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A Time Series Approach to a Structural Model of the Swiss Economy

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Abstract

We use a vintage capital production function to model investment in Switzerland. A special feature is the use of survey data to map observable data on latent variables. In addition, a labour market is modelled. This results in a fairly complicated model structure and so far estimation required ad hoc assumptions and calibration. In contrast to that this paper links the theoretical framework given by the structural model to a multivariate time series representation of the relationships, for which standard estimation procedures (Pesaran et al., 2000) and specification tests are available. The outcomes are improved forecasts and a zero-productivity-growth puzzle.

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1 Introduction

Economic theory very often implies highly non-linear relationships between the variables of interest. Generally speaking estimation therefore becomes complicated and as Laidler (1999) has noted, discussion often centres on where it is 'most fruitful to simplify the theoretical framework in order to bring it into contact with empirical evidence'. At a first glance, the Swiss Institute for Business Cycle Analysis' (KOF) macro model provides yet another example of this kind. In this paper, however it will be shown that the supply side part of the model can be cast in a standard vector error-correction model (*VECM*) form with the long-run relationships being the backbones of the economic structure. Additional testable hypotheses can be formulated for the short-run parameters. For the corresponding tests standard inference can be used. Thus, at a second glance the econometric exercise becomes feasible without relinquishing much of the economics behind it.

1.1 Methodological Considerations

In a series of papers Garrat, Lee, Pesaran and Shin (2000), Pesaran, Shin and Smith (2000), Pesaran and Shin (2002), Garratt, Lee, Pesaran and Shin (2002) have pursued an approach closely related to the current one with a slightly different focus, though. Pesaran et al. (2000) lay out the theory of testing for cointegration in the presence of exogenous $I(1)$ variables which are going to be also applied in this paper. Pesaran and Shin (2002) develop a theory for consistent estimation and hypothesis testing of non-linear restrictions on cointegration matrices by quasi maximum likelihood estimators. Garratt et al. (2002) present an application to the above mentioned methods, and finally Garrat et al. (2000) describe a whole research agenda for merging economic structural models and contemporaneous econometric tools. Using the terminology of the latter one, this work follows the 'structural cointegrating VAR' approach. The supply side part of the KOF macro model has traditionally been regarded central and is therefore the first to be dealt with in a series of investigations.[1]

Being related to 'structural cointegrating VAR' analysis, the paper is distinct from the definition of that approach in that it does not begin 'with an explicit statement of the long-run relationships between the variables of the model obtained from macroeconomic theory' which are then 'embedded within an otherwise unrestricted log-linear VAR model' (cf. Garrat et al. (2000), section 3). Instead, the theoretical model will be shown to yield a multiple time series representation with the underlying theory being a special case of a general $VECM$. The difference between the general and the special case is given by restrictions on the coefficients of both the short-run and long-run dynamics. However, cointegration theory points out that the long-run properties of the model is given by the cointegration relationships. Therefore, a natural hierarchy of the statistical analysis is given and in line with the 'structural cointegrating VAR' approach the focus is on the long-run coefficients in the first place.

Scrutinising the structural model by means of multivariate time series analysis thus serves two aims. First, revising the running structural model which is used for policy analysis and forecasting exercises, and second finding out where it would be most fruitful to consider theoretical as well as empirical alternatives to the current procedures. Given the most important application which is doing forecasts for the Swiss economy, the forecasting performance guides the choice of the final model.

The remainder of the paper is organized as follows. At first, the economic model is sketched, then time series properties of some of the variables are determined. Based on the economic theory equations are found which represent the observable variables in terms of their own and each other's past values. This produces a five dimensional multiple time series model which can be easily estimated. Finally, the five dimensional model will be reduced to a core relationship that passes the statistical tests and the thereby obtained model alternatives are compared to each other and to the outcome of the running large scale structural model.

[1] The terms 'core' and 'satellite' models are avoided here, because they lack a proper definition.

2 The Economic Theory

We start with a sketch of the economic theory underlying the current version of the KOF macro model. In order to save space we only provide the central relationships and refer the interested reader to the KOF institute's working paper series for details.[2]

2.1 A Vintage Capital Production Function Augmented by Survey Data

2.1.1 Goods Demand and Supply

This section is a based on Stalder (1994). More recent adjustments are accounted for in the following section. Throughout the paper we use Latin letters to denote variables and the coefficients on more or less reasonable ad-hoc explanatory variables of the model. Greek letters indicate either structural parameters or coefficients of the empirical model.

The economy is characterized by monopolistic competition and its production function is assumed to be of a Cobb-Douglas type where capacity output ∇YC_t is related to capacity labour input ∇L_t and gross investment I_t in the following manner

$$\nabla YC_t = D\left(\nabla L_t e^{\theta t}\right)^{\rho} I_t^{1-\rho} \qquad t = 1, 2, \ldots \tag{1}$$

Here, ρ represents the labour share in the vintage production function and θ measures the rate of labour augmenting technical progress.

For the current purpose it is sufficient to collect the following variables definitions.[3] The price for labour is the nominal wage level W_t while the price of new capital goods is denoted V_t. The nominal interest rate and the rate by which labour productivity on existing machines deteriorates are signified by r and ϕ respectively. It is also convenient to define $Q_t = W_t/V_t$, and the average growth rate of the factor

[2] Another source is Sneesens (1990), for example.

[3] See table 7 for all variable definitions and symbols used.

price ratio $q_t = w_t - v_t$ by $\dot{q}$ where we make use of the convention that lower case letters denote the natural logarithm. It can then be shown that the optimal factor choice depends on G_t defined as

$$G_t(\triangle w_t + \phi - r, T) = \frac{1 - e^{-(r - \triangle w_t - \phi)T}}{r - \triangle w_t - \phi},$$

and allows to write the cost-minimizing technical productivities of labour A_t and capital B_t

$$\begin{aligned} A_t &\equiv \frac{\nabla YC_t}{\nabla L_t}, \\ &= D\left(\frac{1-\rho}{\rho}\right)^{1-\rho}\left(\frac{W_t G_t}{V_t}\right)^{1-\rho} e^{\theta\rho t}, \end{aligned} \tag{2}$$

$$\begin{aligned} B_t &\equiv \frac{\nabla YC_t}{\nabla I_t}, \\ &= D\left(\frac{1-\rho}{\rho}\right)^{-\rho}\left(\frac{W_t G_t}{V_t}\right)^{-\rho} e^{\theta\rho t}. \end{aligned} \tag{3}$$

Treating ρ, θ, ϕ and $\dot{q}$ as constants, (2) and (3) can be re-written to yield

$$A_t = A_0\left(\frac{W_t}{V_t}\right)^{1-\rho} e^{\theta\rho t} \tag{4}$$

$$B_t = B_0\left(\frac{W_t}{V_t}\right)^{-\rho} e^{\theta\rho t}. \tag{5}$$

Furthermore, the normal mark-up price, $\bar{P}_t$ is expressed as

$$\bar{P}_t = mW_t^{\rho} V_t^{1-\rho} e^{-\theta\rho t} \tag{6}$$

with m defining the firm specific elasticity of the demand curve and which is assumed constant over time. Production capacity is updated over time according to[4]

$$YC_t = S_t YC_{t-1} + B_t I_t \tag{7}$$

where S_t is the share of equipment which is kept from one period to the next. In the steady state the optimal scrapping rate δ will be equal to $1/T_{opt}$ which is a consequence of having a constant $\dot{q}$. In the short-run however, S_t will fluctuate around $\dot{q}$. Stalder (1994) therefore suggests to specify

$$S_t = (1-\delta)\left(\frac{W_t/V_t}{(W_{t-1}/V_{t-1})\, e^{\dot{q}}}\right)^{-\xi} \tag{8}$$

[4]In (7) we deviate from the Stalder (1995) model in that we omit the innovation term. For a more thorough reasoning see Müller (2002).

with ξ being the scrapping elasticity with respect to the factor price ratio.

