Modeling Production and Employment in the Norwegian Private Services*

Junior Maih†
The University of Oslo

August 30, 2002

Abstract

We use quarterly data to estimate models for production and labor demand over 1979Q1-2001Q3. The results show that in the long-run the production function is consistent with a profit-maximizing behavior. Moreover, Norwegian private services are labor intensive, which accords with the stylized facts of the literature on services economics. However, due to its sluggish movements, the role of capital in the production process is difficult to grasp. Finally, not only the models presented track the data pretty well, they also are serious contenders to the rival explanations of the current models in RIMINI, the Norwegian Central Bank macro-model.

*This paper is an abridged version of a thesis I wrote in partial fulfillment of the degree of master of Sciences in Economics at the University of Oslo. The study was carried out during my internship at the Research Department of the Central Bank of Norway, whose hospitality and financial support are gratefully acknowledged. I would like to give special thanks to Asbjørn Rødseth both for his valuable assistance and for agreeing to act as supervisor. My thanks also go to Ragnar Nymoen, Gunnar Bårdsen, and Fredrik Wulfsberg for insightful suggestions, to Qaisar Farooq Akram for helpful comments, to Ida W. Bache and Solveig K. Erlandsen. However, the responsibility for all errors, opinions and failures to understand the workings of the Norwegian economy rests with me.

†Address: Department of Economics, University of Oslo, P.O. Box 1095 Blindern, N-0317 Oslo, Norway. E-mail: jmaih@econ.uio.no

Contents

1 Introduction

Norway can be regarded as a service economy. Figure 1 plots the shares of service output in the GDP (panel 1), the share of service employment in total employment (panel 2) and the services-manufacturing employment ratio (panel 3). Accounting for more than $2/3$ of the GDP, services output has had the lion's share in the national product for the last two decades. The services sector employs more than 40% of the workforce and the number of service workers has been twice as large as that of the manufacturing sector for at least ten years, with a sustained growth.

But the preponderance of the services sector is not a feature unique to the Norwegian economy. This sector has seen the expansion of both production and employment in most OECD countries too. Perhaps it is then not surprising why the phenomenon has prompted a large number of studies on the subject. To mention a few, Julius (1998) reports that since 1992 more than 80% of the rise in UK employment has been generated by service industries and the rate of output growth has been more than double that of manufacturing. According to Roach (1991), at the beginning of the 1990s, service workers already held four out of every five jobs in private industry. And about 90% of all new jobs in Europe, North America, and Japan are in services as argued by Harrington and Warf (1995, pp 64).

It seems nevertheless that compared to manufacturing and agriculture, the modeling of services at the macro level has received less attention than it deserves despite their major role in modern developed economies (see Heshmati (2000)). Moreover, services are usually treated as conventional goods even if some service industries may have special economic properties that do not fit well with the conventional assumptions of economic models. For instance, as argued by Julius (1998), telephony and computer software production incur high initial costs, but low marginal costs, which makes pricing strategies more complex.

All these considerations raise theoretical as well as empirical issues for the Norwegian Central Bank in its policy design. From an economic standpoint, it is important to know the factors driving the service market in the long run and the way they relate to production and employment. This implies a meticulous choice of both a theory and a parametric form that can describe those features. From an econometric viewpoint, the parametric form has to be translated into a good statistical model allowing for the estimation of the parameters thereof. The Norwegian economy experienced one major shock, a recession from about the fourth quarter of 1987 until the fourth quarter of 1991 or so before going back to its normal growth path. There is an interesting opportunity to re-assess the production and employment equations of the private services sector used in the Central Bank's model RIMINI not only theoretical grounds, but also on empirical grounds and see if they can account for the observations over the period of recession and onwards.

When it comes to policymaking and forecasting, there is a constant need to reexamine the extent to which private services respond to policy decisions undertaken by the Bank. But this can be achieved only if there exists a stable relationship between production, employment and their determinants, and hence a possibility of targeting the service market through policies a¤ecting those determinants. In this case, it is not merely the equilibria that are of interest, but rather the manner in which production and employment would respond to changes in the policy instruments in the long run as well as in the short-run. A potential bene…t of a disaggregated study focusing on private services is to see whether the sectorial sensitivity has been stable over time and if it signi…cantly di¤ers from the overall one, given that services are increasingly traded[1].

In particular the Bank's policymaking, which is concerned among other things with evaluating future in‡ation patterns, heavily relies on macroeconomic constructs such as the output gap. Not only reviewing the behavioral properties of this key element is a natural activity, but also a sectorial output gap might help to see which sectors are likely to induce more in‡ation than others. This would help re…ning the policies so as to put more emphasis on speci…c sectors. All those considerations invite to a better understanding of how the Norwegian services sector behaves and more speci…cally, how the supply of services comes about and how the sector attracts workers.With these concerns in mind, we try in this paper to build a framework that can handle the analysis of services and hence provide a theoretical basis for an empirical speci…cation. Our intent is to build upon the RIMINI models and give them a stronger empirical foundation.

We organize the remainder of this paper as follows. We start in Section 2 by laying out a strategy for the analysis of services, a strategy leading up to the speci…cation of production and labor demand equations to analyze. Next, Section 3 brie‡y presents the Central Bank's models and assess them in the light of production theory and services economics stylized facts. In particular we argue that the contribution of labor to production is underes-

[1] The service sector used to be considered as sheltered from international competition, however, a number of studies tend to show however that such a line of reasoning is now ‡awed.

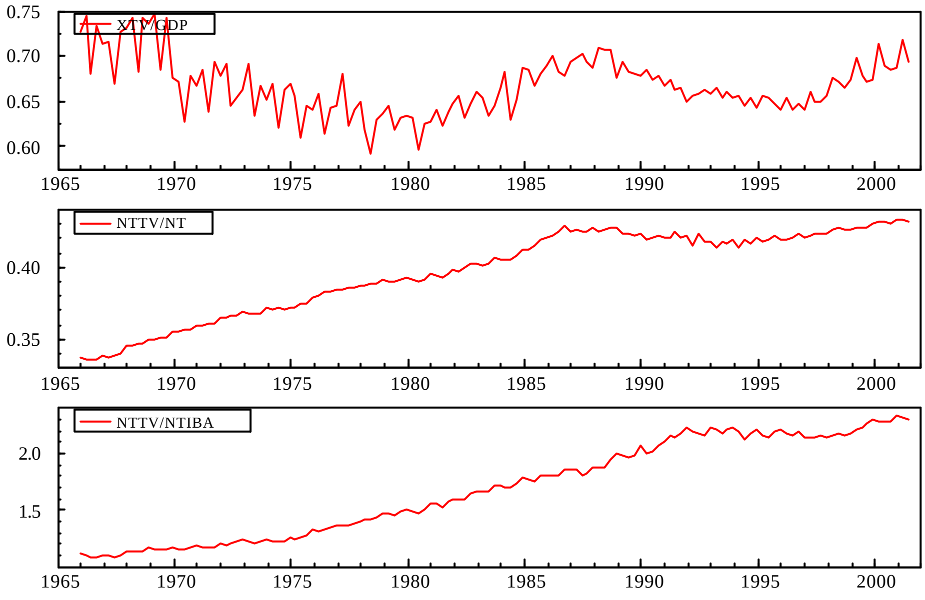

Figure 1: Share of private service production in GDP, share of private service employment in total employment, private-service-manufacture employment ratio

timated. We try to overcome the drawbacks of these models by re-specifying them and presenting the results of our estimations in Section 4. Then we compare the performance of our models to those of the Central Bank in Section 5 and give some concluding remarks in the final section. The dataset used for the calculations is drawn from the RIMINI model database and all the results are computed using PcGive 10.1 (see Doornik and Hendry (2001)).

