

Jansen, Eilev S.

Working Paper

Statistical Issues in Macroeconomic Modelling

Arbeitsnotat, No. 2000/12

Provided in Cooperation with:

Norges Bank, Oslo

Suggested Citation: Jansen, Eilev S. (2000) : Statistical Issues in Macroeconomic Modelling, Arbeitsnotat, No. 2000/12, ISBN 82-7553-160-8, Norges Bank, Oslo, <https://hdl.handle.net/11250/2500396>

This Version is available at:

<https://hdl.handle.net/10419/209785>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.



<https://creativecommons.org/licenses/by-nc-nd/4.0/deed.no>

2000/12

Oslo
November 8, 2000

Arbeidsnotat

Research Department

Statistical issues in macroeconomic modelling

by

Eilev S. Jansen

Arbeidsnotater fra Norges Bank
kan bestilles over Internett:
www.norges-bank.no/publikasjoner
eller ved henvendelse til
Norges Bank, Abonnementsservice,
PB 1179 Sentrum, 0107 Oslo
Telefon 22 31 63 83, Telefaks 22 41 31 05

Norges Banks arbeidsnotater inneholder
forskningsarbeider og utredninger som
vanligvis ikke har fått sin endelige form.
Hensikten er blant annet at forfatteren
kan motta kommentarer fra kolleger og
andre interesserte.

Synspunkter og konklusjoner
står for forfatterens regning.

*Arbeidsnotater/working papers from
Norges Bank can be ordered via Internet:
www.norges-bank.no/english/publications
or from Norges Bank, Subscription service,
P.O.Box. 1179 Sentrum, 0107 Oslo, Norway.
Tel. +47 22 31 63 83, Fax. +47 22 41 31 05*

*Norges Bank's Working papers present
research projects and reports
(not usually in their final form),
and are intended inter alia to enable
the author to benefit from the comments
of colleagues and other interested parties.*

*Views and conclusions expressed are the responsibility
of the author alone.*

ISSN 0801-2504
ISBN 82-7553-160-8

Statistical issues in macroeconomic modelling.*

Eilev S. Jansen

Norges Bank and Norwegian University of Science and Technology

First version: 15 May 2000

This version: 8 November 2000

Abstract

The paper describes the influx of mathematical statistics in economics. It focuses on an approach to macroeconometric modelling which is based on fundamental statistical concepts like the joint distribution function of all observable variables for the whole sample period. The methodology relies on valid conditioning and marginalisation of this function in order to arrive at tractable subsystems, which can be analysed with statistical methods. Two case studies - the modelling of the household sector and the modelling of wages and prices in the Norges Bank RIMINI model - highlight this.

Keywords: *macroeconometric modelling, role of statistics, Norges Bank model RIMINI, Haavelmo distribution, sequential conditioning and marginalisation, dynamic modelling, aggregate consumption, wages and prices, testing of rival models*

JEL classification: *B23, C50, C51, C52, C53, E21, E31, E37*

*Invited paper presented at the 18th Nordic Conference on Mathematical Statistics in Grimstad 5.-8. June 2000. I would like to thank David Hinkley, Søren Johansen and other participants at that conference for their comments. Likewise, comments to various versions of this paper from Q. Farooq Akram, Gunnar Bårdsen, Øyvind Eitrheim, Grayham Mizon, Ragnar Nymoen, Fredrik Wulfsberg and seminar participants at Department of Economics, NTNU, and at Norges Bank have been very helpful. The paper has also been presented to the Fall Meeting of Project LINK in Oslo 2.-6. October 2000. The views expressed are those of the author and should not be interpreted as reflecting those of Norges Bank.

1 Introduction

On this occasion - having the opportunity to give an invited paper to you as statisticians - I would like to convey to you three important points:

- Mathematical statistics has over the years supplied macroeconomic modellers with an essential part of their tool kit.
- The potential for successful macroeconomic model building has increased substantially over the past decade or so through the adoption of new methods from the statistical analysis of time series data.
- Economics is characterized by persistent controversies and statistics can help us resolve these conflicting views. The fact that macroeconomic models are used as a basis for economic policy decisions makes these issues all the more important.

1.1 What is macroeconomic modelling?

Macroeconomic modelling is a term with several meanings. Macroeconomic modelling can be based on a purely theoretical model, as a highly abstract set of mathematical equations describing the determination of unobservable equilibrium values of some economic aggregates like output and employment in a stylised economy. Such models may be calibrated to fit a base year and may not otherwise make any attempt to explain real data. The term has also been attached to mathematical models used for miscellaneous administrative planning purposes be it in centralised socialist economies or as part of budgetary processes of government departments in many Western European countries¹. It can also mean a modelling activity that aims at explaining the empirical behaviour of an actual economic system of all important economic aggregates in full detail, including its growth, cyclical, seasonal and erratic patterns. In the latter case, models will be systems of inter-linked equations estimated from time-series data using statistical or econometric techniques. We would call this a *macroeconometric* model. In this paper I will focus on such models and I will discuss alternative modelling approaches only in passing.

1.2 The influx of statistics into economics

Despite the economists' own contributions, it is obvious that statisticians have had a decisive influence on quantitative economics in general and on modern macroeconomic modelling in particular. Jan Tinbergen - a Dutch economist - built and estimated the first macroeconometric model in 1936 (Tinbergen (1936)), but there

¹The Norwegian modelling tradition is an example. Inspired by the work of Ragnar Frisch, the short and medium term models of Statistics Norway - MODIS and MODAG - were both *planning* models. They were mainly used in the budgetary process of the Ministry of Finance and the issues of econometric specification, testing and evaluation played only a minor role in their construction, see Bjerkholt (1998). Only with the introduction of the KVARTS model (Biørn et al. (1987)) in the late 1980s this was about to be changed.

seems to be universal agreement that statistics enters the discipline of economics and econometrics with the contributions of the Norwegian economist Trygve Haavelmo in his treatise "The Probability Approach in Econometrics", Haavelmo (1944), see Klein (1988), Morgan (1990), or Hendry and Morgan (1995).² As Morgan (1990), p.242 points out, Haavelmo was converted to the usefulness of probability ideas by Jerzy Neyman and he was also influenced by Abraham Wald, who Haavelmo credited as the source of his understanding about statistical theory.³

For our purpose it is central to note that Haavelmo recognised and explained in the context of an economic model how the joint distribution of all observable variables for the whole sample period provides the most general framework for statistical inference, see Hendry et al. (1989). This applies to specification (*op.cit.*, pp 48-49), as well as identification, estimation and hypothesis testing:

..all come down to one and the same thing, namely to study the properties of the joint probability distribution of random (observable) variables in a stochastic equation system.. (Haavelmo (1944), p.85)

Haavelmo's paper was immediately adopted by Jacob Marschak - a Russian-born scientist who had studied statistics with Slutsky - as the research agenda for the Cowles Commission for the period 1943-1947 in reconsidering Tinbergen's work on business cycles cited above. Marschak was joined by a group of statisticians, mathematicians and economists, including Haavelmo himself. Their work was to set the standards for modern econometrics and found its way into the textbooks of econometrics from Klein (1953) onwards.

The work of Cowles Commission also laid the foundations for development of macroeconomic models as they grew into a large industry in the US in the next three decades, see Bodkin et al. (1991) and Wallis (1994). These models were mainly designed for short (and medium) term forecasting, i.e. modelling business cycles. The first model, Klein (1950), was made with the explicit aim of implementing Haavelmo's ideas into Tinbergen's modelling framework for the US economy. Like Tinbergen's model, it was a small model and Klein put much weight on the modelling of simultaneous equations. Later models became extremely large systems in which more than 1000 equations have been used to describe the behaviour of a modern industrial economy. In such models, less care could be taken about each econometric specification, and simultaneity could not be treated in a satisfactory way. The forecasting purpose of these models meant that they were evaluated on their performance. When the models failed to forecast the effects of the oil price shocks in 1973 and in 1979 to the industrial economies, a large part of the macroeconomic modelling industry lost much of its position, particularly in the US.

²See also the press release on 11 October 1989 from The Swedish Academy announcing that Trygve Haavelmo was awarded the Nobel Memorial Prize in Economics 1989, see Royal Swedish Academy of Science (1990)

³J. Neyman and E. Pearson were responsible for the statistical testing procedure which Haavelmo adopted. Abraham Wald is in particular renowned for his contributions to statistical decision theory and, according to Morgan, *op.cit.*, he exerted a considerable influence on the Cowles Commission group in Chicago in the 1940s.

There may be several reasons why that happened. First, those shocks may have altered the functioning of the economies. And it is clear from recent research on forecasting, see Clements and Hendry (1998) and (1999), the presence of such structural breaks will cause forecast failure even for models that are well specified within sample. Second, since those models were essentially static and thus ignored dynamics and the temporal properties of the data, we may - with the advantage of hindsight - conclude that the models were dynamically misspecified.

In the 1980s macroeconometric models took advantage of the methodological and conceptual advances within time series econometrics. Already, Box and Jenkins (1970) had provided and made popular a purely statistical tool for modelling and forecasting univariate and multivariate time series. The second influx of statistical methodology into econometrics has its roots in the study of the non-stationary nature of economic data series. Clive Granger - with his background in statistics - has in a series of influential papers shown the importance of an econometric equation being balanced. A stationary variable cannot be explained by a non-stationary variable and vice versa, see e.g. Granger (1990). Moreover, the concept of cointegration (see Granger (1981), Engle and Granger (1987, 1991b)), - that a linear combination of two or more non-stationary variables can be stationary - has proven extremely useful and important within macroeconometric as well as purely statistical models. Within the framework of a general vector autoregressive model (VAR), the statistician Søren Johansen has provided (see Johansen (1988, 1991, 1995)) the most widely used tools for testing for cointegration in a multivariate setting, drawing on the analytical framework of canonical correlation and multivariate reduced rank regression in Anderson (1951).

