1992) where only relative changes in the oil price, $\Delta oilp$, are included.

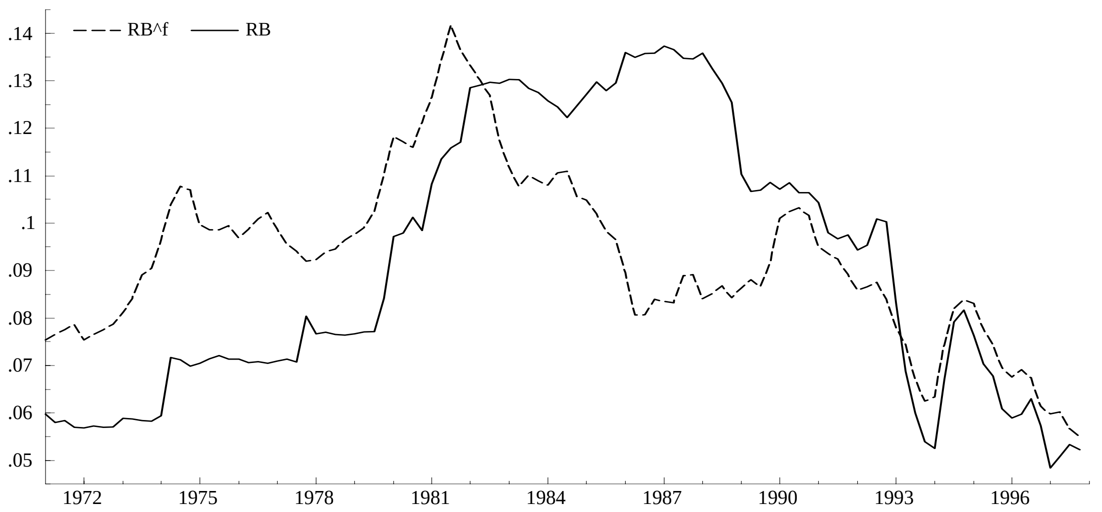

Figure 5.1: *Interest rates on government bonds in Norway and in its trading partners, RB and* RB^f*, respectively. The period is 1971:1-1997:4.*

on a regular basis. As shown in Skånland (1987), current oil prices tend to influence the estimates of future oil prices and thereby the estimates of permanent income from the oil and gas, which are not available on a regular basis. Thus a possible effect of oil prices on the nominal exchange rate and/or on prices can indicate whether revaluations of petroleum wealth and changes in the permanent income have affected the long run real exchange rate. Note that oil prices, as well as $FI.Y$ (to be discussed below), are expected to have short run effects on the real exchange rate within the PPP framework, see subsection 2.2. A number of authors have argued, however, that e.g. oil prices also affect the Norwegian nominal and real equilibrium exchange rates, see e.g. Alexander et al. (1997) and Haldane (1997). An assessment of long run oil price effects on the exchange rate can provide direct evidence on this issue.

Foreign net financial investment in Norway relative to growth in GDP ($FI.Y$), i.e. the negative of net financial investment abroad relative to growth in GDP, is another measure that can be used to assess the possible effects of changes in the petroleum wealth and revenues on the nominal and real exchange rates. As noted in section 3, government savings made possible by the oil revenues have been used to acquire financial assets abroad. This investment, or saving, may reflect current and perceived future revenues from the petroleum sector and future import bills. It can thereby offer an indication of the required size of the sector for non-oil tradables, since import expenses not covered by future oil revenues and returns on assets abroad have to be met by the non-oil sector for tradables. Movements in $FI.Y$ may therefore influence the nominal and real exchange rates.

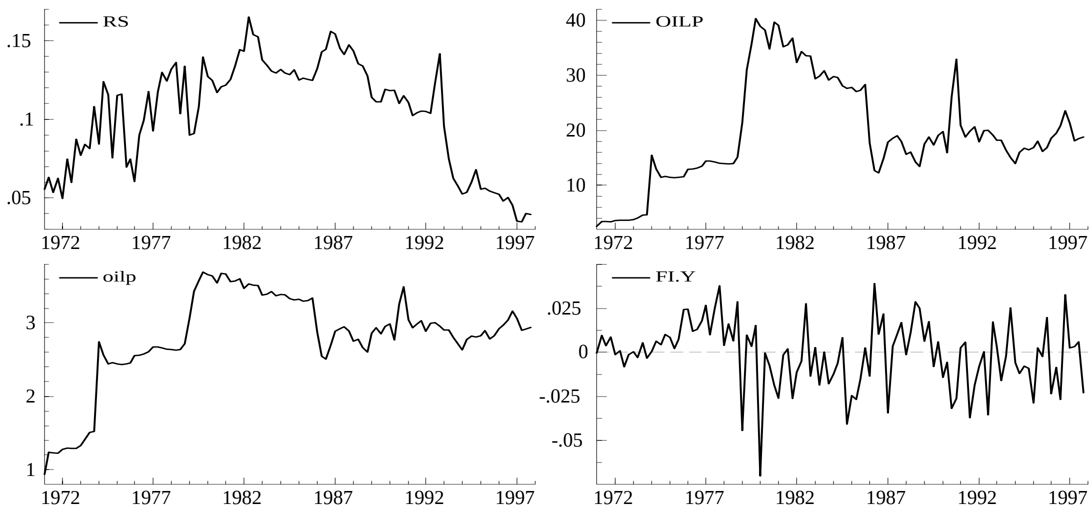

Figure 5.2: *From top left: (a) Three months money market rate in Norway, RS. (b) Price of Brent Blend crude oil in US dollars, OILP. (c) Natural log of OILP, oilp. (d) Foreigners financial investment in Norway scaled by the Norwegian GDP, FI.Y. The period is 1971:1-1997:4.*

Its relevance for the exchange rates is also suggested by the effects of capital flows on the (relative) demand and supply for the domestic currency, see e.g. Gibson (1996).

Productivity differentials and government spendings are omitted from the analysis to keep the analysis of the long run relations tractable. These variables have received mixed support in studies of PPP between developed countries, including those based on Norwegian data, see Froot and Rogoff (1994), Akram (2000), Samiei (1998) and Edison and Klovland (1987). In subsection 4.3, we found the long run real exchange rate to be remarkably constant over most of the sample period. This finding indicates that these variables are unlikely to have had long run effects on the nominal and real exchange rates.

Finally, it should be noted that the chosen set of variables is a reflection of one of the main objectives of this paper, namely to examine the short and long run behaviour of the Norwegian nominal exchange rate. The chosen set of variables is therefore likely to enable a more satisfactory characterisation of the nominal exchange rate behaviour than that of the other variables. However, it may still be adequate to sketch the long run behaviour of the other variables or, at least, illuminate aspects of it that have a bearing on our methods and results. The discussion on the choice of a full VAR model versus a conditional VAR model elaborates on this issue.

5.1.1. Time series properties

The time series properties of the chosen variables are tested to avoid combining variables with different order of integration which can lead to spurious relations, see Banerjee et al. (1993, ch. 3). Information about the degree of integration can also be useful when identifying possible long run relations between the variables.

Table 5.1: ADF tests for unit root, constant and trend included.

Variables	$1-\widehat{\varrho}$	t-ADF	ADF(p)	k
e	-0.094	-3.169	1	4
Δe	-0.815	-8.128**	0	3
cpi	-0.001	-0.111	5	7
Δcpi	-0.521	-4.775**	4	5
cpi^f	-0.006	-1.371	8	11
Δcpi^f	-0.351	-3.864*	7	9
RB	-0.018	-1.151	8	7
ΔRB	-0.724	-6.573**	6	6
RB^f	-0.057	-2.623	3	6
ΔRB^f	-0.686	-6.748**	3	5
$FI.Y$	-0.619	-5.133**	7	7
$oilp$	-0.079	-2.424	5	5
$oilp^a$	-0.170	-3.850*	5	5
$OILP$	-0.059	-1.733	5	6
$OILP^a$	-0.085	-2.195	5	6

Note: Dickey -Fuller critical values: 5% = -3.457, 1% = -4.057. Constant and trend included. Sample 1972:2-1997:4. [a] When using sample 1974:1-1997:4. p denotes the largest significant lag and k denotes the number of regressors.

Table 5.1 sets out the results from ADF tests of the order of integration. ADF models similar to model (4.2) were formulated, but with a trend term, t, in addition to the constant term. The trend was included to allow the null hypothesis of a stochastic trend to be tested against the alternative of a deterministic trend.

The ADF tests were conducted by formulating models with 8 lags of a dependent variable and sequentially omitting lagged terms that appeared to be insignificant, say at 20% level, since attention was also paid to the diagnostics of each of the ADF-models. Note that too few lags may result in overrejection of the null hypothesis when it is true, while too many may lead to underrejection of the null hypothesis when it is false, see e.g. Banerjee et al. (1993, ch. 4). Column 4 of Table 5.1 shows the highest retained lag, p, while column 5 indicates the number of regressors, inclusive a constant and a trend. The data sample covered the period 1972:2-1997:4, except for *oilp* and *OILP* whose time series properties were additionally tested on data from the period 1974:1 to 1997:4, to control for the effect of OPEC I.

Table 5.1 indicates that the level of *e, cpi,* cpi^f, *RB* and RB^f are integrated of order 1 since their first differences seem to be integrated of order zero (stationary).[15] *FI.Y* appears to be a stationary variable, see also Figure 5.2. The evidence on the oil price is mixed. The initial test suggests that *oilp* is an integrated variable. The oil price series is however notorious for breaks, associated with e.g. OPEC I, OPEC II and the Gulf War, see Figure 5.2. Studies show that the ADF test suffers from low power when there are breaks in a series, see e.g. Perron (1989). Indeed, a number of studies argue that the oil price is not an integrated variable once infrequent changes in its mean are allowed for, see e.g. Perron (1989), Green, Mork and Vaage (1996), and Horsnell and Mabro (1993, ch. 11).

When *oilp* is tested on a shorter sample, starting from 1974:1 instead of 1972:2, to pass over the low oil prices in the pre-OPEC I period, the ADF test rejects the null hypothesis of integratedness at the 5% level, even though the other shocks are not accounted for. In the case of *OILP,* however, the null hypothesis is not rejected even when the sample starts in 1974:1. In general, the time series properties of a variable carry over to a non-linear transformation of the variable, see Granger and Hallmann (1991). One possible explanation for this inconsistency may be that abrupt changes in *OILP* are to some extent suppressed in its log transformation, *oilp*, making it "easier" for the ADF test to reject the null hypothesis. The decision on whether or not oil prices should be treated as a non-integrated variable (with infrequent changes in its mean) is left to tests that are conducted within the multivariate cointegration framework.

5.2. Choice of models

This subsection discusses the choice between a full vector autoregressive (VAR) model and a conditional VAR model for the purpose of drawing valid inference on the number of long run relations (cointegrating relations) between variables and on parameters of interest.[16] Parameters of interest define particular long run relations between variables and measure their response to deviations from these long run relations. A conditional VAR model, obtained by conditioning on some of the variables, can simplify the analysis and increase the power of tests owing to its

[15] Note that stationary inflation rates, Δcpi and Δcpi^f, and non-stationary nominal interest rate, RB and RB^f, imply non-stationary real interest rates. This is not consistent with the Fisher hypothesis which implies a stationary real interest rate. A number of studies, however, regard the inflation rate to be integrated of order 1. But then order of integration is not an inherent property of a time series, cf. Hendry (1995). A time series can display a non-stationary behaviour in one sample and a stationary behaviour in another sample.

[16] A given number of variables are said to cointegrate, if e.g. they are integrated of order d, but a linear combination of them is integrated of order $d-1$. A cointegrating vector denotes a vector consisting of the weights/coefficients that define a cointegrating relation between the variables. A stationary variable is by itself a cointegrating relation. This study interchangeably use "long run relation", "equilibrium relation" for "cointegrating relation".

parsimony relative to a full VAR model. The discussion focuses on the conditions for a variable to be regarded as a valid conditional variable, i.e. weakly exogenous for the parameters of interest, see Engle et al. (1983).