2 A modeling strategy for services

Several options can be used when modeling production (see for instance Biørn (2000, chapter 6)). One can start by specifying a system of regression equations and then apply the theoretical restrictions to the parameters of the system so that they satisfy the requirements of factor demand functions. As a second option, one can specify a parametric form of cost function and deduce the factor demands functions by means of Shepard's lemma.

In this study, however, we use a more straightforward approach, the one that consists in specifying a parametric form of the production function and deduce the corresponding factor demand functions. One of the major shortcomings of this method is that there are several types of production functions and the choice of a particular specification is not always obvious. Later on we will motivate the choice of a parametric form before deriving a labor demand equation therefrom and presenting the statistical models we will use to estimate them. But a good empirical study of the Norwegian production of services and the demand for labor by the services sector should probably begin with a definition of services.

2.1 Tentative definition and properties of services

Broadly defined, services include all activities besides extraction, agriculture and manufacturing. A narrower definition of services is more difficult to obtain since service activities display a good deal of heterogeneity. Services are generally defined in terms of the intangibility of their outputs, in contrast to manufacturing, even if that's not a guarantee of similarity in the technology of their supply processes (see Baumol (1985)). But the intangibility nature of services can be discussed. According to Harrington and Warf (1995, pp 53-55) lots of service firms produce a tangible output. Examples are fast-food franchises whose output is indeed tangible but still is considered as a service, computer software firms that store their output on disks.

A second point of contention about the definition of services is whether they can be considered as tradable or not. Until recently, following the conventional wisdom, services were thought of as immune to foreign competition. For instance dividing the Norwegian labor market into two parts, Nymoen (1991) unambiguously terms the services sector as the "sheltered sector", while calling the other sector "export and import competing sector". This is true to the extent that manufactured goods freely flow across borders whereas banking services, say, cannot. This line of thinking is now flawed. With the development of communication technologies, such as internet, domestic services are likely to compete more and more with suppliers from abroad. As noticed by Miozzo and Soete (1999), the increased storability and transmission of information enhances the transportability of services, altering modes of delivery and leading not only to a new technical division of labor, but also to a relocalization of service activities[2].

[2] The reader interested may also want to take a look at Howells (2000) for a discussion of the relationship between services and technological innovation.

Thirdly, it is not clear when talking of services, whether one means industry or occupation because in fact, many workers in the manufacturing sector provide services, secretaries are a case in point. In that respect, it is probably safer, at least for empirical purposes to define services according to their industry. Then, one can enumerate the main components of the services sector. These include (see Harrington and Warf (1995, pp 55)): Finance, insurance and real estate, business services, transportation and telecommunications, wholesale and retail trade, personal services and entertainment, government, non-profit agencies.

More directly connected to the purpose of our study, services can be characterized by their labor intensive nature involving functions that are difficult to automate. Concretely, relatively to the manufacturing sector, more workers are typically required per unit of output in the service industries. While this distinction will be important for the rest of the discussion, we don't delve further into the definition of services. Rather we go on to trying to build models that possibly can represent the supply of services and the demand for labor by service firms in the Norwegian economy.

2.2 A parametric form for the production technology and the implied labor demand equation

To conduct our analysis, we need a functional form for the production technology. Our objective is to work with a parsimoniously parameterized function of the inputs, allowing ease of interpretation, and consistency with the maintained assumptions over the range of the data. The class of constant elasticity of substitution (CES) production technologies (see Arrow et al. (1961)) seems to have such desirable properties. They involve considerably few parameters, are characterized by elasticities of substitution that are constant, and provide a relatively simple specification that allows us to analyze production in the Norwegian services sector. Moreover, the CES framework is fairly flexible because in addition to the Cobb-Douglas (henceforward CD) model, it also has the fixed proportion (Leontief) and the linear production functions as special cases. Furthermore, a constant elasticity of substitution is not a very restrictive assumption since we are interested in modeling a production function with two input factors and in a two-input technology, the elasticity of substitution is uniquely defined.

An important issue when modeling production is how to integrate technological change whose role is undeniable over time. By assuming it away, we would ascribe the full variation in output per unit of labor to factor substitution, when in fact part of the production is accounted for by technological change. And doing so might overstate the size of the elasticity of substitution. However, the way technological progress formally enters production equations is a matter on which economists frown upon. The option we take is that of a non-neutral technological change affecting both capital and labor[3]. The result is the following function:

$$Y_t = A\left[\delta(e^{\gamma_{kt}}K_t)^{\frac{\sigma-1}{\sigma}} + (1-\delta)(e^{\gamma_{lt}}L_t)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\eta\sigma}{\sigma-1}} \quad (1)$$

where Y_t is output, $0 \leq \delta < 1$ is the share parameter, A can be referred to as the (neutral) efficiency parameter, $\rho = \frac{1-\sigma}{\sigma}$ is the substitution parameter and σ is the elasticity of substitution. And finally, γ_{kt} and γ_{lt} are the current states of technological advance augmenting capital, K_t, and labor (number of hours), L_t, respectively, η the degree of homogeneity.

The labor demand we are interested in concerns the number of workers (N_t), and not the number of hours. So replacing L_t by N_t, the first-order condition (in profit maximization) for labor demand derived from (1) expressed in logs is:

$$n_t = \ln[(1-\delta)\eta]^{\sigma} A^{\sigma-1} + (\sigma-1)\gamma_{nt} + \frac{\sigma(\eta-1)+1}{\eta} y_t^{*} - \sigma(w_t - p_t) \quad (2)$$

where y_t^{*} is the demand addressed to the sector, γ_{nt} is the labor-augmenting technological advance, w_t is the nominal wage per worker and p_t the unit price of output. We clearly see how each parameter in the production function affects the demand for labor. Equation (2) says that labor demand is an increasing function of demand, a negative function of real wages, the impact of technical progress depending on whether the elasticity of substitution is less than 1 or not.