Also, there has been an increased attention to the role of evaluation in modern econometrics, see Granger (1990, 1999). The so called LSE methodology in particular emphasizes the importance of testing and evaluation of econometric models, see Hendry (1993a, 1995a) and Mizon (1995). Interestingly, Hendry et al. (1989) claims that many aspects of the Haavelmo research agenda were to be ignored for a long time in econometrics. For instance the joint distribution function for observable variables was recognised by the Cowles Commission as central to solving problems of statistical inference, but the ideas did not influence empirical modelling strategies for decades. By contrast, many developments in econometrics after 1980 are in line with this and other aspects of Haavelmo's research programme. This is also true for the role of economic theory in econometrics:

Theoretical models are necessary tools in our attempts to understand and “explain” events in real life (Haavelmo (1944), p.1)

But whatever “explanations” we prefer, it is not to be forgotten that they are all our own artificial inventions in a search for an understanding of real life; they are not hidden truth to be “discovered” (Haavelmo (1944), p.3).

With this starting point you would not expect that the facts or the observations would agree with any precise statement that is derived from a theoretical model. Economic theories must then be formulated as probabilistic statements and Haavelmo viewed probability theory as indispensable in formalizing the notion of models being approximations to reality.

1.3 The role of economic theory in macroeconometrics

Klein (1988) gives a very readable survey of the interaction between statistics and economics in the context of macroeconomic modelling. He maintains that the model building approach can be contrasted with pure statistical analysis, which is empirical and not so closely related to received economic theory as is model building.

Now, different approaches to macroeconomic modelling differ in the extent they take received economic theory as a given starting point. At one extreme we have theory-driven models that take the received theory for granted and do not test it. Prominent examples are the general equilibrium models - dubbed real business cycle models that have gained a dominating position in academia in the US, see *e.g.* Kydland and Prescott (1991). There is also a new breed of macroeconomic models with optimizing agents endowed with rational forward-looking expectations leading to a set of Euler equations, see Poloz et al. (1994), Willman et al. (2000) and Hunt et al. (2000) for models from the central banks of Canada, Finland and New Zealand, respectively. At another extreme we have data based VAR models which, according to Watson (1994), were introduced in empirical economics by Sims (1980). These models can be seen as either statistical devices that make only minimal use of economic theory or, in the less extreme case of structural VARs, testable theory restrictions are imposed on the error structure of the model.

The rationale for all these approaches - and for theory-driven models in particular - is questionable from the perspective that economics is a discipline that is dominated by persistent controversies. Modelling strategies that ignore testing of controversial issues or preclude tests by imposing the received theory restrictions *a priori*, do not help us to resolve the ambiguities in the existing body of economic theory.

The approach I am recommending - which is also the modelling strategy for the modelling work at Norges Bank - is much in line with the LSE methodology referred to above. It can be seen as a compromise between data based (purely statistical) models and economic theory: On the one hand learning from the process of trying to take serious account of the data whilst on the other hand avoiding to make strong theoretical assumptions - needed to make theories “complete” - which may not make much sense empirically, i.e. that are not supported by the data.

1.4 Organization of the paper

The rest of this paper is organised as follows: In Section 2 we outline briefly the operative empirical macroeconomic model of Norges Bank, RIMINI, and demonstrate the working of the model by describing two monetary transmission channels within that model. The main point of this is to demonstrate the complexity and interdependencies in a realistic macroeconomic model. It transpires clearly that such a model is too big and too complex to be modelled, or let alone estimated, *simultaneously*. Thus, there is a need to deal with subsectors of the economy - i.e. we try to make sense out of bits and pieces rather than handling a complete model. The modelling of subsystems implies making simplifications of the joint distribution of all observable variables in the model through sequential conditioning and marginalisations of it as discussed in Section 3.1.

The methodological approach adopted in the RIMINI project is then shown

by means of two case studies. First, the strategy of sequential simplification is illustrated for the household sector in Section 4. The empirical consumption function in RIMINI we arrive at here has been a main "work-horse" in RIMINI for more than a decade. Thus, it is of particular interest to compare it with rival models in the literature as we do in Section 4.3. Section 5 focuses on the modelling of wages and prices. This is an exercise that includes all ingredients which we regard as important for establishing an econometrically relevant submodel. The credentials of that submodel can be seen as indirect evidence for the validity of the assumptions the larger model must rely on. Being RIMINI "writ small", we also regard it as a working laboratory for various modelling experiments that are cumbersome, time-consuming and in some cases impossible to carry out with the fullblown RIMINI model. The empirical relevance of this submodel is evaluated against a rival model based on a Phillips curve inflation model in Section 5.6. Section 6 concludes.

2 The Norges Bank model RIMINI

The RIMINI model⁴ at Norges Bank has been operative as a forecasting model for nearly ten years. It is used by the policy departments to make short term forecasts for the Norwegian economy four to eight quarters ahead which are published in the Inflation Report of the Bank each quarter. Once a year the forecast horizon is extended to 4-5 years ahead, and these projections also underlie the Bank's published reports on financial stability.

A key quality of the model is thus its ability to forecast variables like output growth and CPI inflation, but in practice there is a large number of other variables that are also of interest to policy makers. The model should therefore be able to give an adequate description of aggregate output, employment, private consumption, housing investments, housing prices, other private real investment, exports, imports, the current account, wages and prices.

RIMINI is by Norwegian standards a fairly aggregated macroeconometric model. The core model consists of some 30 important stochastic equations, and there are about 100 non-trivial exogenous variables which must be projected by the forecaster. RIMINI is a fairly closed model in the sense that the most important variables for the Norwegian economy are determined by the model, while the model conditions upon "outside" variables like foreign prices and output and policy variables like interest rates and tax rates. The model distinguishes several production sectors. The Oil and Shipping sectors are not modelled econometrically as are the sectors for Agriculture, Forestry and Fishing. The two main sectors for which there exist complete submodels are Manufacturing and Construction (traded goods) and Service and Retail Trade (non-traded goods). There are reasons to expect important differences in the responses to changes in interest rates and exchange rates between traded and non-traded goods.

The model is also used by policymakers to illustrate the effects of alternative, counter-factual scenarios for important exogenous variables, for example the effect

⁴RIMINI is an acronym for a model for the Real economy and Income Accounts - a MINI version. This section is based on Eitrheim (2000). Further documentation of RIMINI is given there and in various unpublished papers at Norges Bank.

of changes in world market prices of oil (in USD). It is also frequently used to assess the effects from changes in monetary policy instruments like the short term interest rates and exchange rates, which are currently both treated exogenously in the model.

2.1 Two monetary transmission channels in RIMINI

In RIMINI there are two main channels through which monetary policy instruments affect employment, output and prices - the interest rate channel and the exchange rate channel. Figure 1 below shows for the interest rate channel the important role of the household sector in RIMINI (first dotted box from the top) and also the main interaction between the demand side (second dotted box) and the supply side (bottom dotted box). The main point here is to illustrate the complexity and interdependencies that are typical of macroeconomic systems.

Assuming fixed exchange rates, an increase in the central bank interest rate for loans to the banks (the signal rate) immediately affects the money market interest rate. The money market rate in turn feeds into the deposit and lending rates of commercial and savings banks with a lag. Aggregate demand is affected through several mechanisms, as shown in Figure 1. There is a negative effect on housing prices (for a given stock of housing capital), which causes real household wealth to decline, thus suppressing total consumer expenditure. Also, there are negative direct and indirect effects on real investment in the traded and non-traded sectors and on housing investment.

CPI inflation is reduced after a lag, mainly through the effects from changes in aggregate demand on aggregate output and employment, but also from changes in unit labour costs. Notably, productivity first decrease due to labour hoarding and then increase to create a cyclic pattern in the effects of the change in the interest rate.

An appreciation of the Krone has a more direct effect on CPI inflation compared to the interest rate channel. As illustrated by the first dotted box in Figure 2, it mainly works through reduced import prices with a lagged response which entails complete pass-through in import and export prices after about two years. The model specification allows for a constant mark-up factor on unit labour costs in import and export prices. A currency appreciation has a negative effect on the demand for traded goods. The direct effects are not of a large magnitude, because there are small relative price elasticities in the export equations and secondly because export prices (in local currency) adjust with a lag and tend to restore the relative prices. However, there are also important feedback mechanisms as decreased price level stemming from the appreciation feeds back into aggregate demand from domestic sectors.