A full VAR model: A full VAR model of vector $X = (e,\ cpi,\ RB,\ FI.Y,\ cpi^f,\ RB^f\ ,\ oilp)'$, can be formulated in a reduced form vector equilibrium correction model (VEqCM) as follows:

$$\Delta X_t = \alpha\beta' X_{t-1} + \sum_{i=1}^{\mathrm{p}-1} \Gamma_i \Delta X_{t-i} + \delta + \varepsilon_t, \tag{5.1}$$

where

$$\alpha\beta' = \begin{bmatrix} \alpha_{e,\,1} & \alpha_{e,\,2} & \cdot & \cdot & \alpha_{e,\,r} \\ \alpha_{cpi,\,1} & \alpha_{cpi,\,2} & \cdot & \cdot & \alpha_{cpi,\,r} \\ \alpha_{RB,\,1} & \cdot & \cdot & \cdot & \alpha_{RB,\,r} \\ \alpha_{FI.Y,\,1} & \cdot & \cdot & \cdot & \cdot \\ \alpha_{cpi^f,\,1} & \cdot & \cdot & \cdot & \cdot \\ \alpha_{RB^f,\,1} & \cdot & \cdot & \cdot & \cdot \\ \alpha_{oilp,\,1} & \cdot & \cdot & \cdot & \alpha_{oilp,\,r} \end{bmatrix}_{7\text{ x }r} \begin{bmatrix} \beta_{e,\,1} & \beta_{cpi,\,1} & \cdot & \cdot & \beta_{oilp,\,1} \\ \beta_{e,\,2} & \beta_{cpi,\,2} & \cdot & \cdot & \beta_{oilp,\,2} \\ \beta_{e,\,3} & \cdot & \cdot & \cdot & \beta_{oilp,\,3} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \beta_{e,\,\mathrm{r}} & \beta_{cpi,\,\mathrm{r}} & \cdot & \cdot & \beta_{oilp,\,r} \end{bmatrix}_{r\text{ x }7} \tag{5.2}$$

The VEqCM form is chosen to highlight the long run relations governing the variables, $\beta' X$, and their speed of adjustment towards these long run relations, α. β', the transpose of β, is a r x 7 matrix of coefficients which defines the r linearly independent long run relations between the seven variables in X, where $r \leq 7 - 1 = 6$, since all variables are not stationary. Element $\beta_{j,\,i}$ of β' denotes the weight/coefficient of variable j in the ith long run relation, j = *e, cpi, RB, FI.Y,* cpi^f, RB^f and *oilp,* and i = *1, 2, ...r*. Deviations from the long run relations in a given period are (partially) corrected/adjusted in the subsequent period. Rates of adjustments are contained in the 7 x r matrix α. Element $\alpha_{j,\,i}$ of α denotes the adjustment rate of variable j to deviation from the ith long run relation in period $t{-}1$, . p is the maximum lag length, δ is a vector of constant terms and ε_t is a vector of residuals. Γ_i s' are coefficient vectors representing short run effects of the variables.

The number of cointegrating relations, r, can be determined by following the procedure suggested in e.g. Johansen (1988, 1995). Efficient inference on the basis of the Johansen procedure, however, requires that ε_t is IIDN(.), i.e. ε_t is independently and identically normally distributed, which generally presupposes a well specified model.

However, the information set X is unlikely to be sufficient to provide a reasonable approximation to the underlying processes determining all of the variables in X, in particular, cpi^f, RB^f and *oilp*. Increasing the lag length p can be remedial, but shocks and structural changes over time are likely to require extraneous information in the form of deterministic and/or stochastic stationary variables, cf. Johansen and Juselius (1992), among others. Extraneous stationary variables can, however, invalidate the asymptotic distributions of the relevant test statistics, which are derived by making allowance for a deterministic trend and a constant, at maximum, see e.g. Doornik, Hendry and Nielsen (1999) and Mosconi and Rahbek (1999).[17] Increasing the dimension of the VAR model by increasing the number of endogenous variables can be a solution, but with the possible drawback that identifying long run relations implied by economic theory may become more difficult.

The number of endogenous variables in X is already relatively high (7), so a reduction is desirable to make it less cumbersome to identify interpretable long run relations. In addition, the power of tests that are used to test theory restrictions on the β and α matrices may be low within a full VAR model, given the number of parameters to be estimated on our data sample of about 100 observations; in other words, overparameterisation may lead to the appearance of transient correlation between unrelated variables.

A conditional VAR model: The analysis can be simplified by conditioning on a number of variables, especially those that can be difficult to model using the given information set, and conduct the analysis within a conditional VAR model. A conditional model can, by reducing the dimension of the VAR, increase the power of tests and simplify the analysis in the light of economic theory. A valid conditional model, however, presupposes weak exogeneity of the conditioning variables for parameters of interest, see Engle et al. (1983) and Johansen (1995, ch. 8). Otherwise, a conditional model can lead to inefficient or inconsistent inference on the parameters of interest.

The full VAR model (5.1) can be alternatively written as follows:

$$\Delta Y_t = \alpha_1 \beta' X_{t-1} + \sum_{i=1}^{\mathrm{p}-1} \Gamma_{1,\,i} \Delta X_{t-i} + \delta_1 + \varepsilon_{1,\,t} \tag{5.3}$$

[17] The DisCo programme of Johansen and Nielsen (1993) can be employed when the analysis is conditioned on deterministic variables but not if conditioned on stochastic (stationary) variables.

$$\Delta Z_t = \alpha_2\beta' X_{t-1} + \sum_{i=1}^{p-1}\Gamma_{2,\,i}\Delta X_{t-i} + \delta_2 + \varepsilon_{2,\,t} \tag{5.4}$$

This form is based on the following partition into vectors and submatrices: $X' = (Y',\, Z')$, $\varepsilon' = (\varepsilon_1',\, \varepsilon_2')$, $\alpha' = (\alpha_1',\, \alpha_2')$, $\Gamma_i' = (\Gamma_{1,\,i}',\, \Gamma_{2,\,i}')$ and $\delta' = (\delta_1',\, \delta_2')$.

A conditional VAR model of ΔY on ΔZ can be formulated as:

$$\Delta Y_t = \omega\Delta Z_t + (\alpha_1 - \omega\alpha_2)\beta' X_{t-1} + \sum_{i=1}^{p-1}(\Gamma_{1,\,i} - \omega\Gamma_{2,\,i})\Delta X_{t-i} + (\delta_1 - \omega\delta_2) + (\varepsilon_{1,\,t} - \omega\varepsilon_{2,\,t}) \tag{5.5}$$

Parameter vector ω is a function of the covariance matrix of residual vectors $\varepsilon_{1,\,t}$ and $\varepsilon_{2,\,t}$ and the variance matrix of $\varepsilon_{2,\,t}$.

If $\alpha_2 = 0$, a condition for the weak exogeneity of Z for β and α_1, valid inference on β and α_1 can be based on the conditional model (5.5) alone without loss of information relative to the full VAR model (5.1), see Johansen (1995, pp. 122). For example, consistent estimation of α_1 based on the conditional model requires $\alpha_2 = 0$, even if β is known but $\omega \neq 0$. In particular, one may falsely draw the conclusion that Y does not respond to deviation from a long run relation, if $\alpha_1 \neq 0$ but $\alpha_1 = \omega\alpha_2$.

Since the Norwegian economy is small relative to its trading partners' one would *a priori* believe that cpi^f, RB^f and *oilp* do not respond to disequilibria in different Norwegian markets. This entails the following classification of the variables in X into endogenous and presumedly weakly exogenous variables: $Y = (e,\ cpi,\ RB,\ FI.Y)'$ while $Z = (cpi^f,\ RB^f,\ oilp)'$. Provided that this is a valid classification and the conditional model is well specified, a prerequisite for the residuals $\varepsilon_{c,\,t} \equiv \varepsilon_{1,\,t} - \omega\varepsilon_{2,\,t}$ to be IIDN(.), one can draw inference on r, α_1 and on the identity of the different cointegrating vectors in β by following Harbo, Johansen, Nielsen and Rahbek (1998).

Stationary oil prices imply $\alpha_2 \neq 0$ **:** The possible stationarity of *oilp*, however, poses a problem for conducting the analysis within the conditional VAR model. The suggested classification of variables into Y and Z implies that α_2 can be defined as

$$\alpha_2 = \begin{bmatrix} \alpha_{cpi^f,\,1} & \alpha_{cpi^f,\,2} & \cdot & \cdot & \alpha_{cpi^f,\,r} \\ \alpha_{RB^f,\,1} & \cdot & \cdot & \cdot & \cdot \\ \alpha_{oilp,\,1} & \cdot & \cdot & \cdot & \alpha_{oilp,\,r} \end{bmatrix}_{3\mathrm{x}r} \tag{5.6}$$

The remaining elements of α can be defined as α_1. If *oilp* is a stationary variable then it is, by itself, a cointegrating term. Hence one of the rows, for instance row k, in β' may contain only one non zero coefficient associated with the $oilp_{t-1}$ in vector X_{t-1}, i.e. it would be sufficient that only $\beta_{oilp,\ k} \neq 0$ for row k to define a stationary relation. In which case, $\Delta oilp_t$ (in ΔZ_t) will respond to changes in $oilp_{t-1}$, implying $\alpha_{oilp,\ k} \neq 0$ and hence, $\alpha_2 \neq 0$. If $oilp_{t-1}$ simultaneously appears in the equations for the endogenous variables Y, then *oilp* is not a weakly exogenous variable for $\beta_{oilp,\ k}$ and for the coefficients representing the response of the endogenous variables to $oilp_{t-1}$, $\alpha_{j,\ k} \in \alpha_1$ where $j \in Y$. Moreover, the possibility of $oilp_{t-1}$ appearing in the equations for Δcpi^f and ΔRB^f cannot be neglected, e.g. in the light of the stagflation experience of industrialised countries following OPEC I, which also implies $\alpha_2 \neq 0$. Thus (even) cpi^f and/or RB^f will not be weakly exogenous for $\beta_{oilp,\ k}$ and $\alpha_{j,\ k}$, where $j \in Y$. Consequently, inference on the long run effects of oil prices on the endogenous variables, based on the conditional model alone, can be invalid.

Valid inference feasible on a subset of parameters: Weak exogeneity of a given variable is, however, defined relative to particular parameters of interest. Thus the failure of cpi^f, RB^f and *oilp* to be weakly exogenous for e.g. $\beta_{oilp,\ k}$ and $\alpha_{j,\ k}$, does not preclude that they can be treated as weakly exogenous for other cointegrating vectors in β' and speeds of adjustment in α_1.

The case of a stationary conditional variable resembles the case of cointegrating relation(s) between a set of conditional variables. The matrix β' can be partitioned as $\beta' = (\beta'_y, \beta'_z)$, where β'_y denotes the $r_1 \leq r$ cointegrating relation(s) that either involve both the Y and the Z variables or only the Y variables, while β'_z denotes $r - r_1$ cointegrating relations composed exclusively of Z variables. The adjustment matrices can be partitioned as $\alpha'_1 = (\alpha'_{yy},\ \alpha'_{yz})$ and $\alpha'_2 = (\alpha'_{zz},\ \alpha'_{zy})$, where α_1 contains the weights of $\beta'_y X_{t-1}$ and $\beta'_z Z_{t-1}$ in the Y equation while α_2 contains their weights in the Z equation. A model of ΔY conditional on ΔZ and a marginal model of ΔZ can be formulated as:

$$\begin{aligned} \Delta Y_t &= \omega \Delta Z_t + (\alpha_{yy} - \omega\alpha_{zy})\beta'_y X_{t-1} + (\alpha_{yz} - \omega\alpha_{zz})\beta'_z Z_{t-1} + \\ & \sum_{i=1}^{\mathrm{p}-1} (\Gamma_{1,\ i} - \omega\Gamma_{2,\ i})\Delta X_{t-i} + (\delta_1 - \omega\delta_2) + (\varepsilon_{1,\ t} - \omega\varepsilon_{2,\ t}) \end{aligned} \tag{5.7}$$

$$\Delta Z_t = \alpha_{zy}\beta'_y X_{t-1} + \alpha_{zz}\beta'_z Z_{t-1} + \sum_{i=1}^{\mathrm{p}-1} \Gamma_{2,\ i}\Delta X_{t-i} + \delta_2 + \varepsilon_{2,\ t} \tag{5.8}$$

Analysis of the conditional model (5.7) is without loss of information relative to the VAR model for the purpose of drawing inference on β_y' and α_{yy}, if

$$(1)\ \alpha_{zy} = 0 \text{ and } (2)\ \alpha_{yz} - \omega\alpha_{zz} = 0,$$

see Hendry and Mizon (1993). Under these conditions, $\beta_y' X_{t-1}$ only enters the conditional model while $\beta_z' Z_{t-1}$ only enters the marginal model (5.8). For instance, if $\beta_z' Z$ only consists of *oilp*, valid inference on the other r_1 possible cointegrating relations and the associated adjustment coefficients requires that these r_1 cointegrating relations are absent from the equations for the Z-variables, $Z = (cpi^f,\ RB^f, oilp)'$, and that *oilp* is absent from the conditional model of the Y-variables, $Y = (e,\ cpi,\ RB,\ FI.Y)'$.