2.3 Specification and Estimation

As they stand, (1) and (2) cannot be estimated at least as long as we haven't specified the role of technical progress. Technological change is broadly defined to include, among other things, new scientific discoveries and inventions. It therefore should be considered as endogenous since those inventions

[3] Acemoglu (2001) discusses various reasons why technological progress can be both capital and labor augmenting in a production function. He also points that a neoclassical production function in which technical change is only labor-augmenting can give misleading answers in comparative statics. However, he reckons that technical change has to be more labor augmenting than capital augmenting.

and discoveries are not independent of market conditions, government policies and R&D activities. However, in many empirical studies, it is assumed to occur exogenously and is either inferred indirectly as a residual in the estimation of the production function, or is represented by linear, piece-wise linear or nonlinear functions of time. The first approach assumes an a priori knowledge of the production possibilities and since the residuals obtained from a regression can be negative as well as positive, it implies that technical progress doesn't have a monotonous impact on production[4]. In this study we have opted for the second approach, in particular we assume that technical progress can be proxied by a time trend. More formally, we assume

$$\varphi_{kt} = \lambda_k t, \quad \varphi_{lt} = \lambda_l t \text{ and } \varphi_{nt} = \lambda_n t$$

with t representing the time trend and λ_k, λ_l and λ_n three constants.

This approach is not without drawbacks. As pointed by Lee et al. (1988), it is devoid of a satisfactory theoretical rationale and is adopted by most researchers as a practical method of dealing with a very difficult problem[5]. Moreover, this method is statistically problematic. The use of time trends in regressions involving integrated stationary processes is subject to important econometric pitfalls. Spuriously detrending integrated series can lead to the inappropriate inference that the trend is significant and detrended random walks can exhibit spurious correlation. As shown by Durlauf and Phillips (1988), even if the coefficient of the trend variable converges to its true value of zero, the distribution of the estimated parameters is non-standard. If the series are trend-stationary, this potentially can justify the introduction of a trend in the regressions where there is not any, in order to filter out the trending effect. But more care is required when introducing a trend in a regression where all the other variables are difference-stationary.

The estimation of (2) doesn't pose major problems since all the parameters of interest can be recovered from a linear estimation of the coefficients of each variable. However, a direct estimation of the CES production function as in (1) is not straightforward. Even when one knows the value of

[4] One may argue for the interpretation of those residuals as the "Solow residual", which is a measure of all influences on output growth rather than the contributions of capital and labor through their marginal products. However, under the assumption of real-business cycles apart from capital and labor, only technological change can influence production (see for instance Romer (2001, pp 181))

[5] This view is shared by other authors too. For instance, Arrow (1962) writes:

> "Now trend projections, however necessary they may be in practice, are basically a confession of ignorance, and, what is worse from a practical viewpoint, are not policy variables".

the elasticity of substitution, ad hoc methods are typically required, and some regressors can be endogenous. Over years, however, a number of researchers have estimated the parameters of the CES production function by applying nonlinear regression procedures directly to the function itself. Examples include Tsurumi (1970), Bodkin and Klein (1967) and Krusell et al. (1997). While these authors use computationally costly methods to estimate the CES model, a profit-maximizing behavior can simplify the estimation procedure (see for instance Maih (2002)).

3 The Central Bank's models

The equations can be found in various editions of the "Technical documentation" and "Rikmodnotats". They include two labor demand equations and two production functions for the manufacturing sector and for the private services sector.

The general form of the equations is an ADL model reformulated as an equilibrium correction model, allowing both for a static long-run solution[6] and short-run dynamics. The core structure of the production functions in both sectors relates output to capital and labor. In the labor demand, real wages enter as a combination of nominal wages, the price of output in the sector and the value added labor productivity. In the manufacturing and construction sector, a nonlinear effect of total unemployment in the whole economy is also included as well as the number of working hours, and a price differential, which presumably captures competition effects. In this equation and contrarily to the private service labor demand equation, the capital stock plays an important role and is negatively related to the demand of workers. Since this study is concerned with the private services sector, we consider the equations more in detail.

3.1 The services supply equation

The current equation for the production of services in RIMINI expresses, in logs, real production (xtv) as a function of real capital stock (ktv), labor measured in terms of the number of hours worked by employees (twtv), but also private consumption (cp), government consumption (co) and other demand factors $\ln(J - JJ + AF)$[7], with long-run solution:

[6] The static long-run solution is derived assuming that in the long-run all the variables level off, so that their changes can be set to zero.

[7] J represents total gross investments in fixed capital, JJ total gross investments in the primary sectors, while AF are total exports less exports of capital, oil, gas, and shipping

$$xtv = const + 0{:}6cp + 0{:}169co + 0{:}454ktv + 0{:}154twtv + 0{:}01 \ln(J ¡ JJ + AF)$$

This formulation of the production function has several drawbacks. First, the private services sector's production function is a hybridized equation involving both demand and supply-side factors as right-hand side variables. The presence of demand-side factors in the production equation is potentially justi…ed by the search of a good …t in the presence of poor measures of capital services. But in any case such a formulation, even if it results in coe¢cients that are signi…cant and correctly signed, is not justi…ed by standard production theory.

Secondly, the net e¤ect of a demand shock on production is di¢cult to assess. Not only would such a shock also a¤ect labor demand, but in addition, the production function as it stands has the curious implication that output can increase in the long-run even if the number of hours worked or the capital stock doesn't change.

Thirdly, another implication of a hybridized production function is that there is no consideration with respect to the degree of homogeneity. If the amount of all the inputs is doubled, say, its hard to think of any reason why production should not double.

Fourthly, if the production of services is labor intensive, as is the stylized fact in the services economics literature, then one would expect the labor input elasticity to be greater than what is implied by the current production function. In addition, the elasticity in question is less than that of the manufacturing sector.

Lastly, although production is aggregated over all the private services sector, both private and public consumption are measures over the entire economy and the number of hours worked doesn't include the self-employees in the private services production.

3.2 The labor demand equation for services

The current speci…cation of labor demand expresses the number of wage earners in the private service production (nwtv) as a function of private consumption expenditures (cp), mainland gross investments (jf), public consumption expenditures (co), hourly wage costs (wctvj), the consumer price index (cpi) and the valued added labor productivity in the sector (zytv) with long-run solution:

services.

$$nwtv = const + 0.318cp + 0.240(jf + co) - 0.268(wctvj - cpi - zytv)$$

The following insufficiencies can be listed out for the current specification of the labor demand equation: a) cp jf and co proxy for demand but they represent the demand both for services and goods; b) There's no (explicit) consideration as to the degree of substitution between capital and labor; c) It is not clear how labor demand relates to the production function; d) wctvj, which represents the hourly wage costs is not the relevant wage cost when it comes to modeling the demand for the number of workers. What is needed instead is the quarterly wage costs per employee.