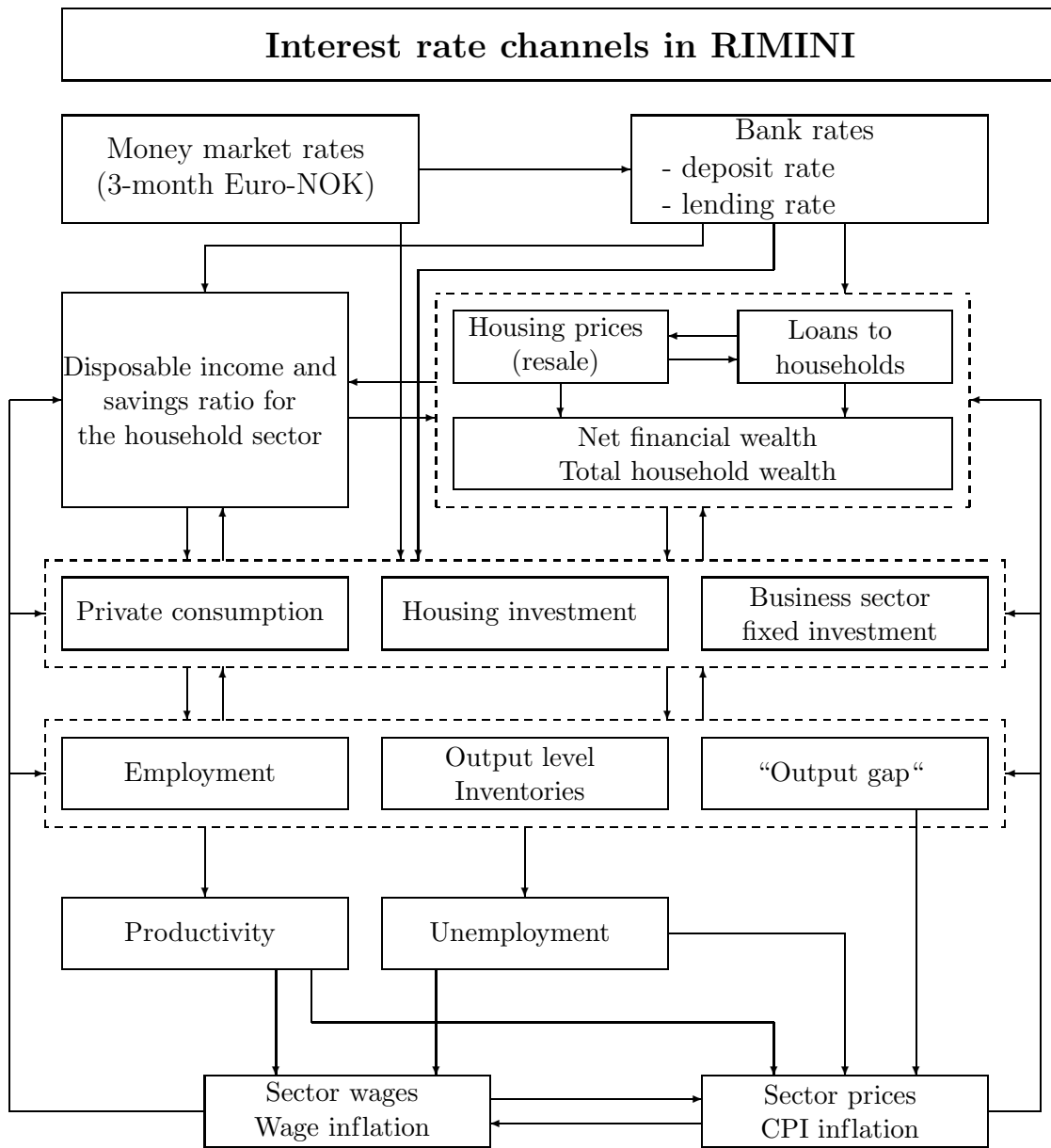


Figure 1: Interest rate channels in RIMINI. Effects on CPI inflation assuming constant exchange rates

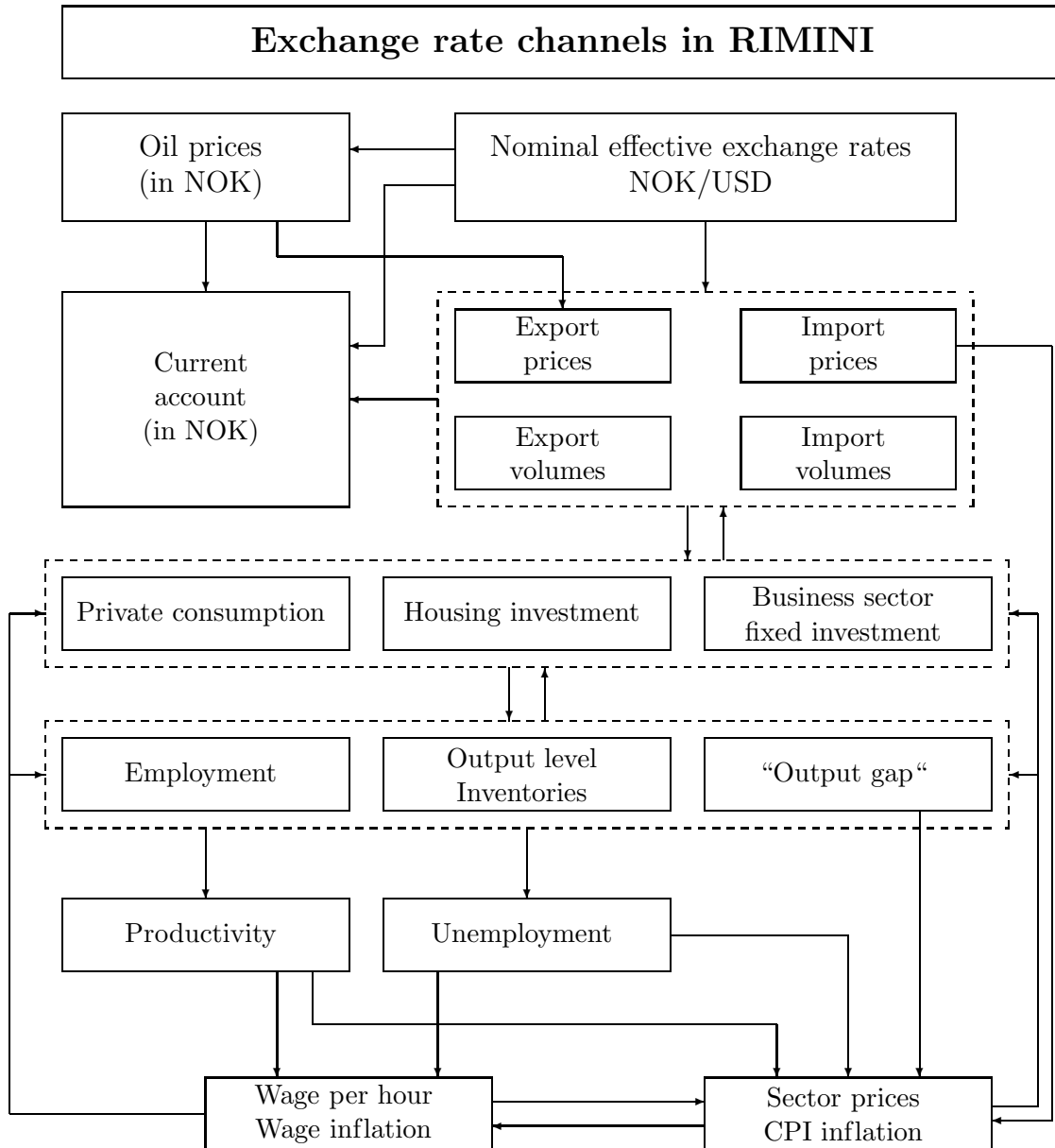


Figure 2: Exchange rate channels in RIMINI. Effects on CPI inflation assuming constant interest rates

3 The modelling strategy

3.1 Identifying partial structure in sub-models

As is clear from the outline above the RIMINI model is too big and too complex to be modelled *simultaneously*. Thus, there is a need to deal with sub-models for the different sectors of the economy. This implies that we need to make simplifications of the joint distribution of all observable variables in the model through sequential factorization, conditioning and marginalisations.

As we shall see, it all goes back to Haavelmo: Consider the joint distribution of $x_t = (x_{1t}, x_{2t}, \dots, x_{nt})'$, $t = 1, \dots, T$, and let $x_T^1 = \{x_t\}_{t=1}^T$. Sequential factorisation means that we factorize the joint density function $D_x(x_T^1 | x_0, \Lambda_{x_T^1})$ into

$$D_x(x_T^1 | x_0; \Lambda_{x_T^1}) = \prod_{t=2}^T D_x(x_t | x_{t-1}^1, x_0; \lambda_x) \cdot D_x(x_0; \lambda_{x_0}) \quad (1)$$

which is what Spanos (1989) called the *Haavelmo distribution*. It explains the present x_t as a function of the past x_{t-1}^1 , initial conditions x_0 , and a time invariant parameter vector λ_x . This is - by assumption - as close as we can get to representing what Hendry (1995a) calls the *data generating process* (DGP), which requires the residuals, $\epsilon_t = x_t - E(x_t | x_{t-1}^1, x_0; \lambda_x)$, to be an innovation process.⁵

The second step in data reduction is conditioning and simplification. We consider the partitioning $x_t = (y_t', z_t')$ and factorize the joint density function into a conditional density function for $y_t | z_t$ and a marginal density function for z_t :

$$D_x(x_t | x_{t-1}^1, x_0; \lambda_x) = D_{y|z}(y_t | z_t, x_{t-1}^1, x_0; \lambda_{y|z}) \cdot D_z(z_t | x_{t-1}^1, x_0; \lambda_z)$$

In practice we then simplify by using approximations by k th order Markov processes and develop models for

$$D_x(x_t | x_{t-1}^1, x_0; \lambda_x) \approx D_x(x_t | x_{t-1}^{t-k}; \theta_x)$$

$$D_{y|z}(y_t | z_t, x_{t-1}^1, x_0, \lambda_{y|z}) \approx D_{y|z}(y_t | z_t, x_{t-1}^{t-k}; \theta_{y|z}) \quad (2)$$

for $t > k$. The validity of this reduction requires that the residuals remain innovation processes.

A general linear dynamic class of models with a finite number of lags which is commonly used to model the n -dimensional process x_t is the k th order VAR with Gaussian error, that is

$$x_t = \mu + \sum_{i=1}^k \Pi_i x_{t-i} + \epsilon_t$$

⁵The following approach has been called “the theory of reduction” as it seeks to explain the origin of empirical models in terms of reduction operations conducted implicitly on the DGP to induce the relevant empirical model (see Hendry and Richard (1982, 1983)).

where ε_t is normally identically distributed, $Niid(0, \Lambda_\varepsilon)$. Such a VAR is also the starting point for analyzing the cointegrating relationships that may be identified in the x_t -vector, see Johansen (1988, 1991, 1995). Economic theory plays an important role both in determining which information sets to study and in interpreting the outcome of the analysis. In the following we assume for simplicity that the elements of x_t are non-stationary $I(1)$ -variables that become stationary after being differenced once. Then, if there is cointegration, it is shown in Engle and Granger (1987) that the VAR always has a Vector Equilibrium Correcting model (VEqCM) representation, which can be written in differences and levels (disregarding the possible presence of deterministic variables and trends) in the following way:

$$\Delta x_t = \sum_{i=1}^{k-1} A_i \Delta x_{t-i} + \alpha(\beta' x_{t-1}) + \varepsilon_t \quad (3)$$

where α and β are $n \times r$ matrices of rank r and $(\beta' x_{t-1})$ comprises r cointegrating $I(0)$ relationships. Cointegrated processes are seen to define a long run equilibrium trajectory and departures from this induce "equilibrium correction" which moves the economy back to its steady state path. These models are very useful as they lend themselves to an economic interpretation of model properties and their long run (steady state) properties can be given an interpretation as long run equilibria between economic variables that are derived from economic theory.