Summary and a guide to the subsequent analysis: The full VAR model defined by the chosen variables set is unlikely to provide a satisfactory characterisation of all the variables unless deterministic and non-modelled stochastic variables are included in the model. This extension may, however, invalidate the test statistics to be employed and make it difficult to derive interpretable results. The latter concern even makes it desirable to reduce the number of variables to be modelled. A conditional VAR model may be a solution since it allows us to condition on variables whose processes are not of primary interest, but only under a certain condition. If oil prices are stationary, this condition will not be satisfied for the purpose of drawing valid inference on the parameters of interest. In particular, the effects of oil prices on the endogenous variables may not be consistently estimated from the conditional model. Inference on a subset of parameters is yet feasible under a set of weaker conditions.

A compromise would be to employ the full VAR model to test for the number of cointegrating relations, make an effort to identify their form, test for long run effects of oil prices on the endogenous variables and test whether or not a subset of variables are weakly exogenous for the parameters of interest; thereafter, if condition (1) for the weak exogeneity is fulfilled for a subset of parameters, to employ a conditional VAR model and check whether condition (2) is satisfied; and if it is, to proceed by conducting tests for the (remaining) hypotheses of interest within the conditional VAR model and by testing robustness of the results obtained from the full VAR model.

The analysis in subsection 5.3 and 5.4 is based on this compromise. The main objectives of the analysis are to test for: (a) the symmetry and proportionality restrictions implied by the PPP theory, (b) possible long run effects of oil prices and (c) whether or not both the nominal exchange rate and the prices adjust upon deviations from the PPP, provided that it holds.

In subsection 5.3: A full VAR model is employed to determine the number of cointegrating relations, r, and to test condition (1), $\alpha_{zy} = 0$, for the possible weak exogeneity of the Z variables, cpi^f, RB^f and *oilp,* for specific vectors in β, i.e. β_y, and the associated adjustment coefficients. An effort is made to identify their form in the light of the PPP theory, the uncovered interest rate parity (UIP) hypothesis and the results from the ADF tests. β is restricted to test whether *oilp* itself constitutes a cointegrating relation by being a stationary variable. The test is not rejected and *oilp* appears to be the only cointegrating term among the Z variables. The model is then used to test for possible long run effects of *oilp* on the Y-variables, i.e. to test the null hypothesis of $\alpha_{yz} = 0$.

In subsection 5.4: Assuming that condition (1) holds, a conditional VAR model is formulated with $Y = (e,\ cpi,\ RB,\ FI.Y)'$ and $Z = (cpi^f,\ RB^f,\ oilp)'$. The number of cointegrating relations r is taken from the VAR model. The model is employed to test the validity of conditioning on Z by checking if condition (2), $\alpha_{yz} - \omega\alpha_{zz} = 0$, is satisfied, which turns out to be the case. Thus *oilp* appears to be redundant in the conditional model of Y. A more parsimonious conditional model is derived by excluding *oilp* (and some of the associated deterministic variables) from the conditional model. The exclusion of *oilp* reduces the number of cointegrating relations by one, to $r - 1$. The resulting parsimonious conditional model is used to check the robustness of the results obtained from the full VAR model and to test the weak exogeneity of *cpi*, *RB* and *FI.Y* for the parameters of interest in the nominal exchange rate equation.

5.3. The VAR model

The full VAR model is presented in Table 5.2. The information set is extended by five dummy variables to take account of the oil price shocks, OPEC I, OPEC II, Gulf War and the oil price fluctuations in 1997, see Figure 5.2. In order to keep the cointegration space tractable, only a step dummy for OPEC II (*OP2*) is allowed to enter the cointegration space. This takes on a value of 1 from 1979:1 to 1985:4 and zero elsewhere. The three other oil price shocks are controlled for by impulse dummies, *OP1*, *id90q3* and *id97q1*, respectively, and entered unrestricted. *OP1* takes on a value of 1 in 1974:1, -0.3 in 1974:2 and zero elsewhere, while *id90q3* and *id97q1* take on a value of 1 in the indicated quarter, -1 in the subsequent quarter and zero elsewhere, cf. Figure 5.2. The dummy variables for the oil price shocks are primarily needed to take account of significant changes in the oil price process since the 1970s. A time trend t is restricted to the cointegration space while the constant term is entered unrestricted, as recommended by Doornik et al. (1999) and Harbo et al. (1998) to safeguard against invalid inference on the cointegration rank, r. Estimation of the unrestricted reduced form indicated the need to include at least 5 lags, p = 5, and at least two centered seasonal dummies for the first and the third quarter, *CS* and *CS2*, respectively, to avoid autocorrelation and violation of the normality assumption for the residuals, see Appendix C.

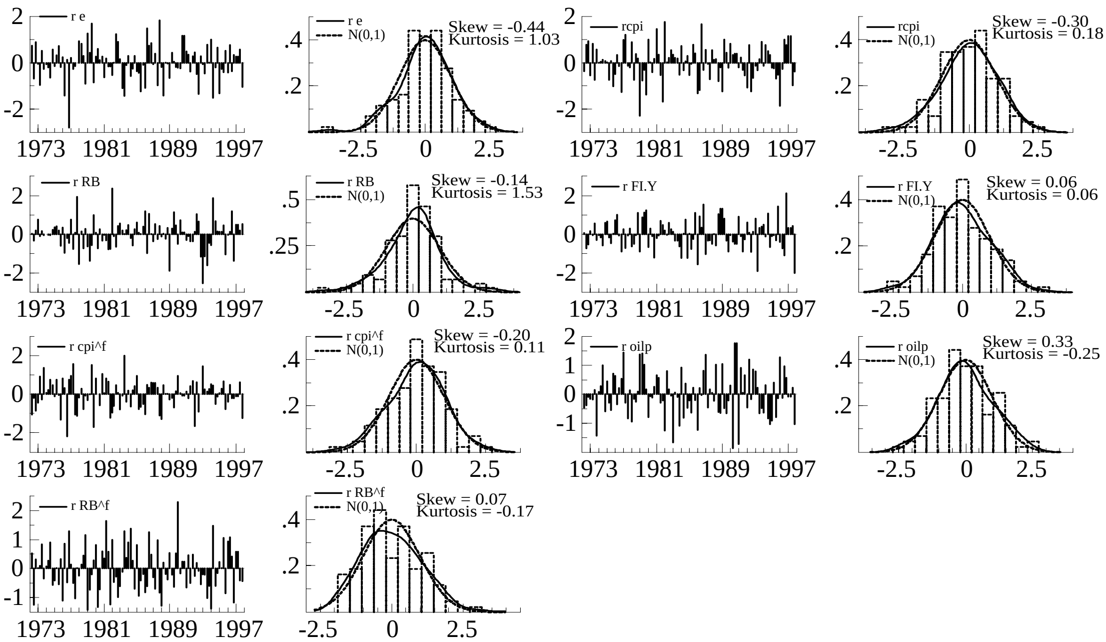

Figure 5.3: *Residual characteristics in the full VAR model. Scaled residuals (in the first and the third column) and the distribution of residuals (in the second and the fourth column) from each of the seven equations in the VAR model. The residual distributions are plotted against the standard normal distribution for comparison. The measures for skewness and excess kurtosis are also reported. The period is 1972:2-1997:4.*

The single equation and system diagnostic tests in Table 5.2 show that the chosen model formulation is able to ensure almost IIDN(.) residuals, both when evaluated at the single equation level and at the system level. The diagnostics do not reject the null hypotheses of no autocorrelation up to 5 lags, ARCH type heteroscedasticity up to order 4 and the null hypotheses of normally distributed residuals at the 5% level. One exception is the domestic bond rate *(RB)* equation, whose residuals do not seem to be normally distributed even at the 1% level. Figure 5.3 suggests that the rejection of the normality hypothesis for the *RB* residuals mainly owes to excess kurtosis, the statistic is 1.53 whereas it should be close to zero under the null hypothesis of normality. There are also a few relatively large outliers that can be associated with the increase in the Norwegian

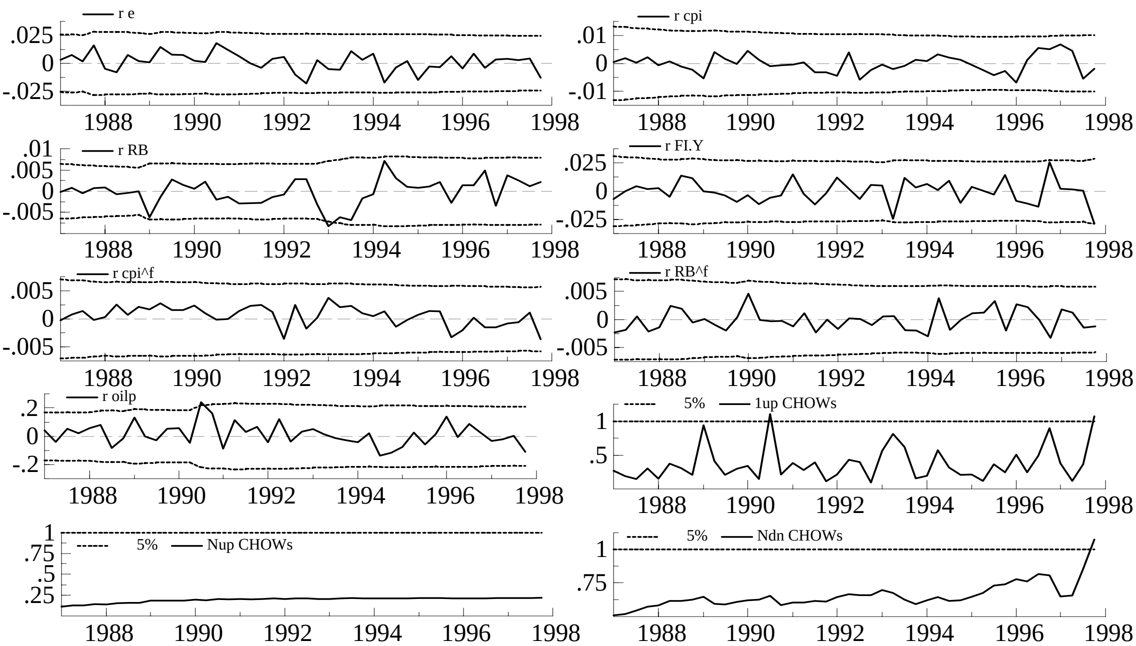

Figure 5.4: *Constancy statistics for the VAR model, obtained by recursive estimation of the VAR model over period 1986:4-1997:4. One-step residuals* $\pm 2SE_t$ *for each equation in the VAR model. One-step ahead Chow statistics (1up Chows), N-step ahead Chow statistics (Nup Chows) and break point Chows (Ndn Chows) for the VAR model. The Chow statistics are scaled by their (one-off) critical values at the 5% level of significance.*

bond rates in 1982 and with the ERM crisis in 1992, but these seem to matter less, see Figure 5.1. The distribution of the residuals from the nominal exchange rate equation, e-residuals, also appears to suffer from excess kurtosis and from one outlier in 1976/77. The normality assumption for e-residuals is however not rejected at the 1% level; the associated p-value is 4%.