The RIMINI equations seem to exploit the available data, institutional knowledge in combination with economic theory. However, apart from their positive drawbacks spelled out above, they might suffer from sample dependence. For instance, extending the estimation period say, might well lead to the rejection of some variables as insignificant. If we take this seriously, tightly embodying such transient features in a model, not only results in spurious estimates, but can also lead to serious forecast failure since it biases the correct responses of the relevant variables. Also important and underpinning those equations the is view that they are conditioned on potentially endogenous regressors. In order to circumvent these drawbacks, two options are possible: The first one is to re-adapt the models by dropping insignificant variables and adding significant ones so as to have a good fit for the sample under consideration. The second option is to try and improve the theory behind the estimated equations. An obvious problem with the former approach is how to select the variables to include. This study is an attempt at the latter.

4 Re-specification of the models and empirical analysis

The re-specification of the Central Bank models involves dropping the variables that are not buttressed by production theory and including those that potentially are. So we proceed with the models presented in (1) and (2). We assume that the production function is homogenous of degree 1 with respect to capital and the number of hours and that the elasticity of substitution is equal to 1. That is we have a constant returns to scale technology and the production function is Cobb-Douglas[8]. In Maih (2002) we test both assumptions and cannot reject them. The long run production function expressed in logs becomes:

$$y_t = \ln A + (\alpha\lambda_k + (1-\alpha)\lambda_l)\,t + \alpha k_t + (1-\alpha)\,l_t \tag{3}$$

In this specification, there's an equivalence of Hicks and Harrod neutralities meaning that technological progress neither uses nor saves any input. Therefore we cannot identify the separate effects of technological progress (λ_k and λ_l). The parameters $\ln A$, $(\alpha\lambda_k + (1-\alpha)\lambda_l)$, and α can be estimated jointly.

Alternatively, under an assumption of profit maximization, we need to take account of the decision equations (first order conditions) implied by the CD production function:

$$(y-k)_t = -\ln\alpha + (r-p)_t \tag{4}$$

$$(y-l)_t = -\ln(1-\alpha) + (w-p)_t \tag{5}$$

In that case the parameter α is estimated in a first step. In the second step the obtained value is imposed in equation (3) for the estimation of the remaining parameters.

But those two first order conditions can also be written differently, so as to allow a simultaneous estimation of the production function and the decision equations. Then the system to estimate is:

$$\left\{\begin{array}{lcl} y_t & = & \ln A + \alpha k_t + (1-\alpha)\,l_t + \lambda t \\ (r-p)_t & = & \ln(\alpha A) - (1-\alpha)\,k_t + (1-\alpha)\,l_t + \lambda t \\ (w-p)_t & = & \ln[(1-\alpha)\,A] + \alpha k_t - \alpha l_t + \lambda t \end{array}\right. \tag{6}$$

As for the labor demand equation, it becomes

$$n_t = \ln[(1-\alpha)\eta]^{\sigma} A^{\frac{\sigma-1}{\eta}} + (\sigma-1)\lambda_n t + \frac{\sigma(\eta-1)+1}{\eta} y_t^{*} - \sigma(w_t - p_t) \tag{7}$$

[8] This, however, doesn't necessarily hold for the labor demand equation in (2). This is because the number of hours is likely a better measure of labor input than the number of workers. Holding everything else constant, a change in the number of hours would induce a change in production without necessarily involving a change in the number of workers. Hence, doubling the amount of capital and number of hours is likely to induce more production than just doubling the number of workers. Also, the elasticity of substitution between capital and hours will be different from the elasticity between capital and workers.

4.1 The data

With some key coefficients having a wrong sign, we failed to consistently estimate a sensible long-run model of production over the full sample 1966(1)-2001(3). There might have been structural breaks and other unknown factors, the ignorance of which presumably is in part responsible for such a problem. That's why we restricted our attention to a shorter sample of quarterly and seasonally unadjusted data covering the period 1979(1) to 2001(3).

Figure (2) contains full sample time plots of the main variables in logs and their annual growth rates. There are two main features of these data: first the series are dominated by positive trends; secondly the Norwegian economy has experienced a recession between the end of the eighties and the beginning of the nineties, which is apparent from a visual look at the plots. But a much closer look at the variables shows four major patterns:

- First, while production, the number of hours worked and the number of workers increase sharply until about the middle of the eighties whereupon they accelerate until the end of 1987 or so, the growth rate of capital remains fairly the same.
- Secondly, during the recession period all the variables but capital went down. Instead of decreasing as would have been expected, capital virtually came to a standstill.
- Thirdly, the volatility of both production and the number of hours are of about the same magnitude and seem constant throughout the sample period.
- Fourthly, capital has the lowest volatility and its growth rate seems not to have a well defined mean. If this is true, then a direct consequence is that the orders of integration of capital and the other variables are likely to be different.

In summary, the main descriptive features of these data are (1) a rapid growth in all the variables, (2) a recession from the end of the eighties to about the mid nineties, and then (3) the beginning of a new expansion.

4.1.1 Transformations and constructions

In order to estimate our models, we need data on: output (Y_t) and its price (P_t), real labor services (number of hours worked, L_t) and their unitary cost