Such theory consistency, *i.e.* that the model contains identifiable structures that are interpretable in the light of economic theory, is but one criterion for a satisfactory - or in the LSE-terminology *congruent* - model. Hendry (1995a) adds more:

- The model residuals must be innovations in order for the model to be a valid simplification of the DGP.
- The conditioning variables must be (at least) *weakly exogenous* for the parameters of interest in the model.⁶
- The parameter must be constant over time and remain invariant to certain classes of interventions (depending the purpose for which the model is to be used). Such invariances are important for the sub-model to represent *partial structure*.
- The model must be data admissible on accurate observations.
- Finally, the model should be able to encompass rival models. A model M_i encompasses other models ($M_j, j \neq i$) if it can explain the results obtained by the other model. One may distinguish between e.g. variance encompassing, parameter encompassing and forecast encompassing.

⁶Cf Section 5.5. This property holds if the parameters of interest are not a function of - and vary independently of - the parameters in the marginal distribution of the conditioning variables. For a formal definition, see Engle et al. (1983).

The third bullet item in the above list is of particular importance for a progressive research programme that aims at identifying those parts of the empirical model that are relatively invariant to structural changes elsewhere in the economy, i.e. the parameters with a high degree of *autonomy*, see Haavelmo (1944), Johansen (1977) and Aldrich (1989). Parameters with a high degree of autonomy are of primary interest to decisions makers. Such parameters represent *structure*, in that they remain invariant to changes in economic policies and shocks to the economic system. However, structure is also partial in at least two respects: First, invariance is a relative concept: An econometric model cannot be invariant to every imaginable shock (e.g. a war), but parameters may be invariant to the policy measures typical of democratic societies. Second, all parameters of an econometric model are unlikely to be equally invariant. Parameters with the highest degree of autonomy represent *partial structure*, see Hendry (1993b, 1995b). Examples are elements of the β -vector in a cointegrating equation, which are often found to represent partial structure.

3.2 Practical implementation

The complete Haavelmo distribution function - *e.g.* the joint distribution (1) of all variables in the RIMINI model - is not tractable and hence not an operational starting point for empirical econometric analysis. In practice, we have to split the system into subsystems of variables and to analyze each of them separately. Joint modelling is considered only within subsystems. But by doing this one is in danger of ignoring possible influences across the subsystems. This would translate into invalid conditioning (weak exogeneity is not fulfilled) and invalid marginalizations (by omitting relevant explanatory variables from the analysis), which is known to imply inefficient statistical estimation and inference.⁷

Examples that highlight the practical implementation of these principles are shown in the case studies of Section 4 and Section 5.

4 Case Study 1: Modelling of the household sector

The process of sequential decomposition into conditional and marginal models is done repeatedly, also within the subsystems. Let us consider the household sector model in RIMINI as one example. In that subsystem, total consumer expenditure, ch_t , is modelled as a function of real household disposable income, yh_t , and real

⁷One line of investigation that may yield new insight is associated with the notion of separation in cointegrated systems as described in Granger and Haldrup (1997). Their idea is to decompose each variable into a persistent (long-memory) component and a transitory (short-memory) component. Within the framework of a vector equilibrium correcting model like (3), the authors consider two subsystems, where the variables of one subsystem do not enter the cointegrating equations of the other subsystem (cointegration separation). Still there may be short term effects of the variables in one subsystem on the variables in the other and the cointegrating equations of one system may also affect the short term development of the variables in the other. Absence of both types of interaction is called complete separation whilst if only one of these is present it is referred to as partial separation. These concepts are of course closely related to strong and weak exogeneity of the variables in one subsystem with respect to the parameters of the other. Both partially and completely separated sub-models are testable hypotheses, which ought to be tested as part of the cointegration analysis.

household wealth, wh_t . (Here and in the rest of the paper small letters denote logs of variables). Total wealth consists of the real value of the stock of housing capital plus net financial wealth. The volume of the residential housing stock is denoted H_t and the real housing price is PH_t/P_t . Net real financial assets is the difference between real gross financial assets and real loans ($M_t - L_t$), yielding

$$wh_t = \ln WH_t = \ln [(PH_t/P_t)H_{t-1} + M_t - L_t].$$

4.1 Sequential decomposition

The joint distribution function for this subsystem can be written as (1) with $x = (ch_t, yh_t, wh_t)$. The conditional submodel for total real consumer expenditure (Brodin and Nymoer (1992) - B&N hereafter) is

$$D_{c|y,w}(ch_t | yh_t, wh_t; \lambda_c),$$

relying on the corresponding conditional density function, (2), being a valid representation of the DGP. RIMINI also contains submodels for yh_t and for all individual components in wh_t : For example, we have a conditional submodel for simultaneous determination of housing prices, ph_t and real household loans, l_t

$$D_{w|y}(ph_t, l_t | RL_t, yh_t, h_{t-1}; \lambda_w),$$

where RL_t denotes the interest rate on loans, and conditional sub-models for the net addition to housing capital stock Δh_t , and the price on new housing capital, phn_t

$$D_{\Delta h|}(\Delta h_t | ph_t, phn_t, RL_t, yh_t, h_{t-1}; \lambda_{\Delta h})$$

$$D_{phn|}(phn_t | ph_t, pj_t, h_{t-1}; \lambda_{phn})$$

where pj_t is the deflator of gross investments in dwellings.

4.2 The aggregate consumption function

The model for aggregate consumption in B&N satisfies the criteria we listed in Section 3.1. They provide a model in which cointegration analysis establishes that the linear relationship

$$ch_t = \text{constant} + 0.56yh_t + 0.27wh_t, \quad (4)$$

is a cointegrating relationship and that the cointegration rank is one. Hence, while the individual variables in (4) are assumed to be non-stationary and integrated, the linear combination of the three variables is stationary with a constant mean showing the discrepancy between the current level of consumption and the long-run equilibrium level $0.56yh_t + 0.27wh_t$. Moreover, income and wealth are *weakly exogenous* for the cointegration parameters. Hence, the equilibrium correction model for Δch_t satisfies the requirements of valid conditioning. Finally, they provide evidence of

invariance. Estimation of the marginal models for income and wealth shows evidence of structural breaks. The joint occurrence of a stable conditional model (the consumption function) and unstable marginal models for the conditional variables is evidence of within sample invariance of the coefficients of the conditional model and hence super exogenous conditional variables (income and wealth). The result of invariance is corroborated by Jansen and Teräsvirta (1996) using an alternative method based on smooth transition models.

4.3 Rival models

Financial deregulation in the mid-1980s led to a strong rise in aggregate consumption relative to income in several European countries. The pre-existing empirical macroeconomic consumption functions in Norway, which typically explained aggregate consumption by income, all broke down,— i.e. they failed in forecasting, and failed to explain the data *ex post*.

As stated in Eitrheim et al. (2000), one view of the forecast failure of consumption functions is that it provided direct evidence in favour of the rivalling rational expectations, permanent income hypothesis: In response to financial deregulation, consumers revised their expected permanent income upward to such an extent that the historical correlation between consumption and current income broke down. The breakdown has also been interpreted as a confirmation of the relevance of the Lucas-critique, in that it was a shock to a non-modelled expectation process that caused the structural break in the modelled causal relationship between income and consumption.

In Eitrheim et al. (2000) we compare the merits of the two competing models: Model A - i.e. the empirical consumption function, conditioning on income in the long run - and Model B, based on an Euler equation. We find that while Model A encompasses Model B on a sample from 1968.2 to 1984.4, both models fail to forecast the annual consumption growth in the next years. In fact, Model B forecasts in some instances better than Model A.

However, a re-specified consumption function - B&N of the previous section - that introduced wealth as a new variable was successful in accounting for the breakdown *ex post*, while retaining parameter constancy in the years of financial consolidation that followed after the initial plunge in the savings rate, see Brodin and Nymoén (1989) and Brubakk (1994) for further details. A key property of these respecified models was that they were able to adequately account for the observed high variability in the savings rate, compared to the earlier models that were subject to forecast failure.

B&N noted the implication that the re-specification explained why the Lucas-critique lacked power in this case: First, while the observed breakdown of conditional consumption functions in 1984-1985 is consistent with the Lucas-critique, that interpretation is refuted by the finding of a conditional model with constant parameters. Second, the invariance result shows that an Euler equation type model (derived from e.g., the stochastic permanent income model) cannot be an encompassing model. Even if the Euler approach can yield parameter constancy it cannot explain why a conditional model is also stable.⁸ Third, finding that invariance holds, at least as

⁸In fact, the Euler equations for Norwegian consumption that have been documented in the

an empirical approximation, yields an important basis for the use of the dynamic consumption function in forecasting and policy analysis, the main practical usages of empirical consumption functions.⁹

In Eitrheim et al. (2000) we extend the data set with 9 more years of quarterly observations, i.e. the sample is from 1968.3 to 1998.4. There are some changes to the measurement system in that the national accounts saw a major revision in that period. We have also extended the wealth measure to include non-liquid financial assets. Still we find that the main findings of B&N are confirmed. There is empirical support for one and only one cointegrating vector between ch_t , yh_t and wh_t , and valid conditioning in the consumption function is reconfirmed on the new data. In fact full information maximum likelihood estimation of a four equation system explaining (the change in) ch_t , yh_t , wh_t and $(ph_t - p_t)$ yields the same empirical results as estimation based on the conditional model.¹⁰

5 Case Study 2: Modelling of wages and prices

In Bårdsen et al. (1999) the focus is on monetary policy and the main message is: A central bank that wants to adopt inflation targeting, is crucially dependent on having (or gaining) access to a well-specified econometric model for inflation. Recent work on monetary policy has focussed on the conditional inflation forecast as the operational target for monetary policy, see Svensson (1997). Good econometric models are therefore necessary, not only as an aid in the preparation of inflation forecasts, but also as a way of elucidating the transmission mechanisms—both to policy makers and to the general public. We maintain that the model must both be coherent with all available information and contain model parameters that are invariant with respects to shocks to the economy as e.g. induced by a change in the monetary policy regime.

However, in our context the model for wages and prices in Bårdsen et al. (1999) highlights all ingredients which we regard as important for establishing an econometrically relevant submodel. To the extent we succeed in our effort, this can be taken as indirect evidence supporting the validity of the assumptions the larger model must rely on.

5.1 A theoretical model for wages and prices

The core model for wages and prices considered is a model of conflicting real wage claims for trade unions and firms in a small open economy, see Kolsrud and Nymo (1998). The real wage claims on the part of the trade unions are affected by consumer prices (p_t) and indirect taxes ($\tau 2_t$), whereas the claims of firms are assumed to be

litterature, are themselves unstable.