The firms expect the demand for their products to be

$$\begin{aligned} YD_t^e &= YD^e(p_t, \varpi_t) \\ &= p_t^{-\eta} f(\varpi_t) \end{aligned} \tag{9}$$

where the vector ϖ_t contains all those variables which are exogenous to the firms including the average price level in the relevant markets. Naturally, expected demand at the normal mark-up price determines the desired production capacity YC_t^* and the desired gross investment rate IR_t^* (see (7)). We follow Stalder (1995) by imposing the restriction that gross investment cannot become negative

$$\begin{aligned} IR_t^* &\equiv \frac{I_t^*}{YC_{t-1}} \\ &= S_t \varphi_0 e^{\varphi_1 \left(\frac{YD_t^e(\bar{p}_t, \varpi_t)}{YC_{t-1} S_t} - 1 \right)} B_t^{-1}. \end{aligned} \tag{10}$$

This formulation allows to distinguish between two basic situations. Firms face either expected demand in excess of or below current production capacity. They therefore receive an incentive to raise prices and extend capacity or to stick to the actual equipment without replacements respectively. In the long-run, the expected expansion rate of capacities E defines the normal investment rate IR_t^0

$$IR_t^0 = (E - (1 - \delta)) B_t^{-1}, \tag{11}$$

which however, will not hold in the short-run where investment is smoothed and where it has to account for variations in demand. This leads to the following actual investment rate

$$IR_t = \left(IR_t^{*\lambda_1} IR_t^{0\,1-\lambda_1} \right)^{\lambda_2} IR_{t-1}^{1-\lambda_2} e^{u_{2,t}}, \qquad 0 < \lambda_1, \lambda_2 \leq 1 \tag{12}$$

where IR_t is defined as

$$IR_t = I_t / YC_{t-1}. \tag{13}$$

The following lines report the modifications necessary for the incorporation of survey data. Define the relative excess demand at the firm level z_j,

$$z_j \equiv \frac{YD^e(\bar{p})_j}{YC}$$

where YC is the aggregate capacity, and assume that z_j is log-normally distributed with

$$lnz_j \sim N\left(\mu_z, \sigma_z^2\right).$$

Then, the moments of the distribution can be related to survey data by forming the three categories: capacities too large, sufficient, and too small with respect to a threshold value. The proportion of firms reporting either excess or sufficient capacity at time t will be denoted $\pi_{z,t}$. Cutting short the outline again, the following approximations will be used to map the observable variables $\pi_{z,t}$ and Y_t onto the unobservable variables

$$YD_t^e(\bar{p}_t) = Y_t(1-\pi_{z,t})^{-\kappa} \tag{14}$$

$$YC_t = Y_t\pi_{z,t}^{-\kappa} \tag{15}$$

$$\bar{p}_t = p_t(1-\pi_{z,t})^{\tau}. \tag{16}$$

This completes the theoretical part of the goods supply model. In the KOF-version three more equations are included which basically rest on ad hoc specifications and have been partly justified by conventions found in the literature. Among the latter is the data generating process (DGP) for the factor price ratio

$$q_t = q_{t-1} + \dot{q} + \varepsilon_t \tag{17}$$

It will turn out that this formulation is one of the main driving forces within the described economy. The remaining two equations describe the evolution of expected demand,[5]

$$\begin{aligned}\triangle lnYD_t^e &= \alpha_{33}\Big[lnYD_{t-1}^e + \beta_{26}lnYW_{t-1} + \beta_{27}lnYNM_{t-1} + \beta_{28}lnIE_{t-1} \\ &\quad + \beta_{212} + \beta_{214}ln\left(\frac{\bar{P}_{t-1}}{PW_{t-1}}\right)\Big] + \phi_{0,32}\triangle lnYW_t + \phi_{0,33}\triangle lnYNM_t \\ &\quad + \phi_{0,34}\triangle lnIE_t + \phi_{0,38}\triangle ln\left(\frac{\bar{P}_t}{PW_t}\right) + u_{3,t}\end{aligned} \tag{18}$$

and inflation,

$$\triangle lnP_t = \alpha_{44}\left[lnP_{t-1} - \left(ln\bar{P}_{t-1} + \beta_{32}ln(1-\pi_{z,t-1})\right)\right]$$

[5]Subscripts will be used to distinguish between the various lags, equation ordering and variables entering the model. This proves helpful for writing the multivariate time series representation.

$$+(\gamma_{0,4\,1} - \phi_{0,4\,5})\triangle lnW_t + \phi_{0,4\,5}\triangle lnV_t + \phi_{0,4\,7}\triangle ln(1 - \pi_{z,t})$$
$$+u_{4,t}. \tag{19}$$

These equations include a number of exogenous variables. The terms YW_t, YNM_t, IE_t and PW_t denote world activity in manufacturing, real value added in the Swiss economy outside manufacturing, total Swiss gross investment in machinery and equipment, and a world price index respectively.

In the following, equations (1) to (17) will be used to express the observable variables in terms of their own pasts. All definition equations will consequently be rewritten in order obtain an econometric model which is accessible by standard estimation techniques.

2.1.2 Labour Demand and Supply

Stalder (1995) complemented the goods supply model by a labour market. One of its distinguishing feature is the differentiation between foreign and domestic labour. As in the previous section survey data is used to identify situations with and without pressure on the market.

On the supply side, foreign and domestic labour are denoted LS_t^F and LS_t^{CH} respectively. It is assumed that the supply of domestic labour depends on the real wage and the potentially active labour force (LPA_t).

$$LS_t^{CH} = C_0 LPA_t \left(\frac{W_t}{PC_t}\right)^{C_1} e^{c_2 t} \tag{20}$$

where PC_t stands for consumer price index and LPA_t is given by

$$LPA_t = LP_t^{\omega}\left(L^{CH}\right)^{1-\omega} \qquad 0 \leq \omega \leq 1 \tag{21}$$

with LP_t being the number of citizen aged between 20 and 64. Stalder (1995) assumes that the demand for foreign labour is a fixed fraction of overall demand for labour adjusted for the fraction $\pi_{L,t}$ of micro labour markets in excess demand.

$$l_t^F = f_0 + f_1 l_t + f_2 e^{f_3 t} ln\left(\frac{\pi_{L,t}}{1 - \pi_{L,t}}\right) \tag{22}$$

The aggregate labour supply is related to total employment by $\pi_{L,t}$ as

$$L_t \pi_{L,t}^{-\nu} = LS_t, \tag{23}$$

and under the assumption that (23) applies to domestic labour supply, the definition $L_t = L_t^{CH} + L_t^F$ gives rise to[6]

$$(L_t - L_t^F)\pi_{L,t}^{-\nu} = LS_t^{CH}. \tag{24}$$

The parameter ν measures the degree of mismatch on the labour market. We can take logarithms, combine it with (20) and (21) to obtain

$$\begin{aligned} -\nu ln(L_t - L_t^F) + ln\pi_{L,t} &= c_0 + \omega LP_t + (1-\omega)ln(L_{t-1} - L_{t-1}^F) \\ &\quad + c_1(w_t - pc_t) + c_2 t \\ \triangle l_t^{CH} &= \gamma_0 + \omega^* lp_t + \gamma_1(w_t - pc_t) + \gamma_2 t \\ &\quad + \nu^* ln\pi_{L,t} + \left(\frac{\omega - 1}{\nu} - 1\right) l_{t-1}^{CH}, \end{aligned} \tag{25}$$

where

$$\begin{aligned} \gamma_i &= -\frac{c_i}{\nu} \\ \omega^* &= -\frac{\omega}{\nu} \\ \nu^* &= \frac{1}{\nu}. \end{aligned}$$

Finally, the wage is assumed to be determined as

$$W_t = k_0 P_t^{K_1} \left(\frac{PC_t}{P_t}\right)^{K_2} \left(\frac{Y_t}{L_t}\right)^{K_3} \left(\frac{\pi_{L,t}}{1-\pi_{L,t}}\right)^{K_4},$$

and after taking logs we find

$$w_t = k_0 + (k_1 - k_2)p_t + k_2 pc_t + k_3(y_t - l_t) + k_4 ln\left(\frac{\pi_{L,t}}{1-\pi_{L,t}}\right). \tag{26}$$

Equation (26) will be used to replace q_t in the above equations in order to derive parsimonious representations of the system equations.

[6]Stalder (1995) justifies this by identical unemployment rates for both demographic groups ($LS_t/L_t = LS_t^{CH}/L_t^{CH}$).

2.2 Structural Equations and Their Implications for Univariate Time Series Properties

We use the definitions given in (14), (15) to substitute for the unknowns in the equations for IR^0 and IR^*. This allows to rewrite equations (11), (12), (10) in a straightforward manner.

$$\begin{aligned} ir_t^0 &= \bar{E} - b_0 + \rho q_t - \theta \rho t && (27) \\ \bar{E} &\equiv ln\left[E - (1-\delta)\right] \\ ir_t^* &= (1-\phi_1)\bar{\delta} - (1-\phi_1)\xi\varepsilon_t + \phi_1 \triangle y_t + \phi_1 \kappa ln\left(\frac{\pi_{z,t-1}}{1-\pi_{z,t}}\right) \\ &\quad -b_0 + \rho q_t - \theta\rho t && (28) \end{aligned}$$