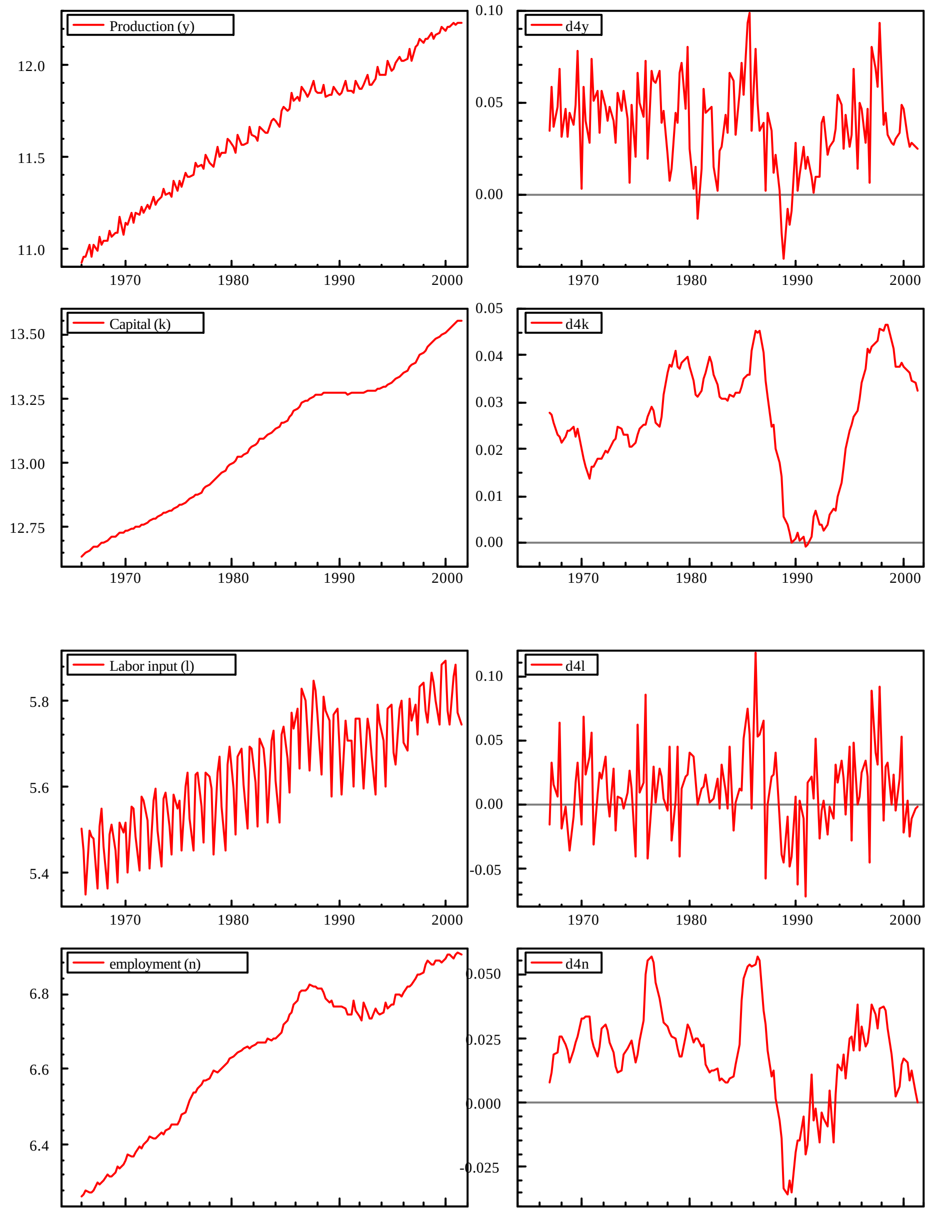

Figure 2: Variables in levels (logs on the left) and annual growth rates (on the right)

(W_t), real capital services (K_t) and the rental price of capital (R_t), and real labor demand (number of workers, N_t) and its unitary cost ($\tilde{W}_t$). But the transition from theory to empirics is not straightforward. The quality of the data is not always good and some assumptions have to be made about unobserved variables. In other words, theoretical variables, unfortunately, need not have obvious definitions in terms of the observables. For instance we have proxied technological advance by a time trend. Here we continue to try and bridge the gap between the variables in our theory universe and those in our data universe. Originally we had observations on output both in real and nominal terms, the capital stock, labor services, hourly wage costs, the number of wage earners, the average number of hours worked by each of them during a quarter. Those data are drawn from the RIMINI database and they aggregate two sub-sectors in the private services. The first sector (called sector 06) includes, banks and insurances, electric power, domestic communications, housing services and private houses, other private services production and lastly indirectly measured bank and finance services. The second sector (called sector 12) is essentially Trade. Our focus is on the private sector of the services, where there's presumably (at least) a domestic competition. We assume that those observations are accurate and that the unobserved capital services can be proxied by the capital stock.

The way we construct the rental price of capital and the (quarterly) wage costs per employee illustrate the fact that the bridges between theory and data are not unique. In constructing our bridges, we try to provide justification for them with reference to our theory and the related empirical work. Those links are therefore the means by which the results of econometric estimations and tests will become interpretable. In particular, we would like to interpret our models as describing the behavior of rational and optimizing agents. In that connection, although the rental price of capital is usually proxied by the interest rate, in this study we use Euler's theorem and assume equality in full competitive equilibrium of the acquisition price of an asset and the discounted value of its services. It follows that the capital rental price can be computed as, $R_t = \frac{1}{K_t}(P_tY_t - W_tL_t)$[9]. Finally, the series for the quarterly wage costs per employee $\tilde{W}$ is computed as the product of W and an estimated average number of working hours. See Appendix A for further details on the construction of the variables and their sources.

[9] This measure has been used in the literature by authors like Berndt (1976) and Antras (2001). In our view, it captures the rental price of the whole stock of capital installed over years, not only the price of new capital goods (investments) as the interest rate would. And we assume that this relationship holds exactly in the long-run.

Table 1: Augmented Dickey-Fuller tests for the levels, 1979(1)-2001(3)

Variable	lag length	τ_μ	τ_δ
y	6	$-$	-2.536
k	5	$-$	-3.339
l	6	-1.588	-2.526
n	5	$-$	-3.564^*
p	6	-2.976^*	-1.414
r	4	-3.734^{**}	-1.344
w	4	-1.822	-1.647
$y-k$	5	$-$	-2.440
$y-l$	6	$-$	-4.109^{**}
$k-l$	6	0.1012	-2.451
$r-p$	4	-1.325	-2.397
$w-p$	5	$-$	-2.127

4.1.2 Time series properties

The econometric literature emphasizes the need to establish the time series properties of the data to use in econometric modeling in order to ensure that statistical inference is valid. So a natural point to start from, before formally looking at the relationships among the variables, is the integration properties of the series. The analysis we did above and the plots of the time series for capital, labor and production reveal potential nonstationarities. In what follows, we use simple "Augmented Dickey-Fuller" (hereinafter ADF) tests to investigate the hypothesis that our series are integrated of order one (or possibly two), against the alternative that they are stationary. The ADF test includes lags of the series under consideration in order to capture any serial correlation in the disturbances. The results obtained from these tests are informative to judge the validity of the estimation techniques that will be used subsequently.

The critical values for the test are directly implemented in PcGive 10.1. and for the selection of the lag length, we retain the highest significant lag, which in most, but not all, cases corresponds to the lag that minimizes the Akaike information criterion (AIC).