⁹Interestingly, the results of B&N sparked off a methodological debate about empirical modelling in *Sosialøkonomen* in 1992. Such debates have been a rare occurrence in Norway, see Jansen (1992) and Magnussen and Moum (1992).

¹⁰These empirical results thus corroborate the validity of the conditional model of B&N. The results in Eitrheim et al. (2000) were obtained with *PcFiml 9.2*—see Doornik and Hendry (1996). This generation of software was not available 10 years earlier.

determined by producer prices (pp_t), productivity (pr_t) and payroll taxes ($\tau 1_t$). Moreover, the unemployment rate (u_t) is taken to represent the tightness of the labour market and that is assumed to affect both parties. In an economy with imperfect competition firms set producer prices as a mark-up over marginal costs, that is wages corrected for productivity and payroll taxes. We are focusing on nominal wages and the consumer prices defined as a weighted sum of producer prices and import prices (pi_t), corrected for the effect of indirect taxes ($\tau 3_t$). Based on these assumptions we can derive target equations for the two parties - the nominal wage claim (w_t^*) for workers in equation (5) and the corresponding claim in terms of prices (p_t^*) for firms in equation (6):

$$w_t^* = (1 + \zeta d_{12}) p_t + \delta_{13} pr_t - \zeta d_{12} pi_t - \delta_{15} u_t - \delta_{16} \tau 1_t - \delta_{17} \tau 2_t - \eta d_{12} \tau 3_t, \quad (5)$$

$$p_t^* = (1 - \zeta) (w_t - pr_t + \tau 1_t) + \zeta pi_t + \eta \tau 3_t, \quad (6)$$

which can also be written in terms of two conflicting real wage claims, one for workers and one for firms. If they are set equal, we arrive at a condition for a static equilibrium of real wages. In terms of economic content the model is incomplete since nothing has been said about the development of targeted and actual real wages. Although firms and unions have separate views about what real wage level should be, they can only influence real wages through nominal adjustment of wages and prices. In this way conflicting views about the desired real wage level become an important source of price and wage adjustments.¹¹

This conflict view of inflation is embedded in a model that captures all the other relevant causes of inflation. In particular we allow *wage growth* Δw_t to interact with current and past price inflation, changes in unemployment, changes in tax-rates, and previous deviations from the desired wage level. Turning to nominal price adjustments - inflation Δp_t - in the short run (*i.e.* with the capital stock fixed), the marginal cost curve is upward sloping, and hence any increase in output above the trend in potential output exerts a (lagged) positive pressure on prices, measured by *gap*_{*t*}. In addition, product price inflation interacts with wage growth and productivity gains and with changes in the payroll tax-rate, as well as with corrections from an earlier period's deviation from the equilibrium price.

The theory points out the information set we need in order to establishing long run cointegrating relationships for wages and prices, and in fact it also suggests a VEqCM model for wage and price growth in accordance with these equilibrium relationships.

5.2 Modelling the core model

In order to model the long run of this wage price sub-model we carry out a cointegration analysis of a congruent 5th order VAR in the variables¹² that the theory

¹¹The role of inflation as a arbiter of conflicting claims was brought out in Haavelmo's conflict model of inflation, see Qvigstad (1975). Kolsrud and Nymoene (1998) also note that the econometric implications are similar to Sargan (1964, 1980).

¹²Compared to the theoretical model the income tax rate $\tau 2$ is omitted from the empirical model, since it is insignificant in the model.

of Section 5.1 suggests we should include.¹³ The analysis yields support for two cointegrating equations which are interpretable in the light of this theory. These long run equations are then simplified by imposing a sequence of data admissible restrictions (Bårdsen et al., 1999, Table 2) Our next step is to impose these steady state equations on the dynamic equations for growth in wages and prices, which are modelled general¹⁴ to specific. The end result is the following wage price model:

$$\begin{aligned}
\Delta w_t &= \Delta p_t - 0.4 \times 0.36 \Delta p i_t - \Delta \tau 1_{t-2} - \underset{(0.08)}{0.36} \Delta \tau 3_{t-2} - \underset{(0.11)}{0.3} \Delta h_t \\
&\quad - \underset{(0.01)}{0.08} [w_{t-2} - p_{t-2} - pr_{t-1} + 0.1 u_{t-2}] + \text{dummies} \\
\hat{\sigma}_{\Delta w} &= 1.01\% \\
\Delta p_t &= \underset{(0.05)}{0.13} (\Delta w_t + \Delta \tau 1_{t-2}) + \underset{(0.02)}{0.06} gap_{t-1} + 0.4 \times \underset{(0.03)}{0.07} \Delta p i_t - \underset{(0.03)}{0.07} \Delta \tau 3_{t-2} \quad (7) \\
&\quad - \underset{(0.01)}{0.08} [p_{t-3} - 0.6(w_{t-1} - pr_{t-1} + \tau 1_{t-1}) - 0.4 p i_{t-1} + \tau 3_{t-3}] + \text{dummies} \\
\hat{\sigma}_{\Delta p} &= 0.41\%
\end{aligned}$$

The two equations in (7) show that the equilibrium correcting terms are significant with equal coefficients. As Engle and Granger (1991a) explain, these terms act as *attractors* on wages and prices. The long run wage attractor is given by prices adjusted for productivity and an effect from unemployment, whereas the price attractor is made up of the indirect tax rate and a weighted sum of import prices and wages corrected for productivity and payroll taxes. Recursive estimates of the long run coefficients of unemployment in the wage equation, and import prices in the price equation are shown in Figure 3, together with tests of constant parameters of the cointegrating vectors over the sample. In the wage equation we have short run homogeneity in consumer prices and in the price equation we find significant effects of wage growth and excess demand.

In addition to the variables in the wage-claims part of the system, we include gap_{t-1} —the lagged output gap measured as deviations from trend output obtained by the Hodrick-Prescott filter. The other non-modelled variables contain first the length of the working day Δh_t , which captures wage compensation for reductions in the length of the working day—see Nymoen (1989). Second, incomes policies and direct price controls have been in operation on several occasions in the sample period and they are represented by the intervention variables $Wdum$ and $Pdum$, and one impulse dummy $i80q2$. Finally, $i70q1$ is a VAT dummy.

¹³The resulting unrestricted conditional sub-system, where all main variables enter with three lags, is estimated over 1966(4)–1996(4). All the empirical results are obtained with *PcFiml 9.2*—see Doornik and Hendry (1996)

¹⁴The general model is formulated as a vector autoregressive distributed lag model of order 3.

Table 1: Model specification tests.

Diagnostic tests for the model in (7)	
The sample is 1966(4) to 1996(4), 121 observations.	
$\hat{\sigma}_{\Delta w}$	= 1.01%
$\hat{\sigma}_{\Delta p}$	= 0.41%
<i>Correlation of residuals</i>	= -0.5
<i>Overidentification</i> $\chi^2(9)$	= 9.92[0.60]
<i>AR 1 – 5</i> $F(20, 200)$	= 1.20[0.26]
<i>Normality</i> $\chi^2(4)$	= 4.14[0.39]
<i>Heteroscedasticity</i> $F(66, 257)$	= 0.81[0.84]

The quality of the model is corroborated by displaying constant parameters, as shown in Figure 4, and non-systematic residuals, documented by the diagnostics of Table 1.¹⁵ What is especially impressive is the encompassing of the system at every sample size—as shown in the lower left panel of Figure 4.

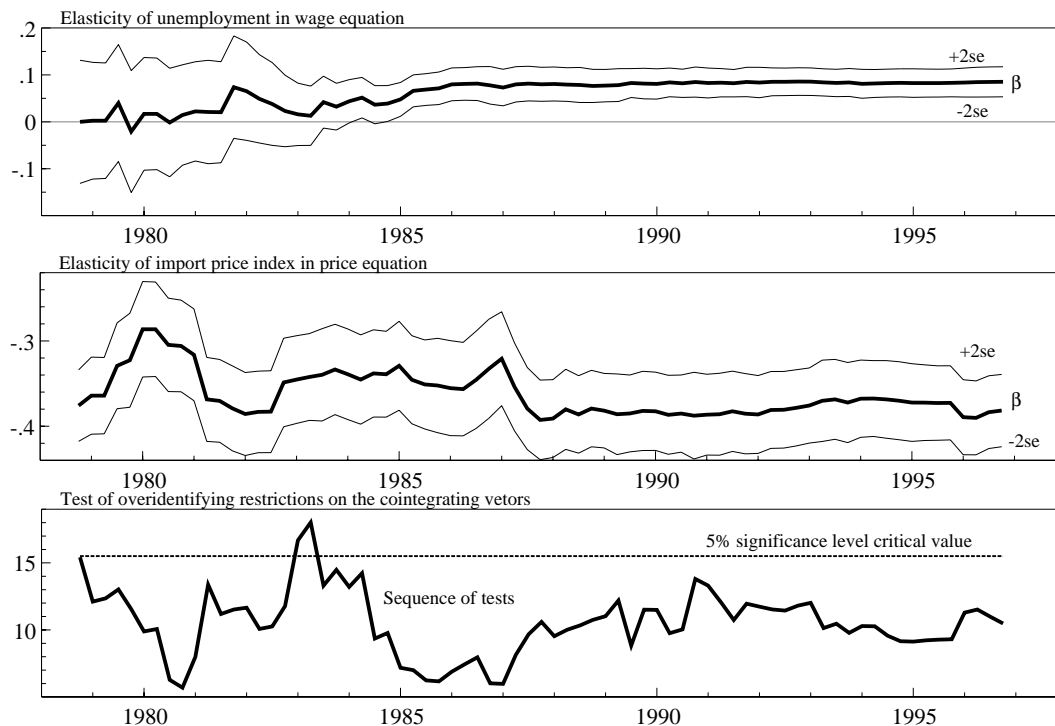


Figure 3: Recursively estimated steady-state parameters (plus/minus 2 standard errors) and recursive tests of the overidentifying restrictions on the cointegrating vectors, see Sargan (1964).