The calculation of ir_t requires some more effort. To save space, we simply note that (27) and (28) are inserted into (12), and combined with (7). By using the following definitions to keep the number of terms entering the equation in check

$$\begin{aligned} \iota &\equiv \rho\lambda_2 + (1-\varphi_1)\lambda_2\lambda_1\xi, \\ u_{2,t}^* &= \iota\varepsilon_t + u_{2,t}, \end{aligned}$$

and replacing q_t by $w_t - v_t$ the error correction representation for investment can be given as

$$\begin{aligned} \triangle i_t &= \gamma_{0,2\,3}\triangle y_t + \phi_{0,2\,7}\triangle ln(1-\pi_{z,t}) \\ &\quad +\alpha_{2\,2}\left[i_{t-1} + \beta_{2\,1}w_{t-1} + \beta_{2\,3}y_{t-1} + \beta_{2\,6}\, ln\, \pi_{z,t-1} + \beta_{2\,10}v_{t-1}\right. \\ &\quad \left. +\beta_{2\,12} ln(1-\pi_{z,t-1}) + \beta_{2\,18}(t-1)\right] \\ &\quad +\gamma_{1,2\,3}\triangle y_{t-1} + \phi_{1,2\,1}\triangle ln\, \pi_{z,t-1} + d_2 \\ &\quad +u_{2,t}, && (29) \end{aligned}$$

with theory implying that

$$\begin{aligned} \gamma_{0,2\,3} &= \varphi_1, & \beta_{2\,6} &= \kappa(1-\varphi_1\lambda_1), \\ \gamma_{1,2\,3} &= (1-\lambda_2), & \beta_{2\,12} &= \varphi_1\kappa\lambda_1 \\ \alpha_{2\,2} &= -\lambda_2, & \beta_{2\,18} &= \rho\theta, \\ \beta_{2\,1} &= -\beta_{2\,10} = -\rho, & \phi_{0,2\,7} &= \lambda_1\lambda_2\kappa\varphi_1, \\ \beta_{2\,3} &= -1, & \phi_{1,2\,1} &= \kappa(\lambda_2 - 1), \end{aligned}$$

as well as $d_2 = \lambda_2 \left(\lambda_1(\bar{\delta}(1-\varphi_1)) + (1-\lambda_1)\bar{E} - b_0 + \rho(\dot{q}-\theta)\right)$. Next, we will revise (19) by expressing $\bar{P}_t$ in terms of the observable variables. This can be done by defining

$$\tilde{m} \equiv ln\, m$$

and applying (6) to (19), yielding

$$\begin{aligned}\triangle p_t &= \gamma_{0,4\,1}\triangle w_t \\ &\quad +\alpha_{4\,4}\left[p_{t-1} + \beta_{4\,1}w_{t-1} + \beta_{4\,10}v_{t-1}\right. \\ &\quad \left.+\beta_{4\,12}ln(1-\pi_{z,t-1}) + \beta_{4\,18}(t-1)\right] + \phi_{0,4\,5}\triangle v_t + \phi_{0,4\,7}\triangle ln(1-\pi_{z,t}) \\ &\quad +d_4 + u_{4,t}, \end{aligned} \tag{30}$$

where, theoretically, the coefficients could be replaced by their following counterparts

$$\begin{aligned}\beta_{4\,1} &= -\rho, & \beta_{4\,12} &= \tau, \\ \beta_{4\,10} &= \phi_{0,4\,5} = -(1-\rho), & \beta_{4\,18} &= \theta\rho,\end{aligned}$$

and $d_4 = \alpha_{4\,3}(\theta\rho - \tilde{m})$. The following equation gives an expression for real GDP. The starting point is the definition of aggregate demand in (14) which will be related to (18) by replacing the definition variables by their appropriate observable counterparts. The ultimate formula is specified ad hoc though. We follow Stalder (1994) in that respect in order to obtain a comparable model.

$$\begin{aligned}\triangle y_t &= \gamma_{0,3\,1}\triangle w_t \\ &\quad +\alpha_{3\,3}\left[y_{t-1} + \beta_{3\,1}w_{t-1} + \beta_{3\,7}yw_{t-1} + \beta_{3\,8}ynm_{t-1}\right. \\ &\quad \left.+\beta_{3\,9}ie_{t-1} + \beta_{3\,10}v_{t-1} + \beta_{3\,11}pw_{t-1} + \beta_{3\,12}ln(1-\pi_{z,t}) + \beta_{3\,18}(t-1)\right] \\ &\quad +\phi_{0,3\,2}\triangle yw_t + \phi_{0,3\,3}\triangle ynm_t + \phi_{0,3\,4}\triangle ie_t + \phi_{0,3\,5}\triangle v_t + d_3 \\ &\quad +\phi_{0,3\,6}\triangle pw_t + \phi_{0,3\,7}\triangle ln(1-\pi_{z,t}) \\ &\quad +u_{3,t}, \end{aligned} \tag{31}$$

where the preceding algebraic exercise implies the following relations between the coefficients

$$\begin{aligned}\tfrac{\gamma_{0,3\,1}}{\phi_{0,3\,6}} &= \tfrac{\beta_{3\,1}}{\beta_{3\,11}} = -\rho, & \beta_{3\,18} &= -\beta_{3\,1}\theta, \\ \tfrac{\gamma_{0,3\,1}}{\phi_{0,3\,5}} &= \tfrac{\beta_{3\,1}}{\beta_{3\,10}} = \tfrac{\rho}{1-\rho}, & \phi_{0,3\,7} &= -\beta_{3\,12} = \kappa,\end{aligned}$$

and $d_3 = \alpha_{3\,3}\beta_{3\,11}(\tilde{m} - \theta\rho) + \phi_{0,3\,6}\theta\rho$. The last exercise will produce error correction representations of (25) and (26). Noting that $x_t = \triangle x_t + x_{t-1}$ and adding an error term to (25) we find for $\triangle w_t$ and $\triangle l_t^{CH}$,

$$\begin{aligned}
\triangle w_t &= d_1 + \gamma_{0,1\,3}\triangle y_t + \gamma_{0,1\,4}\triangle p_t + \phi_{0,1\,8}\triangle pc_t + \phi_{0,1\,9}\triangle l_t \\
&\quad + \phi_{0,1\,10}\triangle ln\left(\frac{\pi_{L,t}}{1-\pi_{L,t}}\right) - \alpha_{1\,1}\left[w_{t-1} + \beta_{1\,4}p_{t-1} + \beta_{1\,13}pc_{t-1}\right. \\
&\quad \left. + \beta_{1\,3}y_{t-1} + \beta_{1\,14}l_{t-1} + \beta_{1\,15}\left(\frac{\pi_{L,t-1}}{1-\pi_{L,t-1}}\right)\right] + u_{1,t} \qquad (32) \\
\triangle l_t^{CH} &= d_5 + \gamma_{0,5\,1}\triangle w_t + \phi_{0,5\,8}\triangle pc_t + \phi_{0,1\,11}\triangle\pi_{L,t} + \phi_{0,5\,12}\triangle lp_t \\
&\quad + \alpha_{5\,5}\left[l_{t-1}^{CH} + \beta_{5\,1}w_{t-1} + \beta_{5\,13}pc_{t-1}\right. \\
&\quad \left. + \beta_{5\,17}ln\pi_{L,t-1} + \beta_{5\,18}lp_{t-1} + \beta_{5\,18}(t-1)\right] + u_{5,t} \qquad (33)
\end{aligned}$$

The following list of coefficient definitions links (32) and (33) to the underlying theory

$$\begin{aligned}
d_1 &= k_0 & d_5 &= -\tfrac{c_0+c_2}{\nu}, \\
\gamma_0 &= k_0 & \gamma_{0,5\,1} &= -\phi_{0,5\,8} = -\tfrac{c_1}{\nu}, \\
\gamma_{0,1\,3} &= \beta_{1\,3} = k_3, & \phi_{0,5\,10} &= \tfrac{1}{\nu}, \\
\gamma_{0,1\,4} &= \beta_{1\,4} = k_1 - k_2, & \phi_{0,5\,11} &= -\tfrac{\omega}{\nu}, \\
\phi_{0,1\,8} &= \beta_{1\,13} = k_2, & \beta_{5\,1} &= -\beta_{5\,13} = -\tfrac{c_1}{\omega-1-\nu}, \\
\phi_{0,1\,9} &= \beta_{1\,14} = -k_3, & \beta_{5\,16} &= \tfrac{1}{\omega-1-\nu}, \\
\phi_{0,1\,10} &= \beta_{1\,15} = k_4, & \beta_{5\,17} &= -\tfrac{\omega}{\omega-1-\nu}, \\
\alpha_{1\,1} &= -1, & \beta_{5\,18} &= -\tfrac{c_2}{\omega-1-\nu}, \\
& & \alpha_{5\,5} &= \tfrac{\omega-1-\nu}{\nu}.
\end{aligned}$$

Note that if $\triangle v_t$ is added to the list of regressors the error $u_{1,t}$ will closely approximate ε_t. Therefore, in the empirical part we add $\triangle v_t$ to the right hand side of (32).

Summarizing the results obtained so far, it is worth mentioning that the observable variables y_t, i_t, p_t, q_t are all driven by stochastic trends where one of them stems from q_t which enters into (29), (30), (31), (32), (33) alike. Potentially, there are further, independent stochastic trends present which may arise from the ad-hoc specification of YD_t^e and P_t given in (18) and (19) respectively. It is less obvious that i_t also follows an independent stochastic trend. In this case, this feature can be derived from rewriting (12).

Second, building on the assumption that all endogenous observable variables are driven by stochastic trends the following long-run relationships should turn out stationary if the economic model was to prove true.

$$\begin{aligned}
w_t &= k_0 + (k_1 - k_2)p_t + k_2 pc_t + k_3(y_t - l_t) + k_4 ln\left(\frac{\pi_{L,t}}{1-\pi_{L,t}}\right) + ec_{1,t} \\
i_t &= \rho w_t + y_t - \kappa(1-\varphi_1\lambda_1)ln\,\pi_{z,t} - \rho v_t - \varphi_1\kappa\lambda_1 ln(1-\pi_{z,t}) - \rho\theta t + ec_{2,t} \\
y_t &= \beta_{3\,1}w_t + \beta_{3\,8}yw_t + \beta_{3\,9}ynm_t + \beta_{3\,10}ie_t - \frac{1-\rho}{\rho}\beta_{3\,1}v_t + \frac{1}{\rho}\beta_{3\,1}pw_t \\
&\quad +\kappa ln\,(1-\pi_{z,t}) + \beta_{3\,1}\theta t + ec_{3,t} \\
p_t &= \rho w_t + v_t - \tau ln\,(1-\pi_{z,t}) + (1-\rho)v_t - \rho\theta t + ec_{4,t}, \\
l_t^{CH} &= \frac{c_1}{\omega-1-\nu}w_t - \frac{c_1}{\omega-1-\nu}pc_t - \frac{1}{\omega-1-\nu}ln\pi_{L,t-1} \\
&\quad +\frac{\omega}{\omega-1-\nu}lp_{t-1} + \frac{c_2}{\omega-1-\nu}t + ec_{5,t}
\end{aligned} \tag{34}$$

where the error correction terms $ec_{1,t}$, $ec_{2,t}$, $ec_{3,t}$, $ec_{4,t}$ and $ec_{5,t}$ are stationary processes. This said, it is not for all the relationships listed above, that the motivation for the long-run properties is equally well founded theoretically. In particular, only for i_t and for l_t^{CH} the structure follows more or less directly from the economic model. The remaining specifications can ultimately considered ad hoc only. From that it follows that the focus will be on i_t and l_t^{CH} when it comes to identification of the structural parameters.