The VAR model was also estimated without the dummy variables and a comparison of the standard errors of residuals with and without dummy variables, $\widehat{\sigma}$ and $\widehat{\sigma}|\text{ND}$, respectively, indicate that the oil price dummies are mainly relevant for the oil price process and to some extent for the exchange rate process. It is the dummy $id97q1$ which seems to matter for the exchange rate equation, cf. Figures 4.2 and 4.4.

Figure 5.4 displays the 1-step ahead recursively estimated residuals $\pm 2SE$ and forecast and break-point Chow tests for the VAR model, scaled by their critical values at the 5% level. The VAR model appears to have relatively constant parameters over time, at least from 1987 and onwards. There are a few exceptions. The outliers among the RB residuals seem to slightly increase the estimates of their standard error over time. The $FI.Y$ residuals display large fluctuations in

Table 5.2: The VAR model

Method: Johansen VAR model of order: 5 Endogenous variables (Y): *e, cpi, RB, FI.Y,* cpi^f, RB^f and *oilp* Conditional variables (restricted): t and *OP2* Unrestricted variables: *Constant, OP1,* $OP1_{-1}$, *id90q3, id97q1, CS* and *CS2* Sample: Seasonally non-adjusted quarterly data, 1972:2-1997:4.

I. Single equation and system diagnostics

Y	$F_{ar,1-5}(5,54)$	$\chi^2_{nd}(2)$	$F_{arch,1-4}(4,51)$	$\widehat{\sigma}$	$\widehat{\sigma}$ | ND
e	0.88[0.50]	6.28[0.04]*	0.43[0.79]	0.0123	0.0134
cpi	1.05[0.40]	1.86[0.40]	0.23[0.92]	0.005	0.005
RB	0.63[0.68]	12.05[0.00]**	0.42[0.80]	0.004	0.004
FI.Y	1.20[0.32]	0.50[0.78]	1.41[0.24]	0.015	0.015
cpi^f	1.99[0.10]	1.09[0.58]	0.08[0.99]	0.003	0.004
RB^f	1.01[0.42]	2.65[0.27]	0.28[0.89]	0.003	0.003
oilp	0.75[0.60]	0.10[0.95]	1.02[0.60]	0.104	0.167
	$F_{ar,1-5}(245, 136)$	$\chi^2_{nd}(14)$			
VAR	1.22[0.09]	17.32[0.24]			

II. Cointegration rank

r	0	1	2	3	4	5	6	7
likl	3569.9	3600.4	3622.7	3640.0	3656.5	3669.2	3675.2	3677.1
$\widehat{\mu}$		0.45	0.35	0.30	0.26	0.22	0.11	0.04
H_0 :	$r=0$	$r\leq 1$	$r\leq 2$	$r\leq 3$	$r\leq 4$	$r\leq 5$	$r\leq 6$	
Trace	214.3**	153.4**	108.8**	72.3**	41.2	15.9	3.7	
95%	146.75	114.96	86.96	62.61	42.20	25.47	12.39	
99%	157.53	124.61	95.38	70.22	48.59	30.65	16.39	
Max	61.0**	44.6*	36.5	31.1	25.3	12.2	3.71	
95%	49.4	44.0	37.5	31.5	25.5	19.0	12.3	

Note: See Table 4.1 for details. $\widehat{\sigma}$ | ND standard error of residuals when all restricted and unrestricted dummy variables are left out from the VAR model. *Trace* denotes the trace statistics and *Max* denotes the max-eigenvalue statistics. The critical values for the tests are from Johansen (1995) and Osterwald-Lenum (1992), respectively.

1996/97. The rejection of the null hypotheses of parameter stability in the VAR model as a whole, by the 1-step ahead Chow tests and break point Chow tests in 1997, is apparently caused by these fluctuations. The rejection is however at the strict 5% level and the N-step ahead forecast Chow tests do not reject the null hypotheses of parameter stability in the VAR model.

5.3.1. Cointegration analysis within the VAR model

Panel II of Table 5.2 reports the estimated eigenvalues ($\widehat{\mu}$), the trace test statistics (*Trace*) and max eigenvalue test statistics (*Max*). These provide information on the cointegration rank, r. Testing the cointegration rank amounts to testing the number of eigenvalues different from zero. In the trace test, the null hypothesis is that the eigenvalues $\mu_i = 0$, $i = r+1$, $r+2$, ..., $r+6$, while the first r eigenvalues are non-zero. It rejects the null hypothesis of $r \leq 3$ against the alternative hypothesis of $r \geq 4$ at the 1% level. The max eigenvalue test, which tests the null hypothesis of $\mu_i = 0$ against the alternative hypothesis of $\mu_{i+1} = 0$, for $i = 0, 1, ...r$, rejects the null hypothesis of $r = 1$ against the alternative of $r = 2$ at the 5% level. The max eigenvalue test also comes quite close to rejecting the null hypotheses of $r = 2$ and $r = 3$ against the alternative of $r = 3$ and $r = 4$, respectively. Both test statistics indicate the possibility of $r = 5$ since their values are only slightly below their 95% quantiles.

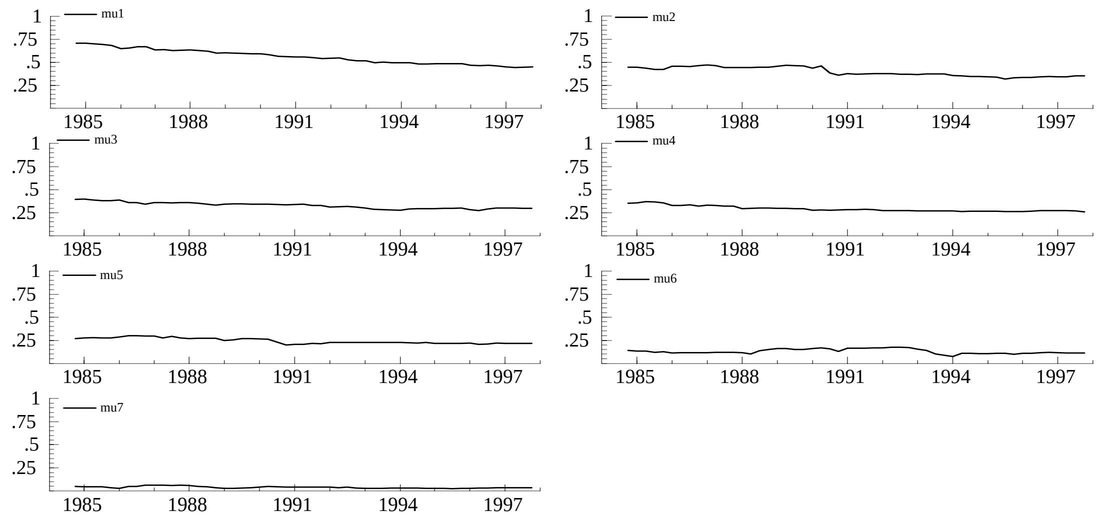

Figure 5.5: *Recursive estimates of eigenvalues based on the VAR model. For instance, mu1 denotes the recursive estimates of* μ_1. *The initial estimation period is 1972:2-1984:4.*

The tabulated critical values from Johansen (1995) and Osterwald-Lenum (1992) may however be lower than the true critical values, since they have been derived under the assumption of at most two deterministic variables, the constant term and the time trend. The inclusion of the step dummy *OP2* in the cointegration space and the unrestricted impulse dummies *OP1* and $OP1_{-1}$ may raise the (true) critical values. This is less likely to be the case with the unrestricted centered dummies, *id90q3*, *id97q1*, *CS* and *CS2* since they quickly converge to zero, cf. Doornik et al. (1999). Inclusion of additional deterministic variables whose effect do not die out asymptotically generally lead to higher critical values and more conservative tests for cointegration rank. However, given the strong rejection of $r \leq 3$ by the trace test and the fairly stable estimates of the eigenvalues, we proceed under the tentative assumption of $r = 4$, see Figure 5.5. Our confidence in the trace test rather than on the max eigenvalue test rests on Monte Carlo experiments suggesting that the former test is relatively more robust to excess kurtosis (and skewness) in the residuals than the latter, see e.g. Cheung and Lai (1993).

Table 5.3 tests restrictions on the β and α matrices when r is set to 4. Panel I tests restrictions on rows, β_i', $i = 1, 2, 3, 4$, of the β' matrix in order to identify the presumedly 4 linearly independent long run relations. Identification of 4 interpretable cointegrating relations can substantiate the choice of $r = 4$. The restrictions on β' are tested row by row, where each of the rows represents a cointegration vector under the null hypothesis. Since all variables in X are assumed to be integrated at most of order one, I(1), each cointegrating relation $\widehat{\beta}_i'X$ is stationary under the null hypothesis and I(1) under the alternative hypothesis. These tests are the multivariate alternative to the univariate ADF tests, but with the null hypothesis being that of stationarity and not of non-stationarity (in the unit root sense). The outcome of the tests is discussed below.

$\widetilde{\beta}_1'$ defines a relation between the nominal exchange rate and domestic and foreign consumer prices where the prices are assumed to be symmetrically related to the exchange rate. This restriction is accepted at a p-value of 0.15 with "correct" signs for both the domestic and foreign prices. The estimated coefficients are -0.57 and 0.57, respectively. In the second row of Table 5.3, $\widehat{\beta}_1'$ defines a relation in strict accordance with the PPP theory by imposing both the symmetry and proportionality restrictions on the domestic and foreign prices. The stationarity of this PPP term, $\widehat{\beta}_1'X = e - cpi + cpi^f$, can be accepted at a p-value of 0.07. This result appeared to be quite robust to a wide range of different specifications of the VAR model. Appendix C indicates this for changes in the number of lags of the VAR model and/or when we exclude the dummy variables. The appendix tabulates test results for the main hypotheses, for 10 different specifications of the VAR model.

$\widetilde{\beta}_2'$ defines a linear relation between the interest rate spread ($RB{-}RB^f$) and the nominal exchange rate, which is entered unrestricted. Stationarity of this relation is not rejected and it entails the following long run relation for the domestic interest rate: $RB = RB^f + 0.69e$. This relation resembles a central bank's interest rate response function under a policy of exchange rate targeting. The test of $\widehat{\beta}_2'$ shows that the interest rate spread is not stationary by itself, as implied by the UIP hypothesis. Experimentation with different model specification, however, suggested that this result is quite sensitive to the specification of the VAR model, (not reported).

The non-rejection of $\widehat{\beta}_3'$ as a cointegration vector, implying $FI.Y$ is a stationary variable, is in line with the result from the ADF test. Similarly, $\widehat{\beta}_4'$ implies that $oilp$ is by itself a stationary term with a "broken" deterministic trend. The non-rejection of this hypothesis lends support to the proposition that the oil price process is not an integrated but a stationary process with infrequent

Table 5.3: Testing for long run relations and weak exogeneity, the VAR model.