¹⁵References for tests in Table 1: Overidentification test (Sargan (1964)), AR-test (Godfrey (1978) and Doornik (1996)), Normality test (Doornik and Hansen (1994)), and Heteroscedasticity test (White (1980) and Doornik (1996))

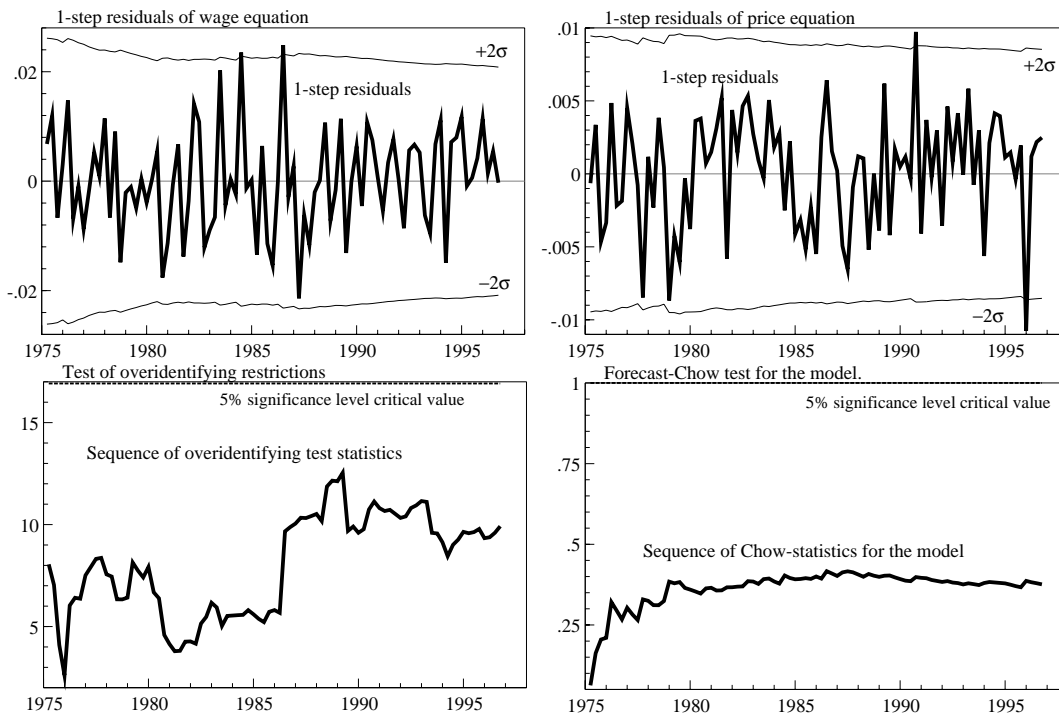


Figure 4: Recursive stability tests for the model. The two upper panels show one step residuals from the wage and the price equations. The lower right panel is recursive Nup Chow-tests for parameter stability (see Chow (1960)), whereas the lower left panel shows recursive tests of the overidentifying restrictions on the estimated model in (7), see Sargan (1964).

5.3 An econometric model of inflation

Equipped with this core model of the determination of wages and prices, we can go on to outline the model we alluded to as “RIMINI writ small” in the introduction to Section 5. The essential steps in constructing a more complete econometric model of inflation are illustrated in Figure 5. The core model of the inflation process corresponds to *wage-price model* in the figure. There are three types of explanatory variables: *feedback* variables, *non-modelled* variables (tax-rates, world prices), and *policy instruments*.

In the wage-price model we treat feedback variables, e.g. unemployment, output gap, productivity, import prices, etc., as weakly exogenous variables. This is a testable property that we address after modelling the feedback relationships [in Section 5.4.] The figure indicates that the feedback variables are not only functions of lagged wages and prices. Empirically they may depend on both the non-modelled explanatory variables and on the policy variables.

Central banks do set interest rates, but presumably *not* in the same way under the different monetary policy regimes found in our sample. Thus finding an empirically constant reaction function from inflation forecasts to interest rates is a non-starter. It is therefore no surprise that we find that the short-run interest rate

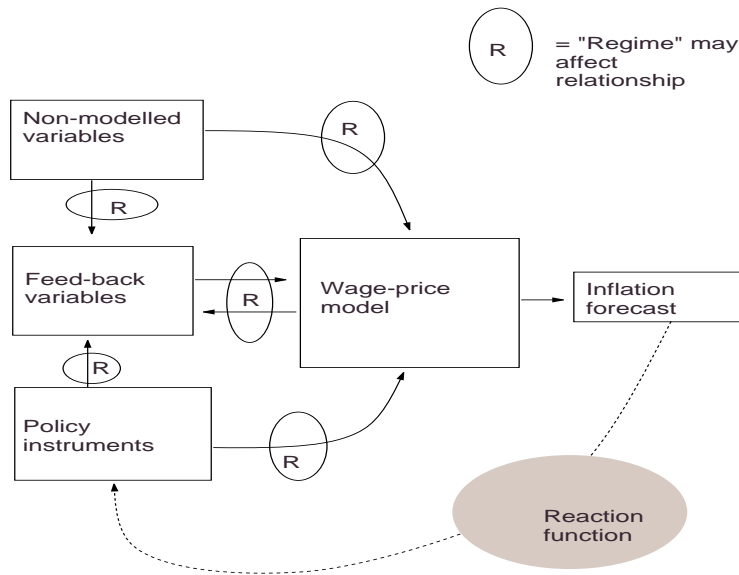


Figure 5: Model based inflation forecasts.

can be treated as strongly exogenous¹⁶. Instead, the important monetary feedback variable is the exchange rate, which depend both on inflation and foreign variables.

Regime shifts may induce non-constancies in the parameters of the *wage-price model*. If that were the case, the usefulness of the model for policy analysis is reduced, as it then falls prey to the Lucas-critique. However, invariance can be tested within the sample. We test if the parameters of the inflation model have remained constant despite the parameter changes in the marginal models in Section 5.4.

We also note that Norway is but a candidate economy to adopt an inflation target. However, unless inflation targeting is in every respect a truly new regime, there may be periods in the sample where monetary instruments were used in a way that resembles what one might expect if a formal inflation target regime was in place. In particular, one can argue that this has been the case after December 1992, when the Norwegian Krone (NOK) went floating. Moreover, the exchange rate that we use in this study is a trade-weighted exchange rate variable, which shows variation even in periods where the official target exchange rate is relatively constant. Thus, even a successful exchange rate targeting regime may entail considerable variation in the trade-weighted exchange rate. Hence, while not claiming to prove invariance of the *wage-price model* with respect to a shift to formal inflation targeting, we believe that invariance (or lack thereof) to changes in the way the managed float regime have been implemented over the sample is a relevant property of the model.

5.4 Marginal models for the feedback variables

As we have seen, the core model for wages and prices is developed conditional upon the rate of unemployment u_t , average labour productivity pr_t , import prices pi_t ,

¹⁶Strong exogeneity is defined as joint occurrence of weak exogeneity and the absence of feedback from the wage and price variables to the conditioning variables.

and GDP mainland output y_t . For forecasting purposes we enlarge the model with relationships for u_t , pr_t , y_t and nominal exchange rate v_t , which multiplied by foreign prices yields pi_t . All of these variables are potentially affected by interest rates and are therefore potential channels for monetary instruments to influence inflation. Also, none of these variables is likely to be strongly exogenous. For example, import prices depend by definition on the nominal exchange rate. Below we report a model that links the exchange rate to the lagged real exchange rate, which in turn depend on the domestic price level. Bårdsen et al. (1999) gives details of the additional relationships, but their qualitative properties can be summarized as

$$\begin{aligned}\Delta v_t &= f\left(\underset{-}{ppp}_{t-1}, \underset{-}{oilprice}_t, \underset{-}{\Delta RS}_t\right) \\ \Delta y_t &= f\left(\underset{-}{EqCM}y_t, \underset{-}{\Delta y}_{t-i}, \underset{+}{\Delta cr}_{t-1}\right) \\ \Delta u_t &= f\left(\underset{-}{\Delta y}_t, \underset{+}{\Delta u}_{t-1}, \underset{-}{u}_{t-1}, \underset{+}{stu}_{t-1}, \underset{-}{\Delta(w-p)}_{t-i}, \underset{-}{amun}_t\right) \\ \Delta pr_t &= f\left(\underset{-}{\Delta_3 pr}_{t-1}, \underset{-}{\Delta u}_{t-1}\right)\end{aligned}$$

where ppp is purchasing power parity (see Akram (2000a,b)), RS is the money market interest rate, $EqCM$ is an equilibrium correction term for an aggregate demand relationship, and cr is a variable which is assumed to be a function of credit demand—see Bårdsen and Klovland (2000). Furthermore, stu denotes non-linear effects in unemployment adjustment, while $amun$ is an indicator picking up the effect of labour market programmes.

5.5 Testing the exogeneity assumptions

Weak and super exogeneity refer to different aspects of “exogeneity”, namely the question of “valid conditioning” in the context of estimation and policy analysis respectively—see Engle et al. (1983). In the light of the results reported above, it is important to assess the possible endogeneity of output, productivity, unemployment, and exchange rates. First, the cointegrating vectors have been estimated conditional on output, productivity, unemployment, and exchange rates, and efficient estimation requires that these variables are weakly exogenous for the cointegration vectors (see e.g. Johansen (1992)). Second, policy analysis involves as a necessary condition that the wage and price equations are *invariant* to the interventions occurring in the marginal models of output, productivity, unemployment, and exchange rates; together with weak exogeneity (if that holds) invariance implies super exogeneity.

As a means to perform tests of weak and super exogeneity, we supplement the two equation models for wages and prices for Norway, with the marginal models for output, productivity, unemployment, and exchange rates of Section 5.4.