This closes the model. To sum up, five independent innovation processes, $u_{2,t}$, $u_{3,t}$, $u_{4,t}$, $u_{5,t}$, and ε_t rule the whole economy. The first is related to the supply side. The error term $u_{3,t}$ describes shocks to the aggregate demand for domestic products. Since inflation is described by (19), the corresponding error term, $u_{4,t}$ can be regarded as inflationary shocks. The innovations ε_t are difficult to interpret. Technically they represent shocks to the factor price ratio. The source of unexpected changes to this ratio cannot be identified per se, though. A positive value of ε_t could either represent a wage increase beyond expectation, or mean a surprisingly low increase in the costs of capital equipment.

2.3 Estimation, Identification and Comparison to Previous Approaches

We can now write the model in a compact form. We have six equations for the six endogenous variables q_t, w_t, i_t, y_t, p_t and l_t^{CH}. Since q_t can be written as $w_t - v_t$ treating v_t as exogenous the vector of dependent variables consists of w_t, i_t, y_t, p_t and l_t^{CH}. Furthermore, define the $(n_\Upsilon \times 1)$, $(n_X \times 1)$, and $(n_\Upsilon \times 1)$ vectors Υ_t, X_t, and D respectively

$$\begin{aligned}\Upsilon_t &= \left(w_t, i_t, y_t, p_t, l_t^{CH}\right)', \\ X_t &= \Bigg(ln\pi_{z,t}, yw_t, ynm_t, ie_t, v_t, pw_t, ln(1-\pi_{z,t}), pc_t, l_t, ln\left(\frac{\pi_{L,t}}{1-\pi_{L,t}}\right), \\ &\quad ln\pi_{L,t}, lp_t)',\end{aligned}$$

and D is a vector of constant terms. Define also the coefficient matrices $\Gamma_i\,(n_\Upsilon \times n_\Upsilon)$, $\alpha\,(n_\Upsilon \times \varrho)$, $\beta\,((n_\Upsilon + n_X + 1) \times \varrho)$, $\Phi_j\,(n_\Upsilon \times n_X)$. Then, the model can be given as in (35)

$$\begin{aligned}\Gamma_0 \triangle \Upsilon_t &= \alpha\beta' \left(\Upsilon'_{t-1} : X'_{t-1} : t-1\right)' + \sum_{i=1}^{l-1} \Gamma_i \triangle \Upsilon_{t-i} \\ &\quad + \sum_{j=0}^{h-1} \Phi_j \triangle X_{t-j} + D + \mathcal{E}_t \end{aligned} \tag{35}$$

where the : indicates the concatenation of two matrices. It is convenient to decompose the $(n_\Upsilon \times 1)$ vector $\mathcal{E}_t$ into $\Xi\mathcal{E}_t^*$ in the following way[7]

$$\begin{aligned}\mathcal{E}_t &= (\varepsilon_t, u^*_{2,t}, u_{3,t}, u_{4,t}, u_{5,t})' \\ &= \Xi\mathcal{E}_t^* \\ &= \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ \iota & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} \varepsilon_t \\ u_{2,t} \\ u_{3,t} \\ u_{4,t} \\ u_{5,t} \end{bmatrix}\end{aligned}$$

[7]See also explanations on page 11.

Finally, (35) will be pre-multiplied by Γ_0^{-1} to arrive at a reduced form of the model. Defining $\Gamma_i^* = \Gamma_0^{-1}\Gamma_i$, for $i > 0$, $\alpha^* = \Gamma_0^{-1}\alpha$, $\Phi_j^* = \Gamma_0^{-1}\Phi_j$, $D^* = \Gamma_0^{-1}D$, and $\Xi^* = \Gamma_0^{-1}\Xi$, we have

$$\begin{aligned} \triangle\Upsilon_t &= \alpha^*\beta'\left(\Upsilon'_{t-1} : X'_{t-1} : t-1\right)' + \sum_{i=1}^{l-1}\Gamma_i^*\triangle\Upsilon_{t-i} \\ &\quad + \sum_{j=0}^{h-1}\Phi_j^*\triangle X_{t-j} + D^* + U_t^* \end{aligned} \tag{36}$$

In (36) the innovations are defined as $U_t^* = \Xi^*\mathcal{E}_t^*$. It is worth noting that (36) fits in the standard framework of non-stationary time series analysis with exogenous variables. Estimation of this kind of models can be handled with standard theory.

The general approach is as follows. In the first step the degree of integration of each of the variables involved is determined by unit root tests. Next, the number of cointegration relations, ϱ is estimated. To do so it seems inevitable to consider sub-system because otherwise, the dimension of the process would be too large. Moreover, since the tests designed for systems with exogenous variables require that no cointegration relation exist between the exogenous variables, this has to be checked in a separate investigation. To simplify life, the model could be estimated conditioning on y_t which is also justified by the poor economic grounds on which the respective equation rests. A further alternative provides the opportunity to assume the number of cointegration relations to be given and to estimate conditioning on that.

Having cast the problem in the framework of standard multiple time series techniques, all well established means for time series econometrics are available. This includes for example the calculation of various kinds of impulse-responses and their corresponding confidence bands, the provision of forecast statistics and so on.

The next section turns to the actual empirical exercise. Further details of estimation procedures and identification of parameters from the estimated coefficients are discussed in the appendix.

3 Empirical Application

The reduced form model will be analyzed in three ways. The principal consideration is that there exists a natural hierarchy in the restrictions implied by the structural model. The most important relationships are those which define the long-run equilibria given in (34). The estimation will focus on those at this stage of the analysis.

First, without further testing it will be assumed that all five relations as of (34) hold.

Second, foreshadowing some preliminary results appropriate testing will lead to a reduction of the relationships finding support while at the same time univariate analysis partly reveals tensions between basic assumptions made with respect to the maximum degree of integration and the model formulation. Therefore, as an auxiliary measure, a subsystem analysis which is both, consistent with the economic model and with the time series facts will be investigated.

At the final stage, all models will be compared with respect to the parameters they estimate, residual properties and the forecasting performance of the endogenous variables. The results obtained by the KOF model estimated in structural form serve as a benchmark.

The times series for the variables entering the model are tested for unit roots. To this end, the augmented Dickey-Fuller (Dickey and Fuller (1979)) test is employed. The appropriate lag order is determined by lag order selection criteria with the final judgement being based on the lag length that ensures no significant autocorrelation in the residuals. If the test result does not appear clear without ambiguity the Kwiatkowski, Phillips, Schmidt and Shin (1992) (henceforth KPSS) test with a inverted hypothesis will also be used.[8]

Generally speaking, all variables seem to have a unit root. Some important exceptions have to be acknowledged, though. These are the price deflator of the GDP, the consumer price index, the labour force potential and the nominal wage. In the latter case the evidence is not clear cut which could be attributed to the

[8]The detailed results are available on request.

fact that the statistical office needs to produce quarterly data from the annually measured wage level. This procedure might introduce effects which could be difficult to distinguish from true $I(2)$ behaviour. Nevertheless, both variables, wages and prices, will be considered $I(2)$ which will be taken into account in the second string of analysis. Finally and as expected, the survey data turns out stationary.

3.1 Multivariate Time Series Properties

For the $VECM$ in (36) contains exogenous variables the standard so-called Johansen trace tests (see Johansen (1991), Johansen (1992)) cannot be applied. Instead, the approach by Pesaran et al. (2000) solves the problem. In that setting efficient estimation and hypothesis testing requires that the exogenous variables entering the long-run regressor matrix X_{t-1} are not cointegrated with each other. Thats why, several $VECM$ are estimated which include the components of X_t as endogenous variables in order to find combinations which are free of cointegration relationships. We refrain from reporting the details of the test results here, but provide them on request. Finally, two groups of exogenous variables $(X_{1,t}, X_{2,t})$ can be identified which fulfill the requirement. We have

$$\begin{aligned} X_{1,t} &= (yw_t, ynm_t, \triangle lp_t)', \\ X_{2,t} &= (l_t, \triangle pc_t, \triangle lp_t)', \end{aligned}$$

where the $I(2)$ property of the consumer price index and the labour force potential have already been taken into account. Table 1 lists the test results of various systems and subsystems all being cast in the framework of (36).