I. Restrictions on rows of β'

	e	cpi	RB	$FI.Y$	cpi^f	RB^f	$oilp$	t	$OP2$	$\chi^2(.)$
$\widetilde{\beta}_1'$	1	-0.57	0	0	0.57	0	0	0	0	6.69[0.15]
$\widehat{\beta}_1'$	1	-1	0	0	1	0	0	0	0	10.16[0.07]
$\widetilde{\beta}_2'$	-0.69	0	1	0	0	-1	0	0	0	7.54[0.11]
$\widehat{\beta}_2'$	0	0	1	0	0	-1	0	0	0	19.01[0.00]**
$\widehat{\beta}_3'$	0	0	0	1	0	0	0	0	0.02	7.13[0.13]
$\widehat{\beta}_4'$	0	0	0	0	0	0	1	-0.03	-0.48	5.52[0.14]

II. Testing weak exogeneity, condition (1): $\alpha_{zy} = 0$.

j						$\chi^2(4)$	
RB^f :	$\alpha_{RB^f,\,1}$	$= \alpha_{RB^f,\,2}$	$= \alpha_{RB^f,\,3}$	$= \alpha_{RB^f,\,4}$	$= 0,$	9.27	[0.06]
cpi^f	$\alpha_{cpi^f,\,1}$	$= \alpha_{cpi^f,\,2}$	$= \alpha_{cpi^f,\,3}$	$= \alpha_{cpi^f,\,4}$	$= 0,$	9.35	[0.05]
$oilp$:	$\alpha_{oilp,\,1}$	$= \alpha_{oilp,\,2}$	$= \alpha_{oilp,\,3}$	$= \alpha_{oilp,\,4}$	$= 0,$	22.91	[0.00]**

					$\widehat{\alpha}_{oilp,\,4}$	$\chi^2(6)$	
$oilp$: $\widetilde{\beta}'$	$\cap$	$\alpha_{oilp,\,1} =$	$\alpha_{oilp,\,2} =$	$\alpha_{oilp,\,3} = 0,$	$-\underset{(0.06)}{0.17}$	12.67	[0.05]
					$\widehat{\alpha}_{e,\,1}$	$\chi^2(8)$	
e : $\widetilde{\beta}_1'$	$\cap$	$\alpha_{e,\,2} =$	$\alpha_{e,\,3} =$	$\alpha_{e,\,4} = 0,$	$-\underset{(0.04)}{0.12}$	13.00	[0.11]

III. Testing $\alpha_{yz} = 0$.

j	e	cpi	RB	$FI.Y$	cpi^f	RB^f	$oilp$	t	$OP2$
$\widetilde{\beta}_1'$	*	*	*	*	*	*	0	*	*
$\widetilde{\beta}_2'$	*	*	*	*	*	*	0	*	*
$\widetilde{\beta}_3'$	*	*	*	*	*	*	0	*	*
$\widehat{\beta}_4'$	0	0	0	0	0	0	1	*	*

$\widetilde{\beta}' = (\widetilde{\beta}_1', \; \widetilde{\beta}_2', \; \widetilde{\beta}_3', \; \widehat{\beta}_4')' \; : \chi^2(3) \; = \; 5.52 \; [0.14]$

e :	$\widetilde{\beta}'$	$\cap$	$\alpha_{e,\,4} =$	0,	$\chi^2(4)$	=	5.57	[0.23]
cpi	$\widetilde{\beta}'$	$\cap$	$\alpha_{cpi,\,4} =$	0,	$\chi^2(4)$	=	6.34	[0.18]
RB :	$\widetilde{\beta}'$	$\cap$	$\alpha_{RB,\,4} =$	0,	$\chi^2(4)$	=	7.16	[0.13]
$FI.Y$:	$\widetilde{\beta}'$	$\cap$	$\alpha_{FI.Y,\,4} =$	0,	$\chi^2(4)$	=	6.44	[0.17]

$\widetilde{\beta}' \cap \quad \alpha_{e,\,4} = \quad \alpha_{cpi,\,4} = \quad \alpha_{RB,\,4} = \quad \alpha_{FI.Y,\,4} = 0, \quad \chi^2(7) \; = \; 9.33 \quad [0.23]$

Note: The star * indicates an unrestricted coefficient value. The cells heading $\widehat{\alpha}_{oilp,\,4}$ and $\widehat{\alpha}_{e,\,1}$contain estimates of the unrestricted coefficients. A "$\sim$" symbolises a less restricted vector or matrix. $\cap$ is used to indicate that restrictions are tested jointly.

changes in its mean level, see also Appendix C.

Identification of the 4 cointegrating relations substantiates the choice of $r = 4$ and suggests that there is only one cointegrating relation between the foreign denominated variables $Z = (cpi^f$, RB^f, *oilp*); namely *oilp* itself, $\widehat{\beta}_4'X$, which can be interpreted as $\widehat{\beta}_z'Z$, cf. equations (5.7) and (5.8).

Panel II of the table starts out by testing whether RB^f, cpi^f and *oilp* can be treated as weakly exogenous variables for all the cointegration vectors and the associated adjustment coefficients, that is, for β' and α. The weak exogeneity of RB^f and cpi^f is barely accepted at the 5% level but rejected of *oilp,* even at the 1% level.

Panel II then tests whether *oilp* can be treated as weakly exogenous for a partial β' and α. A 4 x 9 matrix $\widetilde{\beta}'$ is defined for this purpose, see panel III. The coefficient of *oilp* is set to zero in the first three rows while the fourth row is defined as $\widehat{\beta}_4'$ in panel I. The restrictions defining $\widetilde{\beta}'$ are accepted at a *p*-value of 0.14. The restrictions $\widetilde{\beta}' \cap \alpha_{oilp,\,1} = \alpha_{oilp,\,2} = \alpha_{oilp,\,3} = 0$ make sure that only $\widehat{\beta}_4'X$ (or $\widehat{\beta}_z'Z$) enters the *oilp* equation, see panel II. Any other linear combination between the variables in X is barred from entering the *oilp* equation. These restrictions, which correspond to condition (1) for the weak exogeneity of *oilp* for a partial β' and α, are not rejected at the strict 5% level. The unrestricted coefficient estimate of $\widehat{\beta}_4'X$ in the *oilp* equation is -0.17, and differs significantly from zero. The test result adds to the evidence for treating *oilp* as a stationary variable in the sample at hand.

A joint test of the weak exogeneity of cpi^f, RB^f and condition (1) for the weak exogeneity of *oilp* was rejected at the 1% level (not reported). Yet economic intuition suggests that it is unlikely that these foreign denominated variables respond to deviations from the long run relations governing the relatively small Norwegian sub-markets, defined by e.g. the cointegrating relations above, $\widehat{\beta}_1'X$, $\widetilde{\beta}_2'X$ and $\widehat{\beta}_3'X$. A perhaps more plausible explanation for the rejection of the joint test may be that the VAR model is overparametrised relative to the number of observations. It is well known that overparametrisation often leads to the appearance of transient correlations between unrelated variables in small samples.

The last row of panel II tests the weak exogeneity of the nominal exchange rate for all the cointegration vectors in β' except $\widehat{\beta}_1'$, and for α_1 except $\alpha_{e,\,1}$. The imposed restrictions are accepted and implies that only the PPP vector ($\widehat{\beta}_1'X$) enters the exchange rate equation with an estimated weight of -0.12. Appendix C shows that this result is quite robust across the different specifications of the VAR model. It is shown that (the estimates of) the weight only varies in the range of (-0.135, -0.100), across the 10 different model specifications.

Panel III follows the same procedure as in panel II to test whether *oilp* has any long run effect on the Y variables, e, cpi, RB and $FI.Y$. Now, all other possible linear combinations of the variables in X are let into the equations for the Y variables, except *oilp*. For example, $\widetilde{\beta}' \cap \alpha_{e,\,4} = 0$ tests whether *oilp* can be excluded from the nominal exchange rate equation. These restrictions are accepted at the 5% level when placed equation by equation for all the Y variables, or jointly on all 4 equations. Appendix C indicates the robustness of this result.

To summarise, the results in Table 5.3 are consistent with $r = 4$. One of the identified cointegrating relation conforms with the PPP theory since the symmetry and proportionality restrictions are not rejected at the 5% level. The oil price (*oilp*) has appeared to be a cointegrating term by itself and changes in the oil price ($\Delta oilp$) in a given period have been found to respond to the level of the oil price in a stabilising way. More importantly, the oil price does not seem to have a statistically significant effect on either e or on *cpi, RB* and *FI.Y.* Table 5.3 also provides some support for condition (1) for valid conditioning on cpi^f, RB^f and *oilp,* in a conditional VAR model of *e*, *cpi, RB* and *FI.Y.*

However, the full VAR model is overparameterised, which may lead to underrejection of false null hypotheses and make room for transient correlations between unrelated variables. Hence, some of the obtained results are considered as indicative rather than firm evidence. In the next subsection, we test the robustness of e.g. the symmetry and proportionality restriction and other hypotheses of interest within the parsimonious conditional VAR model.

5.4. The conditional VAR model

This subsection proceeds under the assumption that condition (1) for the weak exogeneity of cpi^f, RB^f and *oilp* is satisfied for the parameters of interest. It starts out by formulating a conditional VAR model to check whether condition (2), i.e. $\alpha_{yz} - \omega\alpha_{zz} = 0$, for the weak exogeneity of these variables is fulfilled. Since there is only one cointegrating term among the Z variables, *oilp* itself, a test of this condition amounts to testing for the presence of *oilp* in the conditional VAR model of the Y variables. Thereafter, a parsimonious conditional VAR model is derived to test the hypotheses of interest.

Table 5.4 defines a conditional VAR model of the endogenous variables, *e, cpi, RB* and *FI.Y.* This model is derived by imposing zero restrictions on some of the parameters of a conditional model that corresponded directly to the full VAR model, cf. equation (5.7). The endogenous variables have four lags while relative changes in the conditioning variables, ΔRB^f, $\Delta oilp$ and Δcpi^f, enter unrestricted with up to 2 and 3 lags, respectively. Due to the conditioning on *oilp,* the impulse dummy for the Gulf War (*id90q3*) also became insignificant at the 5% level but not the dummies for OPEC I and the oil price rise in 1997, *OP1, OP1*$_{-1}$ and *id97q1,* respectively. The model was estimated with cpi^f_{t-1}, RB^f_{t-1}, $oilp_{t-1}$, *OP2* and t restricted to the cointegration space while the remaining dummy variables and the constant term entered unrestricted.

The residuals from the conditional model appear to have the same properties as the residuals from the full VAR model. There are no significant violations of the hypotheses of no residual autocorrelation up to order 5, no heteroscedasticity up to order 4 and no violation of the normality assumption for most of the residuals except the *RB*-residuals, as earlier. Figure 5.6 indicates that the model has fairly stable parameters, in particular the equations for the nominal exchange rate and consumer prices. There are signs of changes in the *RB* and *FI.Y* equations, but not stronger than in the full VAR model, cf. Figure 5.4.

Table 5.4: The conditional VAR model.

Method: Johansen
Conditional VAR model of order: 4
Endogenous variables (Y): *e, cpi, RB* and *FI.Y*
Conditional variables, restricted: cpi^f_{t-1}, RB^f_{t-1}, $oilp_{t-1}$, t and *OP2*
Conditional variables, unrestricted: $\Delta cpi^f_t,...\Delta cpi^f_{t-3}$, $\Delta RB^f_t,...\Delta RB^f_{t-2}$, $\Delta oilp_t,...\Delta oilp_{t-2}$, *OP1, OP*$_{-1}$*, id97q1, Constant*, CS_t and CS_{t-2}.
Sample: Seasonally non-adjusted quarterly data, 1972:2-1997:4.

I. Single equation and system diagnostics

	$F_{ar,1-5}(5,61)$	$\chi^2_{nd}(2)$	$F_{het,\text{Xi}^2}(41,24)$	$F_{arch,1-4}(4,58)$	$\widehat{\sigma}$
e	1.70[0.15]	1.36[0.51]	0.27[1.00]	0.20[0.94]	.0119
cpi	1.62[0.17]	1.26[0.53]	0.48[0.98]	0.15[0.96]	.0050
RB	1.42[0.23]	8.63[0.01]*	0.38[1.00]	0.47[0.76]	.0036
FI.Y	1.81[0.12]	0.50[0.78]	0.92[0.61]	0.49[0.75]	.0149
	$F^v_{ar,1-5}(80,172)$	$\chi^{2,v}_{nd}(8)$	$F^v_{het,\text{Xi}^2}(410,175)$		
VAR	1.04[0.42]	10.28[0.25]	0.35[1.00]		

II. Testing weak exogeneity, condition (2): $\alpha_{yz} - \omega\alpha_{zz} = 0$.

j		$\chi^2(4)$
$e:$	$\widetilde{\beta}' \cap \alpha_{e,4} = 0,$	6.45[0.17]
$cpi:$	$\widetilde{\beta}' \cap \alpha_{cpi,4} = 0,$	6.41[0.17]
RB	$\widetilde{\beta}' \cap \alpha_{RB,4} = 0,$	10.30[0.04]*
$FI.Y:$	$\widetilde{\beta}' \cap \alpha_{FI.Y,4} = 0,$	4.70[0.32]
		$\chi^2(9)$
	$\widetilde{\beta}' \cap \alpha_{e,4} = \alpha_{cpi,4} = \alpha_{RB,4} = \alpha_{FI.Y,4} = 0,$	16.54[0.06]

Note: $\widetilde{\beta}'$ is defined as in Table 5.3. See Table 4.1 for details about the tests.