These marginal models (described in the previous section) can be written as

$$\begin{aligned}
\begin{pmatrix} \Delta y_t \\ \Delta pr \\ \Delta u_t \\ \Delta v_t \end{pmatrix} &= \mathbf{A}(L) \begin{pmatrix} \Delta w_{t-1} \\ \Delta p_{t-1} \\ \Delta y_{t-1} \\ \Delta pr_{t-1} \\ \Delta u_{t-1} \\ \Delta v_{t-1} \end{pmatrix} + \mathbf{B} \cdot \mathbf{X}_t + \mathbf{C} \cdot \mathbf{DUM}_t \\
&+ \mathbf{D} \begin{pmatrix} EqCMw(t) \\ EqCMp(t) \end{pmatrix} + \begin{pmatrix} \varepsilon_{y,t} \\ \varepsilon_{pr,t} \\ \varepsilon_{u,t} \\ \varepsilon_{v,t} \end{pmatrix}. \tag{8}
\end{aligned}$$

where $\mathbf{A}(L)$ denotes an autoregressive lag-polynomial matrix (all roots outside the unit circle). \mathbf{B} denotes the matrix of coefficients of the maintained exogenous variables, i.e. the conditional variables \mathbf{X}_t in the four marginal models described above. Auxiliary variables affecting the mean of the variables under investigation — *i.e.* significant dummies and non-linear terms — are collected in the \mathbf{DUM}_t matrix, with coefficients \mathbf{C} . By definition, the elements in \mathbf{DUM}_t are included because they pick up linear as well as non-linear features of y_t , pr_t , u_t or v_t that are left unexplained by the information set underlying the price wage systems above. In the following, we will refer to the auxiliary variables as *structural break dummies*, notwithstanding the fact that they depend fundamentally on the initial choice of information set used above to model wages and prices.

While the first line of (8) can be seen as a necessary step to ensure that the usual assumptions about constant parameters and white-noise residuals are approximately fulfilled for the marginal model, the second line of the equation enables us to test weak exogeneity. Following Johansen (1992) weak exogeneity of y_t , pr_t , u_t and v_t with respect to the cointegration parameters requires that $\mathbf{D} = \mathbf{0}$, i.e. the coefficients of the equilibrium-correction terms for wages and prices ($EqCMw(t)$ and $EqCMp(t)$) equal zero. Note that, in testing weak exogeneity, we are addressing the validity of an assumption underlying the analysis contained in the sections above. Finally, to test super exogeneity we follow Engle and Hendry (1993) and test the significance of the structural break dummies \mathbf{DUM}_t in the core model for wages and prices in (7).

In Bårdsen et al. (1999) we find that the eight restrictions in $\mathbf{D} = \mathbf{0}$ are each acceptable, individually and jointly, hence the weak exogeneity assumptions of output, productivity, unemployment, and exchange rates for the long-run parameters appear to be tenable. Moreover, the significance of the \mathbf{DUM}_t variables are overall high in the marginal models but they are not significant in the wage and price equations. Thus, we find support for super exogeneity of these variables with respect to long run parameters of the wage price model in (7).

Moreover, the finding of weak exogeneity of the conditioning variables is further corroborated by the fact that full information maximum likelihood estimates of the full system of eleven equations ¹⁷ explaining (the change in) all model variables yields

¹⁷These include the core model, equations for all feedback variables of Section 5.4 and five auxiliary equations needed to close the model for forecasting.

virtually the same empirical results for the wage and price equations as reported in (7) for the conditional model.

5.6 Rival models

Bårdsen et al. (1999) is concerned with the effects of monetary policy on inflation targeting. Simulations indicate that inflation can be affected by changing the short-run interest rate. A one percentage point permanent increase in the interest rate leads to 0.4 percentage point reduction in the annual rate of inflation. Bearing in mind that the main channel is through output growth and the level of unemployment, this supports the view that interest rates can be used to counteract shocks to GDP output.

It is also shown that the model can be used to forecast inflation. Moreover, in a companion paper - Bårdsen et al. (2000) - we compare the forecasting properties of the core model in (7) with an expectations augmented Phillips curve model. It is shown that the theoretical framework of Section 5.1 above also contains the Phillips curve models of inflation as a particular case. Such a model is obtained if the two equilibrium correcting of the VEqC model are insignificant in (7). The fact that we have found both terms to have a significant effect in (7) implies refutation of the Phillips curve formulations that dominates so much of the literature.

We estimate a Phillips curve model starting out from the same information set as in Section 5.2. Moreover, we adopt the same general autoregressive-distributed lag model, but with an additional lag in the dynamics, to make sure we end up with a data-congruent specification. The preferred model reported in Bårdsen et al. (2000) appears to be well specified according to the specification tests, but it is encompassed by the core model in (7).

Moreover, the core model in (7) both forecasts annual inflation better and has significantly smaller forecast error uncertainty than the Phillips curve model. This effect is clearly seen in Figure 6, where the annual inflation forecasts from the two models are put together in the same graph. The dotted lines denote the point forecasts and the 95% prediction error bands of the core model in (7), while the solid lines depict the corresponding results from the forecasts of the Phillips curve specification. At each point of the forecast the uncertainty of the Phillips curve is larger compared with the core model in (7). Indeed, while the latter has a standard error of 0.9 percentage points 4-periods ahead, and 1.2 percentage points 8-periods ahead, the Phillips curve standard errors are 1.6 and 2 percentage points, respectively.

The modelling exercise in Bårdsen et al. (2000) shows that there is a role for econometric model specification and evaluation in order to reducing the amount of model uncertainty. The empirical example shows that different specifications *can* be tested. If one nevertheless insists on using the inferior econometric model, the findings in that paper imply that the excess (and artificial) uncertainty is significant.

6 Conclusion

The purpose of this paper has been to identify and describe the main channels of influence from mathematical statistics on to economics, and how this influence has

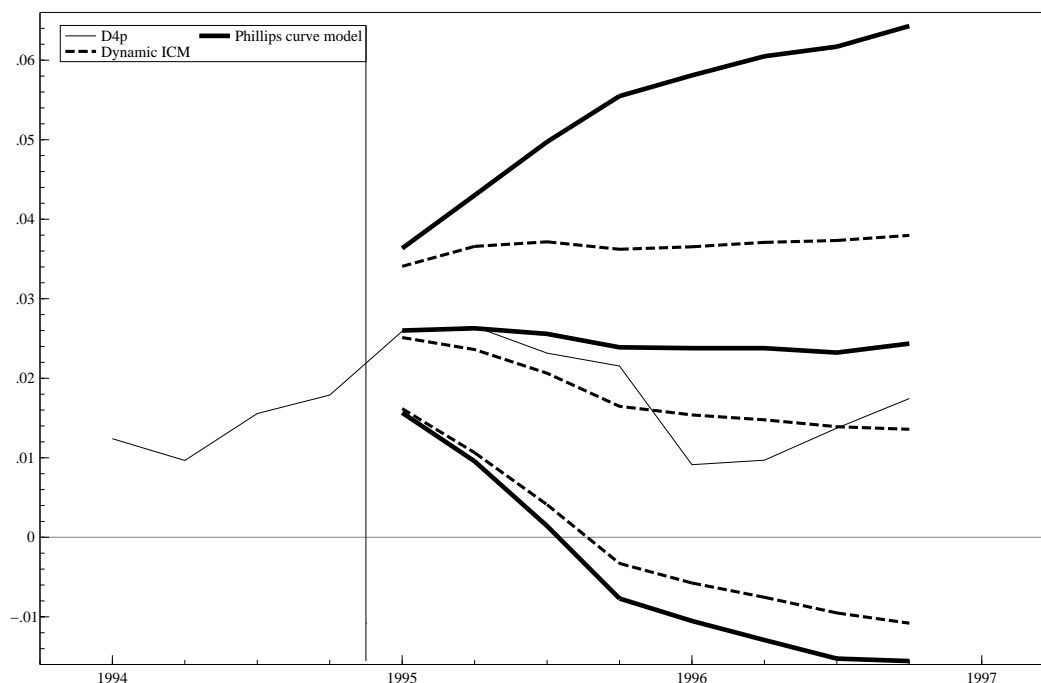


Figure 6: Comparing the forecasts of the two models.

filtered through to current day macroeconometric modelling. The paper links this development up to a modelling project at Norges Bank. The case studies from that project show that a macroeconometric model of this kind would not have been conceivable without the heritage from mathematical statistics.

Looking to the future, it is likely that the development of IT, hardware and software, will enhance our ability to deal with increasingly complex statistical models. Our own experience in building RIMINI supports this view. It is conceivable that this will make it possible to start modelling more general joint distributions than today, and to test the sequential conditioning and marginalisation necessary to obtain relevant conditional models of interest.

References

- Akram, Q. F. (2000a). PPP despite real shocks: An empirical analysis of the Norwegian real exchange rate. *Arbeidsnotat*, 2000/7, Research Department, Norges Bank [Central Bank of Norway].
- Akram, Q. F. (2000b). When does the oil price affect the Norwegian exchange rate? *Arbeidsnotat*, 2000/8, Research Department, Norges Bank [Central Bank of Norway].
- Aldrich, J. (1989). Autonomy. *Oxford Economic Papers*, 41, 15–34.
- Anderson, T. W. (1951). Estimating linear restrictions on regression coefficients for

- multivariate normal distributions. *Annals of Mathematical Statistics*, 22, 327–351.
- Bårdsen, G., E. S. Jansen and R. Nymoen (1999). Econometric Inflation Targeting. Arbeidsnotat 1999/5, Research Department, Norges Bank [Central Bank of Norway].
- Bårdsen, G., E. S. Jansen and R. Nymoen (2000). Model specification and inflation forecast uncertainty. Arbeidsnotat 2000/6. Research Department, Norges Bank [Central Bank of Norway].
- Bårdsen, G. and J. T. Klovland (2000). Shaken, or Stirred? Effects of Financial Deregulation on Money, Credit, and Output in Norway. *Scandinavian Journal of Economics*, forthcoming.
- Biørn, E., M. Jensen and M. Reymert (1987). KVARTS - a quarterly model for the Norwegian economy. *Economic Modelling*, 4, 77–109.
- Bjerkholt, O. (1998). Interaction between model builders and policy makers in the Norwegian tradition. *Economic Modelling*, 15, 317–339.
- Bodkin, R. G., L. R. Klein and K. Marwah (1991). *A History of Macroeconometric Model-Building*. Edward Elgar, Aldershot.
- Box, G. E. P. and G. M. Jenkins (1970). *Time Series Analysis, Forecasting and Control*. Holden Day, San Francisco.
- Brodin, P. A. and R. Nymoen (1989). The Consumption Function in Norway. Breakdown and Reconstruction. Arbeidsnotat 1989/7, Norges Bank [The Central Bank of Norway].
- Brodin, P. A. and R. Nymoen (1992). Wealth Effects and Exogeneity: The Norwegian Consumption Function 1966.1-1989.4. *Oxford Bulletin of Economics and Statistics*, 54, 431–454.
- Brubakk, L. (1994). Estimering av en makrokonsumfunksjon for ikke-varige goder 1968-1991. Rapport 94/9, Statistics Norway.
- Chow, G. C. (1960). Tests of equality between sets of coefficients in two linear regressions. *Econometrica*, 28, 591–605.
- Clements, M. P. and D. F. Hendry (1998). *Forecasting Economic Time Series*. Cambridge University Press, Cambridge.
- Clements, M. P. and D. F. Hendry (1999). *Forecasting Non-stationary Economic Time Series*. The MIT Press, Cambridge, MA.
- Doornik, J. (1996). Testing Vector Autocorrelation and Heteroscedasticity in Dynamic Models. Working paper, Nuffield College.
- Doornik, J. A. and H. Hansen (1994). A Practical Test of Multivariate Normality. Unpublished paper, Nuffield College.