Table 1 provides the test statistics and critical values for the whole system, the full system but $\triangle w_t$ being replaced by q_t, and subsystems that are made of all those variables which should form cointegration relationships according to (34). [9]

The cointegration tests point to the existence of only three stationary relationships. Within the full sample, this result holds independently of what set of exogenous variables is used. The only case where there is indication of a further stationary

[9] The statistics for the alternative set of exogenous variables are available on request. Fortunately, there is no contradiction between these two sets.

Table 1: Cointegration Tests

No.	$H_0 : rank_0 = r$	Pesaran et al. (2000)		
	r	test statistic	5% c.v.	10% c.v.
1	Full System (1) $\Upsilon_t = \left(\triangle w_t, i_t, y_t, \triangle p_t, l_t^{CH}\right)'$, $X_t = X_{1,t}$			
	0	163.11^{**}	120.0	114.7
	1	106.88^{**}	90.02	85.59
	2	68.05^{**}	63.54	59.39
	3	33.37	40.37	37.07
	4	14.81	20.47	18.19
2	Full System (1a) $\Upsilon_t = \left(q_t, i_t, y_t, \triangle p_t, l_t^{CH}\right)'$, $X_t = X_{1,t}$			
	0	178.44^{**}	120.0	114.7
	1	114.94^{**}	90.02	85.59
	2	72.42^{**}	63.54	59.39
	3	38.28^{*}	40.37	37.07
	4	10.31	20.47	18.19
3	Investment (1) $\Upsilon_t = (\triangle w_t, i_t, y_t)'$, $X_t = v_t$			
	0	62.08^{**}	49.36	46.00
	1	32.63^{**}	30.77	27.96
	2	9.74	15.44	13.31
4	Wages (1) $\Upsilon_t = (y_t, \triangle w_t, \triangle p_t)'$, $X_t = \triangle pc_t$			
	0	56.02^{**}	49.36	46.00
	1	22.94	30.77	27.96
	2	3.62	15.44	13.31
5	Labour $\Upsilon_t = (\triangle w_t, l_t)'$, $X_t = (\triangle pc_t, \triangle lp_t)'$			
	0	33.29^{*}	35.37	32.51
	1	6.63	18.08	15.82
6	Income $\Upsilon_t = (\triangle w_t, l_t)'$, $X_t = (\triangle pc_t, \triangle lp_t)'$			
	0	21.78	35.37	32.51
	1	6.70	18.08	15.82
7	Prices $\Upsilon_t = (\triangle w_t, l_t)'$, $X_t = (\triangle pc_t, \triangle lp_t)'$			
	0	31.78	35.37	32.51
	1	4.94	18.08	15.82

* and ** indicate significance at the 10 and 5 percent levels respectively.

$^{+}$ see Table T.4 * of Pesaran et al. (2000).

linear combination within the full system is when q_t replaces $\triangle w_t$ and the set $X_{1,t}$ of exogenous variables is used. However, turning to the theoretically reasonable relationships, it seems that only three of them do find support.[10] Therefore, the conclusion is that the system is cointegrated with β having rank three. Potentially, investment, nominal wage growth, and labour supply are forming stationary relationships with explanatory variables as given in (34).

However, the restricted reduced form has not yet been derived for the nominal wage, the GDP deflator, the consumer price index and the potential labour force to enter in second differences. Therefore, when it comes to identification of the long-run relationships the focus will be on investment within the full system. Moreover, in order to save some interpretability the variable w_t will be replaced by q_t which is equivalent to imposing one of the restrictions implied by the long-run investment relation from the very beginning.

3.2 Estimating and Identifying Cointegration Relationships

The estimation focusses on the coefficients of $\beta' = \beta'_\Upsilon : \beta'_X$ wich should theoretically be representing the following parameters:

$$\beta'_\Upsilon = \begin{bmatrix} 1 & 0 & k_3 & k_1 - k_2 & 0 \\ -\rho & 1 & -1 & 0 & 0 \\ \beta_{3\,1} & 0 & 1 & 0 & 0 \\ -\rho & 0 & 0 & 1 & 0 \\ -\frac{c_1}{\omega-1-\nu} & 0 & 0 & 0 & 1 \end{bmatrix}$$

and

$$\beta'_X = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & k_2 & -k_2 & k_4 & 0 & 0 & 0 \\ \kappa(1-\varphi_1\lambda_1) & 0 & 0 & 0 & \rho & 0 & \varphi_1\kappa\lambda_1 & 0 & 0 & 0 & 0 & 0 & \rho\theta \\ 0 & \beta_{3\,7} & \beta_{3\,8} & \beta_{3\,9} & \beta_{3\,10} & \frac{1-\rho}{\rho}\beta_{3\,1} & -\frac{1}{\rho}\beta_{3\,1} & 0 & 0 & 0 & 0 & 0 & -\beta_{3\,1}\theta \\ 0 & 0 & 0 & 0 & \rho-1 & 0 & \tau & 0 & 0 & 0 & 0 & 0 & \theta\rho \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \beta_{5\,13} & 0 & 0 & \frac{-1}{\omega-1-\nu} & \frac{-\omega}{\omega-1-\nu} & \frac{-c_2}{\omega-1-\nu} \end{bmatrix} \tag{37}$$

[10] For the investment equation whether to include q_t or $\triangle w_t$ seems to matter. In the following, we are obliged to continue with q_t however, for which the result is consistent with the overall picture.

Each row of β corresponds from top to bottom to one of the long-run equilibrium relationships defined in (36). We will refer to this model by the term *Full model* or equivalently *model with* $rk(\beta) = 5$.

In the special case when only the relationship for investment is investigated, the relations defined in the second row of the β'_Υ, β'_X will be used. The regressor matrix X_t will be adjusted accordingly. That case we will refer to by the term *model for investment only*.[11]

3.2.1 Full System Result

Estimating the complete system with all restrictions according to (36) means ignoring the possible $I(2)$ properties of some of the variables as well as imposing more or less arbitrary, economically not well founded restrictions especially with respect to the income equation. These two factors might be the final reason as to why calculating the log-likelihood with the complete set of restrictions fails. Therefore, the following two adjustment was made. All restrictions corresponding to the income equation (rows three) were relaxed except for the zero restrictions. Finally, with $l = h = 3$ the following estimates are obtained (standard errors in parentheses).[12]

$$\beta'_\Upsilon = \begin{bmatrix} 1 & 0 & \underset{(.06)}{-.27} & \underset{(.03)}{-.89} & 0 \\ \underset{(.04)}{-1.00} & 1 & -1 & 0 & 0 \\ \underset{(.12)}{.86} & 0 & 1 & 0 & 0 \\ \underset{(-)}{-1.00} & 0 & 0 & 1 & 0 \\ \underset{(2.22)}{24.28} & 0 & 0 & 0 & 1 \end{bmatrix}$$

and

[11] Replacing the $I(2)$ variables by their first difference and w_t by q_t yields yet another system with empirical cointegration rank three. For that system results are available on request.

[12] For all estimation outcomes reported in section 3.2 the sample is 1983-2001. The model selection has been made on information for the sample 1983-1999.

$$\beta_X' = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & \underset{(.06)}{-.26} & \underset{(-)}{.26} & \underset{(.06)}{-.02} & 0 & 0 & 0 \\ \underset{(.06)}{-.11} & 0 & 0 & \underset{(-)}{1.00} & 0 & \underset{(.53)}{-2.75} & 0 & 0 & 0 & 0 & 0 & \underset{(.0003)}{.002} \\ 0 & \underset{(.23)}{-1.38} & \underset{(.22)}{.45} & \underset{(.07)}{-.53} & \underset{(.04)}{-.09} & \underset{(.15)}{.76} & 0 & 0 & 0 & 0 & 0 & \underset{(.002)}{-.002} \\ 0 & 0 & 0 & \underset{(-)}{.004} & 0 & \underset{(.10)}{.52} & 0 & 0 & 0 & 0 & 0 & \underset{(-)}{.002} \\ 0 & 0 & 0 & 0 & 0 & 0 & \underset{(1.76)}{-9.39} & 0 & 0 & \underset{(.15)}{-.33} & \underset{(5.86)}{-52} & \underset{(.004)}{-.01} \end{bmatrix}$$

Here, we removed ie_t from the list of exogenous regressors because i_t is a sub-aggregate of ie_t and therefore causes problems due to non-informative correlation with the dependent variables. Thus, the vector X_t reads

$$X_t = \Bigg(ln(\pi_{z,t}), yw_t, ynm_t, v_t, pw_t, ln(1-\pi_{z,t}), pc_t, l_t, ln\left(\frac{\pi_{L,t}}{1-\pi_{L,t}}\right), ln(\pi_{L,t}), lp_t\Bigg)'.$$

All those entries in matrices $\beta_.$ for which no numerical standard error is provided, the coefficient estimates are subject to constraints. A discussion of the results follows below jointly with the remaining competing approaches.