Panel II of Table 5.4 tests condition (2) for the weak exogeneity of cpi^f, RB^f and *oilp* by testing whether *oilp* enters any of the equations for the endogenous variables.[18] The tests are

[18] Note that if condition (2) is satisfied, cpi^f, RB^f can be regarded as weakly exogenous for the parameters of

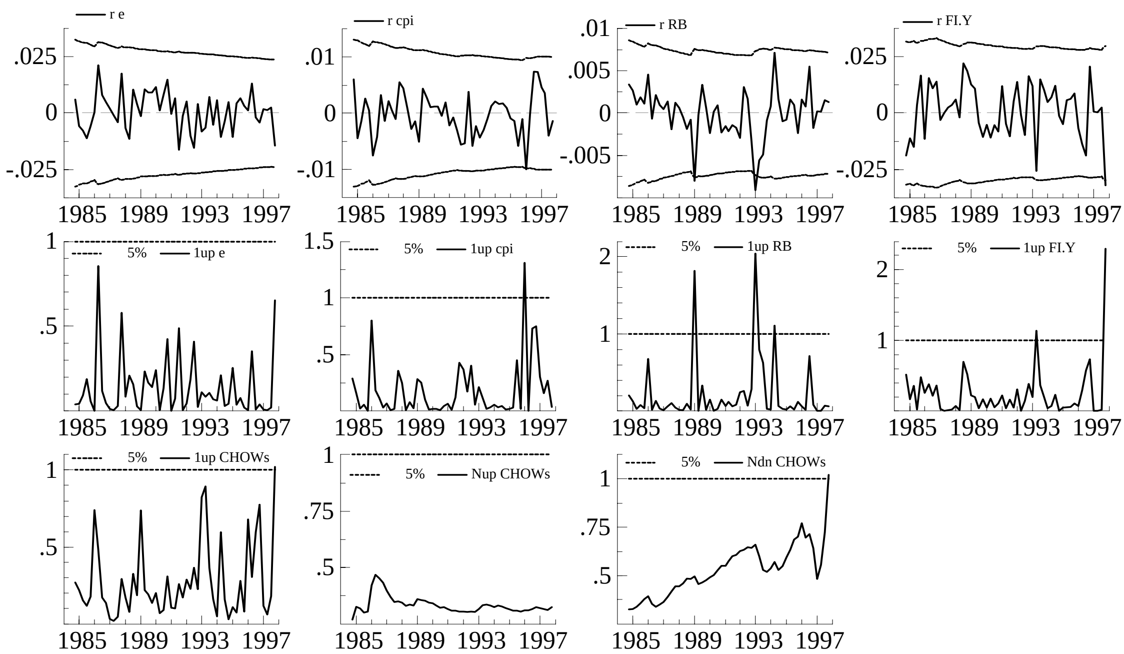

Figure 5.6: *Constancy statistics for the four equation conditional VAR model in Table 5.4. Top panel: One-step residuals* $\pm 2SE_t$*. Middle panel: Chow statistics for each of the four equations. Bottom panel: Chow statistics for the conditional system. All Chow statistics are scaled by their (one-off) critical values at the 5% level of significance. The initial estimation period is 1972:2-1984:4.*

similar to the tests performed in panel III of Table 5.3 and are conducted under the assumption of $r = 4$. Condition (2) seems to be satisfied for all the equations when tested equation by equation and jointly for all equations, at around the 5% level.

oilp does not have statistically significant effect on any of the endogenous variables in the conditional model of Table 5.4, and is therefore left out from the model together with *OP2,* and the trend t. The trend appeared to be relevant only in the oil price vector, $\widehat{\beta}_4$, see panel I in Table 5.3. Table 5.5 presents a conditional model without these variables, denoted as the parsimonious conditional VAR model.

The residual properties from the conditional model in Table 5.4 seem to have carried over to the parsimonious conditional VAR model when judged at the 5% level. The residual standard errors have slightly increased for all equations, however. In addition, the tests of parameter stability show relatively stronger signs of parameter instability in 1997, mainly because of an outlier in the *FI.Y* equation, see Figure 5.7.

interest even if they respond to *oilp*.

Table 5.5: The parsimonious conditional VAR model.

Method: Johansen
Conditional VAR model of order: 4
Endogenous variables (Y): *e, cpi, RB* and *FI.Y*
Conditional variables, restricted: cpi^f_{t-1} and RB^f_{t-1}
Conditional variables, unrestricted: $\Delta cpi^f_t, ...\Delta cpi^f_{t-3}$, $\Delta RB^f_t, ...\Delta RB^f_{t-2}$, $\Delta oilp_t, ...\Delta oilp_{t-2}$, *OP1*, OP_{-1}, *id97q1*, *Constant*, CS_t and CS_{t-2}.
Sample: Seasonally non-adjusted quarterly data, 1972:2-1997:4.

I. Single equation and system diagnostics

	$F_{ar,1-5}(5,64)$	$\chi^2_{nd}(2)$	$F_{het,Xi^2}(36,32)$	$F_{arch,1-4}(4,61)$	$\widehat{\sigma}$
e	1.71[0.15]	1.24[0.54]	0.33[1.00]	0.05[0.99]	.0122
cpi	1.19[0.32]	2.99[0.22]	0.47[0.93]	0.11[0.98]	.0054
RB	1.82[0.12]	10.31[0.01]*	0.48[0.98]	0.40[0.81]	.0036
FI.Y	0.55[0.74]	1.28[0.53]	1.31[0.22]	1.22[0.31]	.0154
	$F^v_{ar,1-5}(80,183)$	$\chi^{2,v}_{nd}(8)$	$F^v_{het,\ Xi^2}(360,250)$		
VAR	1.03[0.44]	13.83[0.09]	0.48[1.000]		

Note: See Table 4.1 for details about the tests.

5.4.1. Cointegration analysis within the parsimonious conditional VAR model

The cointegration analysis proceeds under the assumption of three cointegrating relations, $r = 3$, since the 4th cointegrating term *oilp* has been left out from the conditional model. The rest of the β and α matrices can be interpreted as β_y and α_{yy} , as in equation (5.7). Table 5.6 reports the results when restrictions are placed on β'_y and α_{yy}.

Panel I shows that the PPP hypothesis, UIP hypothesis and the stationarity of *FI.Y* are not rejected at the 5% level, when tested individually or jointly. Figure 5.8 displays the test statistics when PPP restrictions defined by $\widehat{\beta}'_1$ are imposed recursively. The figure indicates that the PPP hypothesis is “easily” accepted by the data, at least from 1985. Notice also that the nominal exchange rate (e) need not be present in the second relation, which implies that the interest rate spread is stationary by itself.

Panel II of Table 5.6 reports the unrestricted estimates of the elements of the α_{yy} matrix when all rows of β'_y matrix are restricted, as shown in panel I. The first row contains the estimated weights of the three cointegrating vectors in the nominal exchange rate equation. The estimated weights are consistent with the results from the full VAR model in Table 5.3. They indicate that only the PPP vector $\widehat{\beta}'_1 X$ enters significantly in the nominal exchange rate equation with a weight of -0.11. This weight is quite close to the estimated weight within the full VAR model, -0.12, cf. also Appendix C. This supplements the evidence in favour of the presumed weak exogeneity of RB^f, cpi^f and *oilp,* at least for the parameters of interest in the nominal exchange rate equation.

Table 5.6: Tests for long run relations and weak exogeneity, conditional VAR model.

I. Testing hypotheses by restrictions on rows of β_y'

		e	cpi	RB	$FI.Y$	cpi^f	RB^f		$\chi^2(3)$
1	$\widehat{\beta}_1'$:	1	−1	0	0	1	0	:	2.23[0.53]
2	$\widehat{\beta}_2'$:	0	0	1	0	0	−1	:	7.11[0.07]
3	$\widehat{\beta}_3'$:	0	0	0	1	0	0	:	6.74[0.08]
	$\widehat{\beta}_y'$:	$\widehat{\beta}_1'$	$\cap$	$\widehat{\beta}_2'$	$\cap$	$\widehat{\beta}_3'$	:	$\chi^2(9)$ = 17.25	[0.05]

II. Unrestricted estimates of α_{yy}

$\widehat{\alpha}_{yy}$	1	2	3
Δe :	$\widehat{\alpha}_{e,1}$	$\widehat{\alpha}_{e,2}$	$\widehat{\alpha}_{e,3}$
Δcpi :	$\widehat{\alpha}_{cpi,1}$	$\widehat{\alpha}_{cpi,2}$	$\widehat{\alpha}_{cpi,3}$
ΔRB :	$\widehat{\alpha}_{RB,1}$	$\widehat{\alpha}_{RB,2}$	$\widehat{\alpha}_{RB,3}$
$\Delta FI.Y$:	$\widehat{\alpha}_{FI.Y,1}$	$\widehat{\alpha}_{FI.Y,2}$	$\widehat{\alpha}_{FI.Y,3}$

=

$\widehat{\alpha}_{yy}$	1	2	3
Δe :	− 0.112 (0.059)	− 0.034 (0.104)	− 0.081 (0.149)
Δcpi :	0.055 (0.026)	0.120 (0.046)	0.052 (0.067)
ΔRB :	− 0.017 (0.017)	− 0.060 (0.031)	− 0.087 (0.044)
$\Delta FI.Y$:	− 0.019 (0.074)	−0.005 (0.131)	− 0.234 (0.189)

III. Testing weak exogeneity

1.	$\widehat{\beta}'$	$\cap$	$\alpha_{e,2} =$	$\alpha_{e,3} =$	0,		$\chi^2(11)$	17.69[0.09]
2.			$\alpha_{cpi,1} =$	$\alpha_{cpi,2} =$	$\alpha_{cpi,3} =$	0,	$\chi^2(3)$	= 20.39[0.02]*
3.	$\widehat{\beta}'$	$\cap$	$\alpha_{cpi,1} =$	$\alpha_{cpi,2} =$	$\alpha_{cpi,3} =$	0,	$\chi^2(12)$	= 26.90[0.01]**
4.	$\widehat{\beta}'$	$\cap$	$\alpha_{cpi,1}$	= 0,			$\chi^2(10)$	= 23.34[0.01]**
5.	$\widehat{\beta}'$	$\cap$	$\alpha_{RB,1}$	= 0,			$\chi^2(10)$	= 18.68[0.05]
6.	$\widehat{\beta}'$	$\cap$	$\alpha_{FI.Y,1}$	= 0,			$\chi^2(10)$	= 17.34[0.07]
7.	$\widehat{\beta}'$	$\cap$	$\alpha_{RB,1}$	=	$\alpha_{FI.Y,1}$	= 0,	$\chi^2(11)$	= 18.86[0.06]
8.	$\widehat{\beta}'$	$\cap$	$\alpha_{RB,1} =$	$\alpha_{FI.Y,1} =$	$\alpha_{e,2} =$	$\alpha_{e,3} = 0,$	$\chi^2(13)$	19.28[0.12]

IV. $\widehat{\alpha}_{yy}\widehat{\beta}_y'X$

$$\widehat{\alpha}_{yy}\widehat{\beta}_y'X = \begin{bmatrix} \Delta e: & \underset{(0.039)}{-\ 0.087} & 0 & 0 \\ \Delta cpi: & \underset{(0.021)}{0.051} & \underset{(0.041)}{0.108} & 0 \\ \Delta RB: & 0 & \underset{(0.023)}{-\ 0.040} & \underset{(0.036)}{-\ 0.071} \\ \Delta FI.Y: & 0 & 0 & \underset{(0.154)}{-\ 0.205} \end{bmatrix} \begin{bmatrix} e-(cpi-cpi^f) \\ RB-RB^f \\ FI.Y \end{bmatrix},$$

$:\chi^2(15) = 20.64[0.15]$

Note: The results in this table are based on the model in Table 5.5.