The plots of some to the variables indicate that most of the variables are non-stationary and this is confirmed by Table 1 and 2, which report

Table 2: Augmented Dickey-Fuller tests for the first and the second differences, 1979(1)-2001(3)

Variable	lag length	τ_μ	Variable	lag length	τ_μ
Δy	6	-4.053^{**}	$\Delta(y-l)$	6	-6.418^{**}
Δk	5	-2.014	$\Delta(k-l)$	6	-4.622^{**}
Δl	6	-3.655^{**}	$\Delta(r-p)$	6	-5.679^{**}
Δn	6	-2.439	$\Delta(w-p)$	4	-4.361^{**}
Δp	5	-3.187^{*}	$\Delta^2 k$	6	-4.044^{**}
Δr	4	-3.215^{*}	$\Delta^2 n$	4	-5.737^{**}
Δw	3	-2.788	$\Delta^2 w$	6	-7.212^{**}
$\Delta(y-k)$	6	-4.974^{**}	$\Delta^2 p$	5	-6.267^{**}

a summary of the ADF tests we carried out. τ_μ refers to the case where the only deterministic variable included is the constant, whereas τ_τ includes both the constant and the time trend. The critical values corresponding to our sample size for τ_τ are -3.46 and -4.06 at 5 and 1% levels of significance respectively. Likewise, the critical values for τ_μ are -2.89 and -3.50 at 5 and 1% respectively. The tests results show that the variables at hand are well represented as $I(1)$ or $I(2)$ processes. The $I(2)$-ness of some series can be discussed. As nicely put by Patterson (2000, pp 270), $I(2)$ series appear smoother and more slowly changing than $I(1)$ series and a log-transformed series, which is $I(2)$, will have an $I(1)$ growth rate. As a consequence shocks to the series will result in persistence in the growth rate and levels of the series. This seems to be the case for hourly wage costs, output price, employment (in numbers) and capital. Wages and prices often increase in a progressive way. It is visible from the plots that employment increases much faster than it decreases, this might be due to the cost of firing workers. As for capital, capital stock series are usually constructed by cumulating investment data. Formally, $K_t = (1-\delta)K_{t-1} + I_t$, which says that the current capital stock is the sum of investments (I_t) and a proportion $(1-\delta)$ of the capital stock from the previous period. δ is the rate of depreciation of capital. As argued by Everaert (2000), slow depreciating assets (δ very small) make the contribution of investments to the capital stock long lasting and thereby introduce a near unit root in the first differences of capital stock series. There's a qualification to make however. Combining $I(2)$ with $I(1)$ variables we should find that the result is an $I(2)$ variable. But as a surprise, all such combinations seem to be I(1). With this evidence, we will treat all the non-stationary variables as I(1) for the moment.

All in all, from the results of the ADF tests we see that most of the variables follow similar trends. In this case, using the OLS estimates of the parameters of the models at hand might lead to the so-called spurious regression problem (see for instance Phillips (1986)). Those estimates will be inconsistent unless (a) a linear combination of the dependent and the independent variables is I(0) or (b) lagged values of both endogenous and exogenous variables are part of the regression , or (c) all I(1) variables are differenced prior to estimation (See for instance Hamilton (1994, pp 561-562)) or, (d) a Cochrane-Orcutt adjustment for first-order serial correlation of the residuals is employed[10].

We also argued above that the regressors in (1) and (2) could be endogenous, but in order to make valid inferences about the parameters of interest we need a framework within which they are at least weakly exogenous[11]. The stochastic feature of the variables in those equilibria implies that the equilibrium adjustment can come from any of them or several of them at the same time, which means that an equilibrium in itself doesn't tell us anything about the direction of causality. A direct implication is that an estimation of such equations by OLS in presence of endogenous regressors will confound the hypothesized causal relationships and lead to misrepresentations of the underlying dynamic characteristics.

All these considerations point to the adoption of cointegrating methods and possibly a systems approach in order to accommodate the possibility of there being multiple cointegrating vectors among non-stationary variables. Such a framework, which allows, as a by-product, for the test of weak exogeneity is discussed below.

---

[10] The Cochrane-Orcutt procedure is asymptotically equivalent to differencing because as the sample size grows, the AR(1) coefficient goes in probability to 1 (cf. Blough (1992))

[11] Let $F_x(x_t;\theta)$ be a density function for a variable x_t, which can be factorized into a conditional density, $F_{y|z}(y_t|z_t;\lambda_1)$ of a variable y_t given another variable z_t, and a marginal density $F_z(z_t;\lambda_2)$, where $\theta \in \Theta$ is the parameter vector for the joint process, $\lambda_1 \in \Lambda_1$ are the parameters of the conditional model and $\lambda_2 \in \Lambda_2$ are the parameters of the marginal model. Two conditions have to be satisfied for weak exogeneity to hold (see for instance Ericsson and Irons (1994)):

1. $\psi = f(\lambda_1)$: the parameters of interest can be expressed uniquely in terms of the parameters of the conditional density.
2. λ_1 and λ_2 are variation-free: λ_1 is free to assume any value in Λ_1, irrespective of the values taken by λ_2 in Λ_2.

4.2 The statistical model

Having characterized on theoretical grounds the set of possible long-run equilibrium relationships[12] among the variables, we now adopt statistical models that are capable of representing these relationships as equilibria, as well as providing a description of the short-run movements out of equilibrium. The baseline statistical models must also be capable of representing the time series characteristics of the data, and so in the light of the descriptive analysis of the previous sections, unless otherwise noted we will model our equations in a cointegrated VAR (vector autoregression), whose estimation is done by means of the maximum likelihood procedure developed by Johansen (1988) and Johansen (1991).

The procedure begins with a VAR in which the variables are at most I(1) and determines the number of cointegrating vectors in a system where the variables of interest are endogenized. If the variables to be modelled cannot be well represented as a multivariate linear process then the VAR will not be congruent, and thus will exhibit signs of mis-specification. Were this to be the case, reformulation of the model through either extension of the information set, variable transformation or/and inclusion of intervention dummies, conditioning on weakly exogenous variables, possibly would enable the reformulated system to be well characterized by a VAR.

More specifically, for k lags on a I(1) vector of n variables X_t in a fully endogenized system, the corresponding VAR[13] is:

$$X_t = \tau + \sum_{i=1}^{k} A_i X_{t-i} + \Psi d_t + \Lambda^* t + \varepsilon_t$$

with $\varepsilon_t \sim IN_n(0; \Omega)$ and $t = 1; 2; ...; T$

where $[A_i]_{i=1}^{k}$ are $n \times n$ matrices of autoregressive coefficients, τ a vector of n constants, Ψ is an $n \times n_d$ matrix of coefficients of event-specific dummies, Λ^* is a $n \times 1$ vector of coefficients on the deterministic trend, and ε_t is a vector of n unobserved errors which have a zero mean and constant variance-covariance matrix Ω. With some algebraic manipulations, the above equation can be rewritten as:

[12] The appellation of long-run relationships or long-run equilibria derives from the fact that they act as attractors towards which convergence occurs whenever there are (significant) departures therefrom. In nonlinear cointegration analysis, the rate of convergence is proportional to the distance away from equilibrium.