3.2.2 Partial System Analysis for Investment Only

We now formulate a partial system that is only made up of those variables relevant for the long-run investment relationship. This is in principal equivalent to the other approach while conditioning on those variables now dropped. This partial system can be described by (36) with $\Upsilon_t = (q_t,\, i_t,\, y_t)'$, $X_t = (ln(\pi_{z,t}),\, ln(1-\pi_{z,t}))'$. As before the optimal values for l and h have been found with lag order selection criteria and studying the residual properties. Finally, the following long-run relationship resulted:

$$\beta' = \begin{bmatrix} \underset{(.08)}{-.57} & 1 & -1 & \underset{(.19)}{.38} & \underset{(.21)}{.70} & 0 \end{bmatrix} \tag{38}$$

This model is the only one for which the restrictions imposed on the coefficients could not be rejected. Further discussion of the results are provided in the next section.

3.3 Evaluation of the Estimation Results

We now present a number of statistics that should help assess the quality of the two model variants estimated. Of course, having conducted cointegration tests and having found that the full system with cointegrating rank five is at odds with the data, already provides some information. In addition, the following aspects will be investigated. First, both models are specified and evaluated for the sample 1983q1 to 1999q4. That leaves eight pre-sample values and allows to perform ex-ante out-of sample forecasts for the years 2000 and 2001.

The model selection process will be documented which includes reports of model selection criteria, LR tests on the restrictions imposed on the cointegration matrix β, and tests for the residual properties. With respect to testing restrictions on the cointegrating space the procedure is as follows. Imposing the respective rank all prospective cointegration relations are tested one by one. That means the theoretical restrictions on the coefficients of the cointegrating matrix will be enforced. In most of the cases these are zero restrictions as can be conceived by checking the estimated matrices above. Each of those restrictions on single cointegration vectors is reflected in single rows of these matrices. Finally, all theoretically reasonable restrictions are imposed jointly.

The model selection criteria are calculated with the theoretical restrictions on β being imposed.

For each of the models SC selects the most restricted version while HQ and AIC chose the more generously parametrised. Since the parsimonious specifications result in model versions with undesirable residual properties, we follow HQ and AIC in the first case. The picture is less clear for the second case. Here, three different possibilities emerge. Again, the suggestion by SC has to be rejected on grounds of unfavourable residual properties. It is worth noting though, that model 5 nests models 6 and 7, and model 6 nests model 7. That enables us to perform F-tests on those regressors which have to be deleted when moving to the more restricted model.

It turns out that neither a reduction from 5 to 6 ($F(18, 76) = 1.33$, p-value

Table 2: Lag Order Selection

No.	$l-1$	$h-1$	SC	HQ	AIC
$rank(\beta)=5,\ \Upsilon_t = \left(\triangle w_t, i_t, y_t, \triangle p_t, l_t^{CH}\right)',\ X_t =$					
1	2	2	-37.524	**-42.076**	**-45.064**
2	2	1	nc	nc	nc
3	1	2	-37.606	-41.666	-44.330
4	1	1	**-38.255**	-41.526	-43.673
$rank(\beta)=1,\ \Upsilon_t = (q_t, i_t, y_t)',$ no X_t					
5	2	3	-13.487	-15.792	**-17.306**
6	2	2	-13.835	-15.786	-17.067
7	2	1	-14.342	**-15.938**	-16.986
8	1	3	-13.517	-15.645	-17.042
9	1	2	-13.997	-15.770	-16.934
10	1	1	**-14.482**	-15.901	-16.832

The model: $\triangle\Upsilon_t = \alpha^*\beta'\left(\Upsilon'_{t-1} : X'_{t-1} : t-1\right)' + \sum_{i=1}^{l-1}\Gamma_i^*\triangle\Upsilon_{t-i} + \sum_{j=0}^{h-1}\Phi_j^*\triangle X_{t-j} + \mathcal{D}^* D_t + U_t^*$.
The symbols SC, HQ, and AIC stand for the Bayesian Schwartz, the Hennon-Quinn and the Akaike information criteria respectively. The table entry nc indicates that the reduced rank regression procedure did not converge.
Bold face indicates the minimum of the respective column.

.19) nor from 5 to 7 ($F(36,80) = 1.33$, p-value .15) can be rejected at conventional levels. The same holds true for an F-test on 6 versus 7 ($F(18,93) = 1.26$, p-value .24). Model 7 however, results in residuals of the investment and the factor price ratio equation for which the hypothesis of normality has to be rejected at the ten and five percent levels of significance respectively. We therefore continue with version 6.

Having specified the models, we can check whether or not the restrictions on the cointegrating vectors are empirically acceptable. For simplicity, we refer to the cointegrating vectors in question in terms of their economic motivation. We test in the order given by the rows in each cointegrating matrix from top to bottom. Together with a test on all restrictions in all vectors this leads to six, four and two tests for the three models respectively.

Obviously, imposing the theoretical restrictions on the cointegrating vectors does not receive much support from the data.[13] However, as can be seen from a com-

[13]Garratt et al. (2002) use bootstrap procedures to derive critical values. Doing the same

Table 3: Likelihood Ratio Tests of Restrictions on the Cointegrating Vectors

vector	χ^2 statistic	d. f.*	p-value
$rank(\beta) = 5$			
wage	28.48	8	.00
investment	20.83	8	.01
GDP	16.95	5	.00
prices	30.93	9	.00
Swiss Labour	nc	-	-
ALL	293.7	39	.00
$rank(\beta) = 1$			
investment	.53	2	.77

* Degrees of freedom of the χ^2 distribution.

For definitions of the models please refer to Table 2.

parison between the test results for the long-run investment relation this conclusion crucially depends on whether or not one conditions on the variables that theoretically do not matter for the relation under consideration. Thus, it appears worthwhile to investigate what particular restrictions cause the test to reject the null hypothesis. Moreover, since the theoretical restrictions for the long-run investment relation cannot be rejected when conditioning on some of the variables, the same procedure could be applied to the remaining relations which found support from the cointegration tests. This however, is beyond the scope of the paper and will be left for future research.

Even though the restrictions on the β matrices are rejected, the residual properties appear satisfying in each of the models. To check this consider Table 4. Overall, the tests do not indicate any significant problem.

3.4 Forecast Evaluation

The ultimate goal of the econometric model is to obtain the best possible forecasts. Both models can be used to forecast the level of investment and the GDP. When considering only the first model, the demand for Swiss labour can also be considered.

potentially would change some conclusions.

Table 4: Residual Properties

Test	Dependent variable	Model $rk(\beta) = 5$ stat.	d.f.	prob.	$rk(\beta) = 1$ stat.	d.f.	prob.
Portman-	w_t	15.83	9	.07	-		
teau♯	q_t	-			5.44	9	.79
AR(12)	i_t	14.02	9	.12	9.80	9	.36
	y_t	10.47	9	.31	7.23	9	.61
	p_t	10.85	9	.29	-		
	$\triangle p_t$	-			-		
	l_t^{CH}	8.13	9	.84	-		
	ALL	296.26	230	.00	99.36	90	.24
Normality	w_t	.09	2	.96	-		
(χ^2)	q_t	-			.43	2	.81
	i_t	.89	2	.64	2.37	2	.31
	y_t	1.82	2	.40	3.74	2	.15
	p_t	2.32	2	.31	-		
	$\triangle p_t$	-			-		
	l_t^{CH}	1.20	2	.55	-		
	ALL	4.61	10	.92	5.03	6	.54

The model definitions are given in Table 2.

Portmanteau AR(12) tests for autocorrelation within the residuals of up to order 12. Normality checks whether or not the null hypothesis of normality of the residuals can be rejected.

The abbreviations stat., d.f., prob. are short for value of the test statistic, degree of freedom, and probability respectively.

♯Calculation of the degrees of freedom of the Portmanteau statistic is subject to discussion. We subtract from the number of regressors of the auxiliary regression the number of autoregressive coefficients in the model where we count the long-run coefficients as autoregressive ones.

We therefore focus on the forecasting performance of investment and GDP income. In addition to these two models we also look at the forecasting performance of the KOF structural model. In contrast to the modelling strategy used so far, we will use the specification of the KOF model derived with all information up to 2002. This should generally work in favour of that purely structural model.

The forecast period extends over the eight quarters following the last one of 1999. Table 5 reports the root mean squared (RMSE), the mean absolute percentage (MAPE), and the mean forecast (MFE) errors.