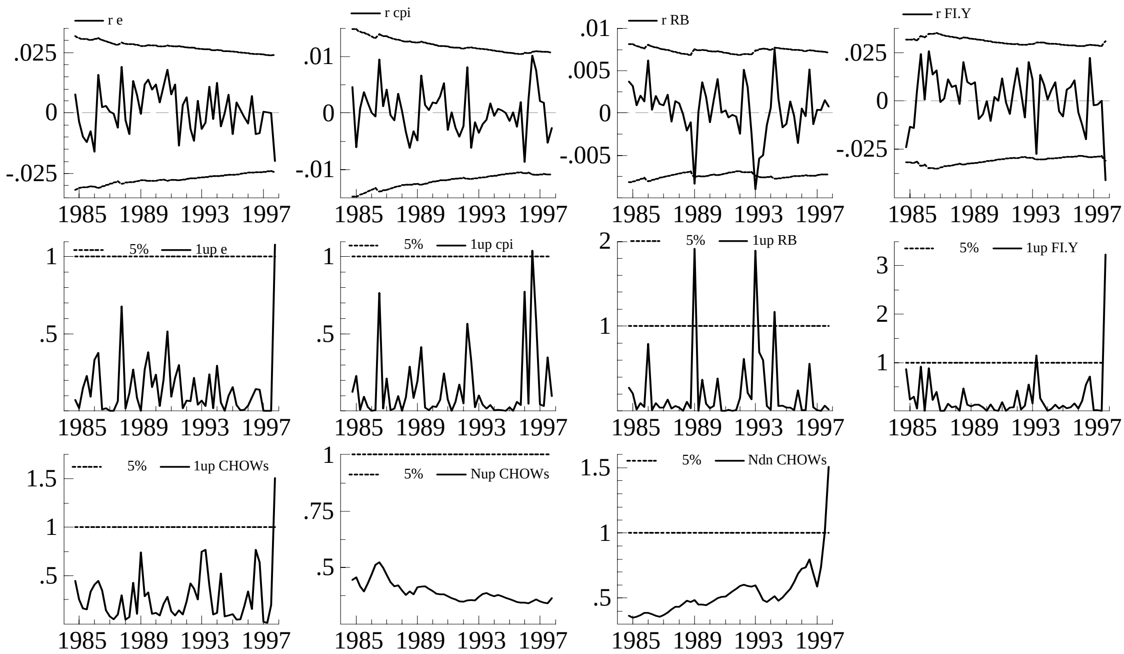

Figure 5.7: *Constancy statistics for the four equation conditional VAR model in table 5.5. Top panel: One-step residuals* $\pm 2SE_t$*. Middle panel: Chow statistics for each of the four equations. Bottom panel: Chow statistics for the conditional system. All Chow statistics are scaled by their (one-off) critical values at the 5% level of significance. The initial estimation period is 1972:2-1984:4.*

The second row of the estimated α_{yy} matrix indicates that Δcpi responds positively to deviations from the purchasing power parity and to the interest rate spread. The spread can be interpreted as the expected rate of depreciation, in accordance with the UIP hypothesis. The unrestricted estimates of the elements of the α_{yy} matrix also suggest that $\widehat{\beta}_1'X$ is not significant in the ΔRB equation nor in the $\Delta FI.Y$ equation.

The unrestricted estimate of the weight of $FI.Y_{t-1}$ in the $\Delta FI.Y$ equation is insignificant at the 5% level , with a t-value of -1.24. The estimated weight of the interest rate spread in the ΔRB equation is also a borderline case with a t-value of -1.94. The insignificance of $FI.Y$ might owe to inadequate modelling of $\Delta FI.Y$, which generally leads to higher standard errors and biased coefficient estimates. This interpretation fits well with the results from the ADF test where up to 7 lags of $\Delta FI.Y$ are significant while the coefficient estimate of $FI.Y_{t-1}$ is -0.62, see Table 5.1. This suggests that a larger information set, and/or variables of more relevance for the behaviour of $\Delta FI.Y$ are required to obtain more precise estimates of $FI.Y_{t-1}$ and in modelling $\Delta FI.Y$. Similarly, the ΔRB equation might also benefit from an extension of the information set, e.g. by including short term domestic and foreign interest rates. Moreover, by taking proper account of regulations of capital flows, in particular during the 1970s and the early 1980s; for instance, by allowing for separate equilibrium terms before and after the dismantling of the Norwegian foreign exchange rate regulations in 1990, cf. Figure 5.1. A more satisfactory modelling of $\Delta FI.Y$ and ΔRB is however not among the main concerns of this study and is therefore not pursued further.

Panel III tests restrictions on the feedback coefficients (weights) jointly with the restrictions on the β_y' matrix (in all cases but one) and the results support the impression from panel II. The first row shows that the exclusion of the second and the third cointegrating relations from the nominal exchange rate equation is accepted at a p-value of 0.09. The tests in the second, third and the fourth row suggest that *cpi* adjusts to divergence from PPP, that is, $\alpha_{cpi,1}$ is not zero. The second and third row of panel III show that the weak exogeneity of *cpi* for all cointegrating relations is rejected at the 5% level. The fourth row tests explicitly for the absence of the PPP vector ($\widehat{\beta}_1'X$) from the consumer price equation and rejects this hypothesis at the 5% level. The remaining tests in panel III test whether the PPP vector is absent from the equations for *RB* and *FI.Y.* The tests are conducted equation by equation and jointly. In particular, the final row tests the valditity of excluding the interest rate spread and *FI.Y*, jointly with the exclusion of the PPP vector from the *RB* and *FI.Y* equations. The imposed restrictions are not rejected at the 5 % level.

Panel IV shows the three long run relations together with their weights in the four equations for the endogenous variables. Two additional zero restrictions have been imposed on the α_{yy} matrix, relative to the last row in panel III. The joint restrictions on the α_{yy} and β_y' matrices are accepted with a p-value of 0.15. The joint restrictions are also tested recursively from 1985 and onwards in Figure 5.8. The graphed values of the test statistics do not show rejection of these restrictions at the 5% level, in any period from 1985 to the end of the sample in 1997:4.

The elements of the α_{yy} matrix are more precisely estimated in panel IV since their estimated standard errors are slightly lower than in panel II. Taken at face value, the estimate of $\widehat{\alpha}_{e,1}$, now -0.087, is slightly lower than the unrestricted estimate of -0.11. The $\widehat{\alpha}_{yy}$ matrix shows that $FI.Y$ only adjusts to its own level and that only RB appears to respond to the level of $FI.Y.$ A joint test with a zero restriction on $FI.Y$ in the ΔRB-equation is however accepted at the 5% level. The relevant $\chi^2(16)$ test statistic is 25.9 with at p-value of 0.06. This implies that $FI.Y$ can be treated as a weakly exogenous variable when modelling e, cpi and *RB.* This, however, does not apply to RB when modelling the nominal exchange rate. Even though $\widehat{\beta}_1'X$ is absent from the RB equation, cf. condition (1), it "shares" $\widehat{\beta}_2'X$ with the cpi equation that contains $\widehat{\beta}_1'X$. Hence RB is not weakly exogenous for $\widehat{\beta}_1'$. Consequently, valid inference on the long run parameters in the nominal exchange rate equation is not warranted on the basis of a conditional model of the nominal exchange rate alone. It requires a joint conditional model of at least e, cpi and RB.[19]

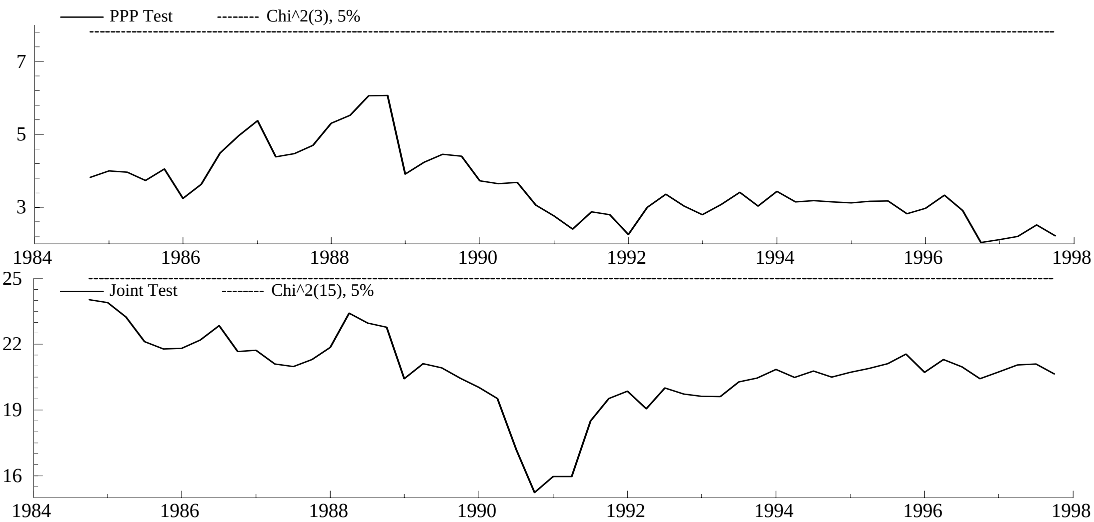

Figure 5.8: *Recursive encompassing tests for the conditional VAR model in table 5.5. The upper graph shows the recursive test statistcis when only the PPP restrictions are imposed. The lower graph shows the recursive statistcis when all restrictions defined in panel III of the table are jointly imposed. The initial estimation period is 1972:2-1984:4.*

To summarise, the results from the (parsimonious) conditional VAR model are consistent with the results from the full VAR model. Accordingly, the symmetry and proportionality restrictions implied by the PPP theory are not rejected. Moreover, oil prices and financial investment abroad do not have long run effects on the nominal exchange rate. Their effects on the domestic consumer prices and interest rates have also been found to be insignificant. Domestic consumer prices respond positively to the interest rate spread, which can be interpreted as an indicator of expected depreciation. More importantly, they respond to deviations from the PPP in a statistically significant way, and contribute to re-establish the purchasing power parity in the long run. This is not only consistent with the view that the PPP is a theory for both the nominal exchange rate and prices, but also with the Scandinavian model of inflation, see subsection 2.3.

[19] Alternatively, valid inference on the parameters of interest in the nominal exchange rate equation requires joint modelling of cpi. Valid modelling of cpi, however, cannot be pursued unless RB is modelled.

6. Conclusions

Despite the emerging consensus on the validity of purchasing power parity (PPP) between trading countries in the long run, it is commonly rejected in data predominantly exposed to real shocks. This paper presents novel results against this background. The paper tests for PPP between Norway and its trading partners by examining its implications for the behaviour of the Norwegian real and nominal exchange rates. The empirical results are based on quarterly data from the post Bretton Woods period in which the Norwegian economy has been exposed to numerous real shocks such as discoveries of oil and gas resources and their revaluations through major shocks to oil prices. Yet, we find that the empirical evidence, obtained by employing a wide range of empirical models, is remarkably consistent with the PPP theory.

The evidence suggests that the real exchange rate is a stationary process which converges towards an equilibrium level that has been remarkably stable over most of the sample period. Moreover, the half life of a given deviation from the equilibrium rate is about 1 and 1/2 years, which is relatively fast when compared with the consensus estimates from the vast PPP literature. The symmetry and proportionality restrictions implied by the PPP theory are not rejected and the additional variables, including oil prices, are not found to have long run effects on the nominal exchange rate and prices. Furthermore, the PPP theory is found to characterise the long run behaviour of both the nominal exchange rate and domestic prices. Both variables respond to deviations from the PPP and contribute to re-establish the parity in the long run. The response of the nominal exchange rate is however found to be almost twice the size of that for the domestic prices.