[13] A good treatment of VAR modeling can be found in Hayashi (2000, chapter 10). For a more detailed exposition, see Hamilton (1994, chapter 20).

$$\Delta X_t = \tau - \left(I_n - \sum_{i=1}^{k} A_i \right) X_{t-1} + \sum_{i=1}^{k-1} \left(- \sum_{s=i+1}^{k} A_s \right) \Delta X_{t-i} + \Psi d_t + \Lambda^* t + \varepsilon_t$$

Since X_{t-1} is the only level term in the equation, assuming that X_t is a vector of I(1) variables, then $\left(I_n - \sum_{i=1}^{k} A_i \right)$ is the only matrix containing information about the long-run relationships among the variables. Denote by r, the rank of the long-run matrix. There are three possible cases: If $r = n$, all the variables are I(0), meaning that they are stationary. The second case when $r = 0$ implies that Δx_t is I(0), or put another way, that all the variables are difference stationary (integrated of order 1). The third case is when $0 < r < n$, implying that the long-run matrix has reduced rank.

When r is known and provided that we are in the third case, the next step is to reparameterize the equation above as a vector equilibrium correction mechanism (VEqCM):

$$\Delta X_t = \tau + \alpha\beta' X_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta X_{t-i} + \Psi d_t + \Lambda^* t + \varepsilon_t \qquad (8)$$

where $\alpha\beta' = -\left(I_n - \sum_{i=1}^{k} A_i \right)$ and $\Gamma_i = -\sum_{s=i+1}^{k} A_s$, with α and β being $n \times r$ matrices of rank r. Then there are r independent linear combinations (cointegrating vectors) of the variables $\beta' X_t$ which are trend-stationary (when $\Lambda^* \neq 0$) or simply I(0) (when $\Lambda^* = 0$), and the matrix α measuring the speed of adjustment towards the long-run equilibrium. Under those conditions, there is no stochastic trend remaining in equation (8) and the system is said to be in the I(0) space. Since the model assumes no quadratic trend behavior in any of the endogenous variables, the trend can be restricted to the cointegrating space[14] by letting $\Lambda^* = -\alpha\Lambda$, where Λ is a $r \times 1$ vector. Taking the expectation of equation (8), we can decompose τ as $\tau = \left(I_n - \sum_{i=1}^{k-1} \Gamma_i \right) \gamma - \alpha(\mu - \Lambda)$, such that vector X_t has expected unconditional growth rate $E(\Delta X_t) = \gamma$ (a $n \times 1$ vector) and an expected long-run solution $E\left(\beta' X_t\right) = \mu + \Lambda t$ (a $r \times 1$ vector), which is the empirical counterpart of all the long-run solutions derived earlier. Then we can reformulate equation (8) in a VEqCM as:

$$\Delta X_t - \gamma = \alpha \left(\beta' X_{t-1} - \Lambda (t-1) - \mu \right) + \sum_{i=1}^{k-1} \Gamma_i (\Delta X_{t-i} - \gamma) + \Psi d_t + \varepsilon_t$$

[14] This will be the case throughout the paper.

Identification restrictions are required to ensure uniqueness of α and β. When correctly specified, this model is in the I(0) space so that inference concerning its parameters of interest (¿; ®; ¡ i; ª; ¤¤; -) can be conducted using conventional procedures. The rank r has to be determined empirically, and the the maximum likelihood procedure adopted in this study is implemented in PcGive 10.1.

As known from elementary econometrics, statistical inference is sensitive to the validity of the assumptions (parameter non-constancy, serially-correlated residuals, residual skewness, excess kurtosis, etc.) underlying the estimation methods. In particular, the Johansen procedure requires the parameters of the VAR to be constant. So testing for parameter constancy has an important role to play in warranting a valid application of the procedure. Therefore, we will often present the results of parameter constancy, by means of recursive estimation and Chow tests, as a prelude to the application of that method. Finally, we know, following King et al. (1991), that in a n-dimensional system with r cointegrating relations, $n - r$ common stochastic trends determine the long-run behavior of the variables.

4.3 Cointegration analysis of production

In this subsection, two models for the estimation of the parameters of the production function are presented. The reason for doing this is that even if the models are accepted by the data, they still need to be interpreted both statistically and economically. The model we retain in the end will then be the one that satisfies all the requirements imposed by production theory and the stylized facts on service economics, and the estimation method.

4.3.1 System estimation of the production function

In prelude to a system cointegration analysis of production, the appropriate lag order of the VAR, whose hypothesized long run solution is given by equation (3), had to be determined. To do so, the unrestricted VAR was estimated starting with a relatively long lag-length (6 lags), jointly with a time trend, three (centered) seasonal dummies (CS) and one event-specific dummy id971($-$2)[15]. Subsequently, system specification tests (not reported) were applied to assess whether some lags and non-significant variables could be eliminated. The results of these tests pointed to a reduction of the system to 5 lags. A possible hypothesis for the explanation of why the simplification

[15] This step dummy, which takes values 1 in the first quarter of 1997 and -1 in the second quarter, corresponds to the time when the Norwegian Kroner is allowed to float.

doesn't go further down is that the full capacity of production is not used as from the first period and it takes time for that capacity to adjust to its equilibrium.

Table 3 diagnoses the statistical adequacy of the maintained specification with univariate and multivariate mis-specification tests, with the associated p-values given in square brackets. The included statistics are: single equation residual standard deviations $\hat{\sigma}$, pth order serial autocorrelation AR(p), heteroskedasticity Hetero, qth-order autoregressive conditional heteroskedasticity ARCH(q), normality test statistics; and their system versions when enough degrees of freedom are available[16]. From these diagnostics we conclude that the system is congruent. The system is also stable from the recursive constancy tests, not reported in order to save space. The simplified VAR obtained could thus be used as a basis to derive a reduced model in terms of the growth rates of the variables. The same table also reports the results for the cointegration rank test, which unambiguously is 1, both by the max and the trace test, as the hypothesis that $r \leq 0$ is rejected, confirming what the theory suggests.

Next, we determine the equilibrium relationship and the associated feedback coefficients.

$$eqcm = y - 4.3221 - \underset{(0.1082)}{0.1801}k - 0.8199l - \underset{(0.0004)}{0.0047}t \qquad (9)$$

The equilibrium correction mechanism in (9) implies that the role of capital in production relatively low. The interpretation is that only 18% of a relative change in production is attributable to capital, the rest of the contribution of input factors being explained by the number of hours worked. This figures seem more plausible than those of the services production function in RIMINI, and in line with what would be expected from a labor intensive production process.

$$\hat{\alpha}' = \left[\underset{(-)}{0} \quad \underset{(-)}{0} \quad \underset{(0.2524)}{1.3736}\right] \qquad (10)$$

The three over-identifying restrictions of constant returns to scale, of no feedback from a deviant supply behavior onto both capital and production (see (10)) are not rejected from the results of the LR test ($\chi^2(3) = 2.0102$ [0.5703]). This means that production and capital are weakly exogenous for the determination of the number of hours. The weak exogeneity of production suggests that it is demand-driven, rather than being impulsed by the input factors as one could have thought. Instead, demand decides the level

[16] See Hendry and Doornik (2001) for further details.