Judging on grounds of the forecast performances, the decision as to what model

Table 5: Forecasting Performance

Dependent variable	criterion	$rk(\beta) = 5$	Model $rk(\beta) = 1$	KOF 2002
	RMSE×100	10.265	**6.972**	11.766
i_t	MAPE×100	89.786	**54.486**	95.517
	MFE×100	-8.159	**-3.890**	-8.399
	RMSE×100	**.253**	.565	3.114
y_t	MAPE×100	**1.728**	4.050	20.270
	MFE×100	**.019**	-.368	-2.269

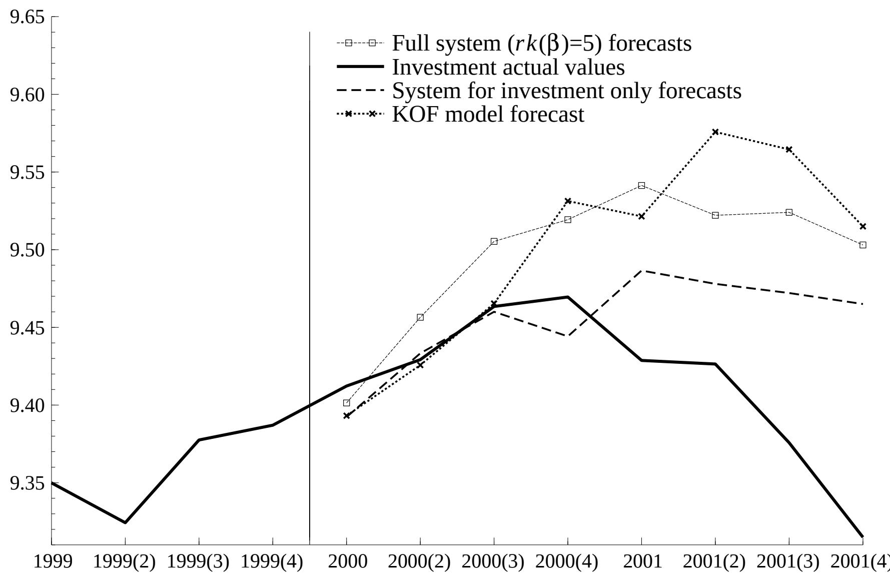
The model definitions are given in Table 2. KOF 2002 stands for the strcuctural model of the KOF (Institute for Business Cycle Research) used for the autumn 2002 economic report.
Bold face signfies the minimum of the absolute values in the respective column.

is the best depends on what variable one focusses. The full model with cointegration rank five does best with respect to forecasting aggregate income. Considering that the most important difference between this model and the system for investment only mainly lays in the fact that the latter comprises fewer exogenous variables, the better performance of the larger model can certainly be attributed to exactly that reason.

Looking at the performances paying particular attention to investment leaves no doubt though that the smallest model definition does best. Moreover, given the extraordinary economic development between 1999 and 2001 where the economy went from a huge boom into a recession like situation, the ability to mimic the moves in investment appears impressive (see Figure 1). It should also be noticed that the model with the single cointegration relation for investment is very parsimoniously specified but still outperforms the other two with respect to forecasting investment.

Finally, the structural model does worst on all accounts. Interestingly though, it comes very close to the model where all restrictions, theoretical and the inherited ad-hoc ones, have been imposed in the multivariate time series estimation approach (model with $rk(\beta) = 5$). This can be explained by the thereby imposed similarity between these models. It underlines again the necessity to carefully check whether

Figure 1: Forecasting Investment - Performances of All Models



or not the assumed long-run relationships can be justified empirically.

3.5 Recovering the Structural Parameters

The tests for restrictions on the cointegration relations revealed that the theoretical model is partially at odds with the recent data. At the same time an important part of it could be shown to be in line with the observations, though. This is the long-run relationship for the investment in machinery and equipment. Therefore, when it comes to identifying the structural parameters of the model it seems natural to look at those parts of the model that have found support empirically. Doing so restricts the number of parameters that can be recovered, though. On the other hand, it appears not reasonable to report parameters of a structural model which is not supported by the data.

In the following we use the estimates of (38) for identification. Remember that the long-run relationship has been found to be:

$$i_t = \underset{(.08)}{.57}\ q_t + y_t - \underset{(.19)}{.38}\ ln(\pi_{z,t}) - \underset{(.21)}{.70}\ ln(1-\pi_{z,t}) + 0t + ec_{2,t}$$

Table 6: Comparison of Estimates

para-meter	Model reference $rk(\beta)=5$ 1983-2001	i_t only 1983-2001	KOF 2002 1980-2001	Stalder '95 1970-1994	relevance
ρ	1 (.04)	.57 (.08)	.65	.7	labour share
κ	2.64 (−)	.32 (−)	.062	.042	mismatch on goods market
θ	0 (0)	0 (0)	.0017	.007	labour augmenting technical progress
φ_1	1.04 (−)	2.20 (−)	1	3.82 (.45)	

with $ec_{2,t}$ being a stationary process. All coefficients are significant and the restrictions imposed on the trend and on the income variable have been accepted. Moreover, although not reported here, these restrictions are not rejected even for smaller sample sizes and the point estimates are pretty stable over time too. The corresponding theoretical relationship is of the structure

$$i_t = \rho(w_t - v_t) + y_t - \kappa(1-\varphi_1\lambda_1)ln\,\pi_{z,t} - \varphi_1\kappa\lambda_1 ln(1-\pi_{z,t}) - \rho\theta t + ec_{2,t}$$

Using the same restriction as in the KOF model, $\lambda_1 = 1$, this provides us with the necessary tools to identify the parameters ρ, θ, κ, and φ_1.

We compare the estimates for these coefficients to the parameters used in the KOF macro model in the following table and add those parameter values that can be obtained by a similar procedure from the other model considered in the previous analysis.

The parameter values obviously differ quite substantially in some cases. Among them the value of .65 for ρ appears to be the most robust against various estimation procedures. Thus, even the very crude OLS estimate on (17) which is used to derive it in the structural approach seems to deliver reasonable values. It is worthwhile remembering that taking simply the wage share of the GDP might be a poor representative of the labour share in the economy since it neglects all labour income of the self-employed for example.

With respect to κ the difference is more pronounced. It measures the mismatch on the goods markets. Following Stalder (1995) in an equilibrium on the markets ($\pi_{z,t} = .5$) the capacity utilisation can be computed as $(\pi_{z,t})^{\kappa}$ which would be equivalent to approximately .80 with the new estimates ($\kappa = .32$) and .96 for $\kappa = .064$ as in the current version of the KOF model. Stalder (1995) notes that a value of .97 which he found to be rather high in an equilibrium situation. Therefore, the recent result might well yield a reasonable value. Moreover, during the sample period the reported value of $\pi_{z,t}$ has never had a mean value of .5 when estimating the sample average recursively. That means on average, the equilibrium value has never been observed for a significant period of time. What is therefore more important for the new estimate is the implication for the dispersion of the capacity constrained firms. The larger κ the more firms produce at the given price above or below their capacity. In the limit $\kappa = 0$ means that all firms face a demand such that they produce at their normal capacity.

The next parameter of interest is θ. According to (1) it measures the labour augmenting technical process in the economy. Therefore a value of zero implies a puzzling picture of the Swiss economy to say the least. In comparison to the alternative estimates, we note that Stalder (1995) already has pointed to the fact that $\theta = .007$ has been estimated with a large standard error from which we conjecture that the hypothesis $\theta = 0$ could hardly be rejected.

Finally, φ_1 measures the extent to which the investment rate changes due to changes in the ratio between expected demand and production capacity. Its sign should be positive, which actually is the case.

At this stage we refrain from attempting to recover the remaining parameters. In most of the cases they are linear combinations of the short-run coefficients for which we do not yet have results regarding their stability over time. The latter requirement would be desirable however. On the other hand, all those parameters defining the price, income, and wage relationships will not be identified because the implicit time series models have not found support.

4 Conclusions

We looked at a structural economic model and turned it into a multivariate time series representation by linearising the underlying partly non-linear relationships. This could be done without rendering the steady state non-identified as is often the case when economic models are linearised *around* the steady state.

Being more general than the pure structural form the multivariate time series representation enabled us to test whether or not the economically plausible relationships are in line with the observed data. It turned out that this is not the case in all respects. In particular, the hypothesised price and wage setting behaviour did not find support. This finding however hinges to some extent on the fact that the derived multivariate time series representation cannot map the empirically $I(2)$ variables into the $I(0)$ space. This will therefore be the subject of future research.

With respect to the labour market, the empirical results were not yet promising. However, given the fact that in the case of long-run investment modelling the economically and empirically reasonable relationship could only be recovered from a partial model, the same might be true for the labour market. It is therefore desirable to obtain a more parsimoniously specified system which is free of potentially slack regressors which introduce statistical noise and may distort the statistical inference.

Finally, the most robust part of the model appeared to be the investment equation. Built on a vintage capital production function the optimal investment decisions can be derived theoretically and a long-run equilibrium between investment, economy wide income, and the factor price ratio results. Taking into account that production capacity and actual output of firms may differ offers the scope for introducing the outcome of data generated by business surveys. Although not being strictly speaking part of the long-run solution they could be shown to play an important role for explaining the path of investment. Despite the observed and unexplained productivity puzzle, we therefore conclude that the vintage capital production function fairly well approximates the behaviour of economic agents in Switzerland.