The relatively fast convergence of the real exchange rate towards its equilibrium rate is interpreted as a reflection of the active use of devaluations until the mid of 1986, centralised wage bargaining and of possibly strong international arbitrage pressure owing to the openness of the Norwegian economy. The relatively strong response of the nominal exchange rate to deviations from the parity, compared with that of domestic prices, is consistent with this interpretation.

The empirical analysis shows that the processes determining the exchange rate, consumer prices and interest rates are interdependent (in the sense of not being weakly exogenous for each others long run parameters). It follows that a change in the process of one of the variables is likely to induce a change in the processes of the other variables. For instance, a change from exchange rate targeting to inflation targeting may imply a simultaneous change in the exchange rate process, from stable to floating, and in the interest rate process. In the latter case, interest rates will no longer shadow the foreign interest rates to keep the exchange rate stable but become more attuned to the domestic activity level in order to achieve the inflation target. It is therefore not unlikely that a change from exchange rate targeting to inflation targeting affects the process that determines prices, as pointed out by Holden (1997) and Rødseth (1997a) *inter alia.*

This paper argues that one needs to take into account institutional features of an economy in order to assess the partial effect of e.g. a nominal exchange rate regime, or centralised wage setting, on the real exchange rate behaviour. An empirical assessment is however left to future studies since it is likely to involve a cross country data set. One possible way to proceed would be to model e.g. the half life of a deviation from a real exchange rate equilibrium using data on the degree of centralisation and/or coordinations of wage setting, degree of openness and by taking into account the nature of fiscal and exchange rate policies of each country; the latter, possibly by taking into account the degree of central bank independence, which usually makes a central bank less disposed to undertake devaluations in order to make up for deterioration in the competitiveness of an economy. A cross country study along the sketched lines might add weight to the interpretation of results in this paper and throw more light on the empirical regularities encountered in the PPP literature.

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Appendices

Appendix A lists the trade weights of Norway's main trading partners, used in constructing the trade weighted exchange rate. The countries listed in the table are also known as basket countries. The trade weighted exchange rate is a weighted average of the value of these countries' currencies measured in NOK. Appendix B provides definitions and sources of the data used in this study. Appendix C tests some of the main hypotheses in different specifications of the full VAR model. This exercise is partly meant as an illustration of the robustness of results, to different types of model (mis)specifications, even though the usual distributions of the test statistics are unlikely to be valid.

Appendix A Trade weights

Table 6.1: Trade weights based on import shares of basket countries

Austria	Belgium	Canada	Denmark	Finland	France	Germany
0.014	0.033	0.020	0.077	0.049	0.044	0.175
Italy	Japan	Netherland	Sweden	Switzerland	UK	USA
0.033	0.063	0.041	0.206	0.019	0.134	0.092

Note: Each country is assigned a weight equal to its average import share, in the total import from the 14 countries in this table. These 14 countries were the basket countries until October 1990. The average import shares are based on data for period 1978-1987, see Naug (1990, pp. 103).

Appendix B Data definitions

Unless stated otherwise, the variables listed below are taken from the data base for RIMINI, the quarterly macroeconometric model used in Norges Bank. The main sources for RIMINI's data base are Quarterly National Accounts, FINDATR, TROLL8 , OECD_MEI and IFS. These data bases are maintained by Statistics Norway, Norges Bank, Norges Bank, OECD and IMF, respectively. The RIMINI names of the variables are indicated in square brackets []. Note that this paper employs seasonally unadjusted quarterly data.

CPI : Consumer price index for Norway, 1991 = 1. [CPI].

CPI^f: Trade weighted average of consumer price indices for Norway's trading partners. Measured in foreign currency, 1991 = 1. [PCKONK].

C_G : Public consumption expenditures, fixed 1995 prices, Mill. Norwegian krone (NOK). [CO].

CS : Centered seasonal dummy variable (mean zero) for the first quarter in each year. It is 0.75 in the first quarter and -0.25 in each of the three other quarters, for every year.

E : Trade weighted nominal value of NOK, 1991 = 1. [PBVAL].

$FI.Y$: A measure of foreign net financial investment in Norway, fixed 1991 prices, Mill. NOK. Constructed by taking the first difference of the net foreign debts' share of GDP, [LZ.Y], i.e. $FI.Y = \Delta$LZ.Y.

g : Public expenditures' share of GDP, i.e. $g = (C_G+J_G)/Y$.

id86q2 : Impulse dummy related to the oil price fall in 1986. It has a value of 1 in 1986:2 and zero elsewhere.

id90q3 : Impulse dummy for the Gulf War. It has a value of 1 in 1990:3, -1 in 1990:4 and zero elsewhere.

id97q1 : Impulse dummy related to the oil price hike in 1996/97. It has a value of 1 in 1997:1, -1 in 1997:2 and zero elsewhere.

J_G : Public expenditures for gross real investment, fixed 1995 prices, Mill. NOK. [JO].

OILP : Price per barrel of Brent Blend crude oil in US dollars. Source TROLL8, series no. Q2001712.

OP1 : Impulse dummy for OPEC I. It has a value of 1 in 1974:1, -0.3 in 1974:2 and zero elsewhere.

OP2 : Step dummy for OPEC II. It has a value of 1 over period 1979:1-1985:4 and zero elsewhere.

Q : Value added per unit labour cost in Norway. The inverse of value added based unit labour costs. 1/[LPE.Y].

Q^f: Value added per unit labour cost in trading partners. The inverse of trade weighted average of value added based unit labour costs. 1/[M.LPE].

R : Trade weighted real exchange rate, defined as R = $(E$ x $CPI^f)/CPI$. [RPBVAL].

RB : Yield on 6 years Norwegian government bonds, quarterly average. [R.BS].

RB^f : NOK basket-weighted average of interest rates on long term foreign bonds. [R.BKUR].

RS : *3* month Euro krone interest rate. [RS].

U : Total unemployment rate, fraction of labour force exclusive self employed and on labour market programs. [UTOT].

Y : Gross domestic product for Norway. Mill. NOK, fixed 1995 prices. [Y].

Appendix C Sensitivity analysis of the main results

Here some of the main results in section 5 are tested in different specifications of the full VAR model. Specifically, we reexamine the key hypotheses in more restricted versions of the full VAR model employed in section 5. These different specifications might be preferred by some analysts on the basis of their parsimony, higher degrees of freedom or because of distaste for the use of dummy variables in general, or for the way they have been specified and used in this study. For convenience and transparency, the VAR model is only changed in two different ways. First, the hypotheses are tested within VAR models that only differ from each other in the number of lags. Next, all dummy variables including seasonal dummies are excluded from the model and hypotheses are tested by changing the number of lags in the VAR model. Another simplification is that only those hypotheses are tested which are of direct relevance for the theme of this study. This exercise serves two purposes:

Firstly, it substantiates the choice of the VAR model in Table 5.2 as an approximation to the data generating process. Note that none of the other models in the table have residuals which are normally distributed and free of autocorrelation.

Secondly, it lends some credibility to the results reported in this study. The main hypotheses seem to be accepted by the tests even in models that display signs of misspecification, see the test statistics for the autocorrelation tests and the normality tests. Note however, that the results are only indicative, since the residuals are in general not IIDN(.).

Table 6.2: Tests of hypotheses within different specifications of the VAR model.

I. Defining hypotheses

		e	cpi	RB	$FI.Y$	cpi^f	RB^f	$oilp$	t	$OP2$
a)	$\widehat{\beta}_1'$	1	−1	0	0	1	0	0	0	0
b)	$\widehat{\beta}_4'$	0	0	0	0	0	0	1	*	*
c)	$\alpha_{cpi} = 0:$		$\alpha_{cpi,\,1} =$		$\alpha_{cpi,\,2} =$		$\alpha_{cpi,\,3} =$		$\alpha_{cpi,\,4} =$	0
d)	$\widehat{\beta}_1' \cap \widetilde{\alpha}_e = 0:$			$\widehat{\beta}_1' \cap$	$\alpha_{e,\,2} =$		$\alpha_{e,\,3} =$		$\alpha_{e,\,4} =$	0
e)	$\widetilde{\beta}' \cap \widetilde{\alpha}_{oilp} = 0:$	$\widetilde{\beta}' \cap$	$\alpha_{e,\,4} =$		$\alpha_{cpi,\,4} =$		$\alpha_{RB,\,4} =$		$\alpha_{FI.Y,\,4} =$	0

II. Changing lag length p

H_0	VAR(5)	VAR(4)	VAR(3)	VAR(2)	VAR(1)
$\widehat{\beta}_1'$	10.16[.07]	12.10[.04]	9.65[.09]	15.43[0.01]	6.54[.26]
$\widehat{\beta}_4'$	5.52[.14]	6.32[.10]	5.28[0.15]	2.35[0.50]	7.74[.05]
$\alpha_{cpi} = 0$	18.61[.00]	24.95[.00]	18.65[.00]	28.70[.00]	95.40[.00]
$\widehat{\beta}_1' \cap \widetilde{\alpha}_e = 0$	13.00[.11]	15.50[0.05]	11.26[.19]	15.99[.04]	21.91[.01]
$(\widehat{\alpha}_{e,1})$	(−0.121)	(−0.112)	(−0.104)	(−0.122)	(−0.100)
$\widetilde{\beta}' \cap \widetilde{\alpha}_{oilp} = 0$	9.34[.23]	14.60[0.04]	9.12[.24]	13.28[.07]	14.48[.04]
$F^v_{ar,1-5}(.)$	1.23[.09]	1.34[.01]	1.67[.00]	1.50[.00]	1.70[.00]
$\chi^{v,\,2}_{nd}(14)$	17.32[.24]	24.41[.04]	31.20[.01]	45.17[.00]	52.34[.00]

III. Excluding all dummies and changing p

H_0	VAR(5)	VAR(4)	VAR(3)	VAR(2)	VAR(1)
$\widehat{\beta}_1'$	4.47[.35]	4.26[.37]	4.58[.33]	10.99[.03]	6.16[.19]
$\widehat{\beta}_4'$	3.01[.39]	1.21[.75]	3.26[.35]	11.80[.01]	8.70[.03]
$\alpha_{cpi} = 0$	23.56[.00]	12.19[.02]	17.62[.00]	31.55[.00]	73.70[.00]
$\widehat{\beta}_1' \cap \widetilde{\alpha}_e = 0$	9.46[.22]	8.19[.32]	8.59[.28]	13.98[.05]	18.45[.01]
$(\widehat{\alpha}_{e,1})$	(−0.132)	(−0.130)	(−0.103)	(−0.135)	(−0.113)
$\widetilde{\beta}' \cap \widetilde{\alpha}_{oilp} = 0$	4.61[.71]	4.30[.75]	5.27[.63]	16.83[.02]	12.11[.10]
$F^v_{ar,1-5}(.)$	1.17[.15]	1.07[.31]	1.40[.00]	1.34[.01]	1.77[.00]
$\chi^{v,\,2}_{nd}(14)$	50.52[.00]	57.62[.00]	67.99[.00]	70.52[.00]	75.89[.00]

Note: Panel I: a) the PPP relation is stationary, b) the *oilp* is a cointegrating term by itself. * denotes an unrestricted coefficient. c) *cpi* is weak exogenous in the system, i.e. does not respond to any of the disequilibria in the VAR model. d) only the PPP relation enters the exchange rate equation. e) oilp does not enter any of the equation for the domestic variables, e, cpi, RB and FI.Y, i.e. oil price does not have long run effects on any of these variables. Panel II: The hypotheses defined above are tested within the full VAR model for different number of lags. Here VAR(5) is as in Table 5.2. $\widehat{\alpha}_{e,1}$ is the adjustment coefficient associated with the PPP term in the exchange rate equation. The numbers in each of the columns are χ^2 tests statistics under the different null hypotheses. The square brackets contain the p-values under the null hypotheses. These are not valid since the residuals do not have IIDN(.) properties. The (system) tests for auto-correlation and normality, strongly rejects the hypotheses that the residuals in this system are in possession of such properties in most of the cases. $\widetilde{\beta}'$ is defined in panel III of table 5.3.
Panel III: Tests the same hypotheses as above, but within VAR models which do not include dummy variables at all. Note that $\widehat{\beta}_4'$ is defined without OP2 in this case.

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