- Doornik, J. A. and D. F. Hendry (1996). *Modelling Dynamic Systems Using PcFiml 9.0 for Windows*. International Thomson Publishing, London.
- Eitrheim, Ø. (2000). The analytical framework for monetary analysis and use of econometric models. Arbeidsnotat forthcoming, Norges Bank [Central Bank of Norway].
- Eitrheim, Ø., E. S. Jansen and R. Nymoen (2000). Progress from forecast failure - The Norwegian consumption function. Arbeidsnotat 2000/10. Research Department, Norges Bank [Central Bank of Norway].
- Engle, R. F. and C. W. J. Granger (1987). Co-integration and Error Correction: Representation, Estimation and Testing. *Econometrica*, 55, 251–276.
- Engle, R. F. and C. W. J. Granger (1991a). Introduction. In Engle, R. F. and C. W. J. Granger (eds.), *Long-Run Economic Relationships. Readings in Cointegration*, 1–23. Oxford University Press, Oxford.
- Engle, R. F. and C. W. J. Granger (1991b). *Long-Run Economic Relationships. Readings in Cointegration*. Oxford University Press, Oxford.
- Engle, R. F. and D. F. Hendry (1993). Testing Super Exogeneity and Invariance in Regression Models. *Journal of Econometrics*, 56, 119–139.
- Engle, R. F., D. F. Hendry and J.-F. Richard (1983). Exogeneity. *Econometrica*, 51, 277–304.
- Godfrey, L. G. (1978). Testing for higher order serial correlation when the regressors include lagged dependent variables. *Econometrica*, 46, 1303–1313.
- Granger, C. W. J. (1981). Some Properties of Time Series Data and use in Econometric Model Specification. *Journal of Econometrics*, 16, 121–130.
- Granger, C. W. J. (1990). General Introduction: Where are the Controversies in Econometric Methodology? In Granger, C. W. J. (ed.), *Modelling Economic Series. Readings in Econometric Methodology*, 1–23. Oxford University Press, Oxford.
- Granger, C. W. J. (1999). *Empirical Modeling in Economics. Specification and Evaluation*. Cambridge University Press, Cambridge.
- Granger, C. W. J. and N. Haldrup (1997). Separation in cointegrated systems and persistent-transitory decompositions. *Oxford Bulletin of Economics and Statistics*, 59, 449–463.
- Haavelmo, T. (1944). The Probability Approach in Econometrics. *Econometrica*, 12, 1–118. Supplement.
- Hendry, D. F. (1993a). *Econometrics. Alchemy or Science?*. Blackwell, Oxford.
- Hendry, D. F. (1993b). The Roles of Economic Theory and Econometrics in Time Series Econometrics. Paper presented at the European Meeting of the Econometric Society in Uppsala, 1993.

- Hendry, D. F. (1995a). *Dynamic Econometrics*. Oxford University Press, Oxford.
- Hendry, D. F. (1995b). Econometrics and Business Cycle Empirics. *The Economic Journal*, *105*, 1622–1636.
- Hendry, D. F. and M. Morgan (1995). *The Foundations of Econometric Analysis*. Cambridge University Press, Cambridge.
- Hendry, D. F. and J. F. Richard (1982). On the formulation of Empirical Models in Dynamic Econometrics. *Journal of Econometrics*, *20*, 3–33.
- Hendry, D. F. and J. F. Richard (1983). The Econometric Analysis of Economic Time Series. *International Statistical Review*, *51*, 111–163.
- Hendry, D. F., A. Spanos and N. R. Ericsson (1989). The Contributions to Econometrics in Trygve Haavelmo's The Probability Approach in Econometrics. *Sosialøkonomen*, *43(11)*, 12–17.
- Hunt, B., D. Rose and A. Scott (2000). The core model of the Reserve Bank of New Zealand's Forecasting and Policy System. *Economic Modelling*, *17*, 247–274.
- Jansen, E. S. (1992). Makrokonsumfunksjonen - tas empirien p alvor? (The macro consumption function - is empirical work taken seriously?). *Sosialøkonomen*, *46(5)*, 2–6.
- Jansen, E. S. and T. Teräsvirta (1996). Testing Parameter Constancy and Super Exogeneity in Econometric Equations. *Oxford Bulletin of Economics and Statistics*, *58*, 735–763.
- Johansen, L. (1977). *Lectures on Macroeconomic Planning. 1. general aspects*. North-Holland, Amsterdam.
- Johansen, S. (1988). Statistical Analysis of Cointegration Vectors. *Journal of Economic Dynamics and Control*, *12*, 231–254.
- Johansen, S. (1991). Estimation and Testing of Cointegrating Vectors in Gaussian Vector Autoregressive Models. *Econometrica*, *59*, 1551–1580.
- Johansen, S. (1992). Cointegration in Partial Systems and the Efficiency of Single-Equation Analysis. *Journal of Econometrics*, *52*, 389–402.
- Johansen, S. (1995). *Likelihood-Based Inference in Cointegrated Vector Autoregressive Models*. Oxford University Press, Oxford.
- Klein, L. R. (1950). *Economic Fluctuations in the United States 1921-1941*. Cowles Commission Monograph 11. Wiley, New York.
- Klein, L. R. (1953). *A Textbook of Econometrics*. Row, Peterson & Co, Evanston, Illinois.
- Klein, L. R. (1988). The statistical approach to economics. *Journal of Econometrics*, *37*, 7–26.

- Kolsrud, D. and R. Nymoen (1998). Unemployment and the Open Economy Wage-Price Spiral. *Journal of Economic Studies*, 25, 450–467.
- Kydland, F. E. and E. C. Prescott (1991). The econometrics of the general equilibrium approach to business cycles. *Scandinavian Journal of Economics*, 93, 161–178.
- Magnussen, K. and K. Moum (1992). Tar Eilev Jansen likevel feil? (Is Eilev Jansen wrong all the same?). *Sosialøkonomen*, 46(6), 12–18.
- Mizon, G. M. (1995). Progressive Modelling of Macroeconomic Time Series: The LSE Methodology. In Hoover, K. D. (ed.), *Macroeconometrics: Developments, Tensions and Prospects*, chap. 4. Kluwer Academic Publishers.
- Morgan, M. S. (1990). *The History of Econometric Ideas*. Cambridge University Press, Cambridge.
- Nymoen, R. (1989). Wages and the Length of the Working Day. An empirical test based on Norwegian Quarterly Manufacturing Data. *Scandinavian Journal of Economics*, 91, 599–612.
- Poloz, S., D. Rose and R. Tetlow (1994). The Bank of Canada’s New Quarterly Projection Model (QPM): An Introduction—Le Nouveau Modèle Trimestrier de Prévision (MTP) de la Banque Du Canada: Un Aperçu. *Bank of Canada Review—Revue de la Banque du Canada*, 1994 (Autumn), 23–28.
- Qvigstad, J. F. (1975). Noen emner fra inflasjonsteorien (Topics from the theory of inflation). Memorandum 13.2.1975, Institute of Economics University of Oslo. Notes from Professor Haavelmo’s lectures spring 1974.
- Royal Swedish Academy of Science (1990). The Nobel Memorial Prize in Economics. Press release from the Royal Swedish Academy of Sciences. *Scandinavian Journal of Economics*, 92, 11–15.
- Sargan, J. D. (1964). Wages and Prices in the United Kingdom: A Study of Econometric Methodology. Butterworth Co., London.
- Sargan, J. D. (1980). A Model of Wage-Price Inflation. *Review of Economic Studies*, 47, 113–135.
- Sims, A., Christopher (1980). Macroeconomics and Reality. *Econometrica*, 48, 1–48.
- Spanos, A. (1989). On Rereading Haavelmo: A Retrospective View of Econometric Modeling. *Econometric Theory*, 5, 405–429.
- Svensson, L. (1997). Inflation Forecast Targeting: Implementing and Monitoring Inflation Targets. *European Economic Review*, 41, 1111–1146.
- Tinbergen, J. (1936). *Grondproblemen der Theoretische Statistik*. F. Bohn, Haarlem.
- Wallis, K. F. (1994). Introduction. In Wallis, K. F. (ed.), *Macroeconometric Modelling*, vol. 2. Edward Elgar, Aldershot.

- Watson, M. W. (1994). Vector autoregressions and cointegration. In Engle, R. F. and D. L. McFadden (eds.), *Handbook of Econometrics*, vol. 4, chap. 47. Elsevier, Amsterdam.
- White, H. (1980). A Heteroskedasticity-Consistent Covariance Matrix Estimator and a Direct Test of Heteroskedasticity. *Econometrica*, 48, 817–838.
- Willman, A., M. Kortelainen, H.-L. Männistö and M. Tujula (2000). The BOF5 macroeconomic model of Finland, structure and dynamic microfoundations. *Economic Modelling*, 17, 275–303.

KEYWORDS:

Macroeconometric modelling

Role of statistics

Norges Bank model RIMINI

Haavelmo distribution

Sequential conditioning and marginalisation

Dynamic modelling

Aggregate consumption

Wages and prices

Testing of rival models