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A Appendix: Definitions of Coefficient Matrices

A.1 Matrix Definitions

The complete model can be written as in (35) and in (36). With

$$\Upsilon_t = \left(w_t,\, i_t,\, y_t,\, p_t,\, l_t^{CH}\right)'$$

and

$$X_t = \Big(ln(\pi_{z,t}), yw_t, ynm_t, ie_t, v_t, pw_t, ln(1-\pi_{z,t}), pc_t, l_t, ln\left(\frac{\pi_{L,t}}{1-\pi_{L,t}}\right), ln(\pi_{L,t}), lp_t\Big)'$$

the corresponding coefficient matrices are defined as follows:

$$\Gamma_0 = \begin{bmatrix} 1 & 0 & -\gamma_{0,1\,3} & -\gamma_{0,1\,4} & 0 \\ 0 & 1 & 0 & 0 & 0 \\ -\gamma_{0,3\,1} & 0 & 1 & 0 & 0 \\ -\gamma_{0,4\,1} & 0 & 0 & 1 & 0 \\ -\gamma_{0,5\,1} & 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\Gamma_0 = \begin{bmatrix} 1 & 0 & -\gamma_{0,1\,3} & -\gamma_{0,1\,4} & 0 \\ 0 & 1 & -\gamma_{0,2\,3} & 0 & 0 \\ -\gamma_{0,3\,1} & 0 & 1 & 0 & 0 \\ -\gamma_{0,4\,1} & 0 & 0 & 1 & 0 \\ -\gamma_{0,5\,1} & 0 & 0 & 0 & 1 \end{bmatrix}$$

Letting $z^* = \frac{1}{1-\gamma_{0,1\,3}\gamma_{0,3\,1}}$ and $z^{**} = \frac{z^*}{1-\gamma_{0,1\,4}\gamma_{0,4\,1}z^*}$ we find

$$\Gamma_0^{-1} = \begin{bmatrix} z^{**} & 0 & \gamma_{0,1\,3}z^{**} & \gamma_{0,1\,4}z^{**} & 0 \\ 0 & 1 & 0 & 0 & 0 \\ \gamma_{0,3\,1}z^{**} & 0 & (1-\gamma_{0,1\,4}\gamma_{0,4\,1})z^{**} & \gamma_{0,1\,4}\gamma_{0,3\,1}z^{**} & 0 \\ \gamma_{0,4\,1}z^{**} & 0 & \gamma_{0,1\,3}\gamma_{0,4\,1}z^{**} & \frac{z^{**}}{z^*} & 0 \\ \gamma_{0,5\,1}z^{**} & 0 & \gamma_{0,1\,3}\gamma_{0,5\,1}z^{**} & \gamma_{0,5\,1}\gamma_{0,1\,4}z^{**} & 1 \end{bmatrix},$$

and,

$$\Phi_0 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & \phi_{0,1\,8} & \phi_{0,1\,9} & \phi_{0,1\,10} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \phi_{0,3\,2} & \phi_{0,3\,3} & \phi_{0,3\,4} & \phi_{0,3\,5} & \phi_{0,3\,6} & \phi_{0,3\,7} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \phi_{0,4\,5} & 0 & \phi_{0,4\,7} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \phi_{0,5\,8} & 0 & 0 & \phi_{0,5\,11} & \phi_{0,5\,12} \end{bmatrix}$$

$$\Phi_1 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \phi_{1,2\,1} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix},$$

as well as,

$$\beta' = \beta'_\Upsilon : \beta'_X \tag{39}$$

with the $(\varrho \times n_\Upsilon)$ matrix

$$\beta'_\Upsilon = \begin{bmatrix} 1 & 0 & \beta_{1\,3} & \beta_{1\,4} & 0 \\ \beta_{2\,1} & 1 & \beta_{2\,3} & 0 & 0 \\ \beta_{3\,1} & 0 & 1 & 0 & 0 \\ \beta_{4\,1} & 0 & 0 & 1 & 0 \\ \beta_{5\,1} & 0 & 0 & 0 & 1 \end{bmatrix}$$

and the $((n_X + 1) \times \varrho)$ matrix

$$\beta'_X = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \beta_{1\,14} & \beta_{1\,15} & 0 & 0 & 0 \\ \beta_{2\,6} & 0 & 0 & 0 & \beta_{2\,10} & 0 & \beta_{2\,12} & 0 & 0 & 0 & 0 & 0 & \beta_{2\,18} \\ 0 & \beta_{3\,7} & \beta_{3\,8} & \beta_{3\,9} & \beta_{3\,10} & \beta_{3\,11} & \beta_{3\,12} & 0 & 0 & 0 & 0 & 0 & \beta_{3\,18} \\ 0 & 0 & 0 & 0 & \beta_{4\,10} & 0 & \beta_{4\,12} & 0 & 0 & 0 & 0 & 0 & \beta_{4\,18} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \beta_{5\,13} & 0 & 0 & \beta_{5\,16} & \beta_{5\,17} & \beta_{5\,18} \end{bmatrix}$$

For the adjustment to deviations from the long-run relations and for $\mathcal{D}$ we find

$$\alpha = \begin{bmatrix} \alpha_{1\,1} & 0 & 0 & 0 & 0 \\ 0 & \alpha_{2\,2} & 0 & 0 & 0 \\ 0 & 0 & \alpha_{3\,3} & 0 & 0 \\ 0 & 0 & 0 & \alpha_{4\,4} & 0 \\ 0 & 0 & 0 & 0 & \alpha_{5\,5} \end{bmatrix}$$

$$D = \begin{bmatrix} d_{1\,1} \\ d_{2\,1} \\ d_{3\,1} \\ d_{4\,1} \\ d_{5\,1} \end{bmatrix} = \begin{bmatrix} k_0 \\ \lambda_2 \Big(\lambda_1(\bar{\delta}(1-\varphi_1)) + (1-\lambda_1)\bar{E} - b_0 + \rho(\dot{q} - \theta)\Big) \\ \alpha_{3\,3}\beta_{3\,11}(\tilde{m} - \theta\rho) + \phi_{0,3\,6}\theta\rho \\ \alpha_{4\,3}(\theta\rho - \tilde{m}) \\ -\frac{c_0 + c_2}{\nu} \end{bmatrix}.$$

For the identification of coefficients and the impact of changes in the model structure the theoretical definition of the matrix D is of special interest. We call these intercepts the structural means. Some of the structural coefficients of the model turn up in these means only. Therefore, identification of the innovations $\mathcal{E}$ is a pre-condition of recovering all those parameters when estimating the whole model in reduced form.

An easy way to identify all parameters is to first estimate the β coefficients, to fix them in turn and proceed by imposing the coincident restrictions on the matrix Γ_0 by assuming an diagonal variance/covariance matrix of the residuals. For that appropriate standard software tools exist.

A.2 Further Output

Estimation result for the sample 1983-1999 which has been used for the forecasting comparisons.

- The model with $rk(\beta) = 5$, $\Upsilon_t = \left(w_t,\, i_t,\, y_t,\, p_t,\, l_t^{CH}\right)'$, and

$$\begin{aligned} X_t &= \left(ln(\pi_{z,t}), yw_t, ynm_t, v_t, pw_t, ln(1-\pi_{z,t}), pc_t, l_t, ln\left(\frac{\pi_{L,t}}{1-\pi_{L,t}}\right),\right. \\ &\quad \left. ln(\pi_{L,t}), lp_t\right)' \end{aligned}$$

$$\beta'_{\Upsilon} = \begin{bmatrix} 1 & 0 & \underset{(.02)}{-.33} & \underset{(.01)}{-1.42} & 0 \\ \underset{(.02)}{-.97} & 1 & -1 & 0 & 0 \\ \underset{(.06)}{-1.52} & 0 & 1 & 0 & 0 \\ \underset{(-)}{-.97} & 0 & 0 & 1 & 0 \\ \underset{(3.32)}{-6.51} & 0 & 0 & 0 & 1 \end{bmatrix}$$

and

$$\beta'_X = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & \underset{(.01)}{.04} & \underset{(-)}{.04} & \underset{(0)}{0} & 0 & 0 & 0 \\ \underset{(.05)}{-.06} & 0 & 0 & \underset{(-)}{.96} & 0 & \underset{(.03)}{-1.52} & 0 & 0 & 0 & 0 & 0 & \underset{(.001)}{.001} \\ 0 & \underset{(.06)}{.16} & \underset{(.05)}{.32} & \underset{(.11)}{.09} & \underset{(.007)}{-.02} & \underset{(.23)}{-1.01} & 0 & 0 & 0 & 0 & 0 & \underset{(.001)}{-.009} \\ 0 & 0 & 0 & \underset{(-)}{-.03} & 0 & \underset{(.05)}{.20} & 0 & 0 & 0 & 0 & 0 & \underset{(-)}{.001} \\ 0 & 0 & 0 & 0 & 0 & 0 & \underset{(1.66)}{.77} & 0 & 0 & \underset{(.15)}{.13} & \underset{(8.53)}{-34} & \underset{(.008)}{.05} \end{bmatrix}$$

- Model for investment only with $\Upsilon_t = (q_t,\, i_t,\, y_t)'$, and $X_t = (ln(\pi_{z,t}),\, ln(1-\pi_{z,t}))'$

$$\beta' = \begin{bmatrix} \underset{(.19)}{-.91} & 1 & -1 & \underset{(.35)}{1.12} & \underset{(.38)}{1.56} & 0 \end{bmatrix}$$

A.3 Data Definition

Table 7: Data Description

Data description and variable symbols

symbol	description
w_t	nominal wages, Federal Statistical Office compilation
$icnstr_t$	real gross fixed capital formation in construction
i_t	real investment in machinery and equipment
ie_t	real investment in machinery, equipment, and buildings ($ie_t = i_t + icnstr_t$)
y_t	real GDP
p_t	deflator of GDP (base year 1995)
l_t^{CH}	labour force (full time equivalent), Swiss residents
$\pi_{z,t}$	share of firms reporting capacity utilisation above or on the limit
v_t	price of i_t at 1995 prices
pc_t	consumer price index (1995 prices)
pw_t	price index of the rest of the world (1995 prices)
$ltotv_t$	total labour force (full time equivalent)
$\pi_{L,t}$	proportion of firms reporting too few or just enough (bottleneck) labour supply
lp_t	potential labour force (total number of permanent residents in the age range 20 to 64 years)