Table 3: Diagnostic statistics of the unrestricted VAR and cointegration statistics for the system estimation of the production function

	Diagnostic tests				
	¾	AR(p)	Normality	ARCH(p)	Hetero
y	0.0149	1.4066 [0.2334]	0.6810 [0.7114]	1.4162 [0.2389]	0.6941 [0.8533]
k	0.0018	1.5323 [0.1919]	0.8406 [0.6568]	2.4479 [0.0553]	0.9092 [0.6058]
l	0.0222	1.1992 [0.3194]	0.1931 [0.9079]	0.8788 [0.4818]	0.6074 [0.9239]
System		1.1613 [0.2486]	3.1905 [0.7846]		0.6749 [0.9970]
	Cointegration rank determination				
r	0	1	2	3	
log lik	934.4902	950.5982	959.1892	961.5485	
1		0.29814	0.17206	0.050532	
Trace	[0.002]**	[0.146]	[0.642]		
Max	[0.004]**	[0.102]	[0.644]		

of production and inputs have to adjust in order to satisfy demand. In fact, with a slow-moving capital, all the adjustment seems to come from the number of hours worked, correctly signed but with an implausible magnitude of 1.37. The interpretation is that in one quarter, the number of hours adjusts more than proportionally to a short run disequilibrium in the production. And since the adjustment is more than enough what is needed, the system never comes back to equilibrium. What is the way forward?

In Maih (2002) we argue that this is due to the fact that we mistakenly treated capital as I(1), although the ADF tests revealed it is I(2). We also claim that a combination of and I(2) and an I(1) variable, although it is I(2), can behave as I(1) if in the sample period under consideration, changes in the I(2) variable are completely swamped by those in the I(1) variables, in which case the ADF test has low power. This is the case for the combination of capital with other variables as we saw in the results of the unit root tests. As mentioned earlier, the Johansen maximum likelihood procedure requires that all the variables in the system at hand be at most I(1). The procedure is weakened in power in presence of higher order processes.

4.3.2 Simultaneous estimation of the production function and the decision equations

One way to get around the problem above is to relax the assumption of $I(1)$-ness of capital made earlier and motivate the use of $(k - l)$ as the regressor in order to have a more balanced system that the Johansen procedure can handle. There's another benefit from this strategy, and this is the reduced dimensionality of the system obtained thereof. So we express the production function as deviation from labor, and this time we also take account of the fact that producers are likely to be profit maximizers. We then reparameterize (6) as

$$\begin{cases} (y - l)_t = \ln(A) + \delta(k - l)_t + \varepsilon_t \\ (r - p)_t = \ln(\delta A) - (1 - \delta)(k - l)_t + \varepsilon_t \\ (w - p)_t = \ln(1 - \delta) A + \delta(k - l)_t + \varepsilon_t \end{cases}$$

We found in Maih (2002) that the real rental price of capital was weakly exogenous for the estimation of the parameters of both labor and capital demand equations. This implies that the system can be reduced further by conditioning on the real rental price of capital. The estimation of this system started with 5 lags in both the endogenous variables, and the (exogenous) real rental price of capital together with a trend (restricted to the cointegrating space), three centered seasonal dummies and two impulse dummies (id86q3[17] and id971(-2)). The system reduced to four lags, the impulse dummies, the trend and the third centered seasonal is congruent as table 4 shows. There is no sign of mis-specification and the recursive constancy statistics in figure 3 also show that the system is recursively stable[18].

Under the assumption weak exogeneity of some regressors with respect to the modeled variables, the likelihood ratio test of Johansen is not appropriate for the determination of the number of cointegrating vectors. Harbo et al. (1998) have studied the asymptotic distribution of the cointegrating parameters in partial systems and provided their critical values. Those

---

[17] id86q3 corresponds to the devaluation of the Norwegian Kroner in May 1986, following oil prices falls. This period is also associated with labor market conflicts and expensive wage settlements.

[18] The tests successively presented in this figure are: The 1-step residuals, showing that almost all the residuals lie within their anticipated $0 \pm 2\hat{\sigma}_t$ confidence interval; the recursive log-likelihood scaled by the sample size; the 1-step Chow tests (1-step forecast tests or 1up Chow tests), which exhibits an outlier for the real hourly wage equation in about 1994 (9th graph), which is also marginally reflected in the system version of the test (graph 10) but without being significant; the break point Chow tests (or N↓ or Ndn Chow tests) ; and the forecast Chow tests (are also called N↑).

Table 4: Diagnostic statistics of the unrestricted VAR for the estimation of the production per hour

	σ	AR(p)	Normality	ARCH	Hetero
$(y - l)$	0.0157	0.7321 [0.6020]	0.4856 [0.7844]	0.7382 [0.5695]	0.701 [0.8360]
$(k - l)$	0.0227	0.59044 [0.7072]	0.3218 [0.8514]	0.2601 [0.9024]	0.6198 [0.9061]
$(w - p)$	0.0133	0.50730 [0.7697]	0.9216 [0.6308]	0.4342 [0.7834]	0.8959 [0.6146]
System		1.1790 [0.2297]	7.2894 [0.2949]		0.7033 [0.9914]

values are a function of the number of exogenous variables, the number of endogenous variables, the rank of the long-run matrix and the LOS. We choose 5% as the LOS[19]. As table 5 shows, the hypothesis that the rank is zero is rejected, suggesting that **b** = 1 is appropriate. But looking at the roots of the companion matrix, we see that under that assumption there's a unit root remaining in the system, which is not the case when **b** = 2. So we proceed under the assumption that **b** = 2.

Table 6 shows the resulting equilibria together with the associated feedback coefficients. The first equilibrium relationship can be interpreted as a fixed proportion (Leontief-type) production function in one factor, namely the number of hours, with productivity increasing through technical progress at a rate of 0.55 percent per quarter. The second relationship seems to indicate that the capital stock adjusts to labor, depending on the rental price of capital. This means that although capital doesn't explicitly appear in the production function, it does play a role. If production is weakly exogenous for the estimation of the number of hours as argued above, this model says that exogenous factors (presumably demand) drive the number of hours, which in turn defines the amount of capital to use in a production process in which capital services and labor input seem indistinguishable.

There's no feedback onto production per hour consecutively to a disequilibrium in the first relationship. A positive disequilibrium (production per hour greater than its long-run value) will lead to a decrease in real wages

[19] The critical values are from table 2 in Harbo et al. (1998).

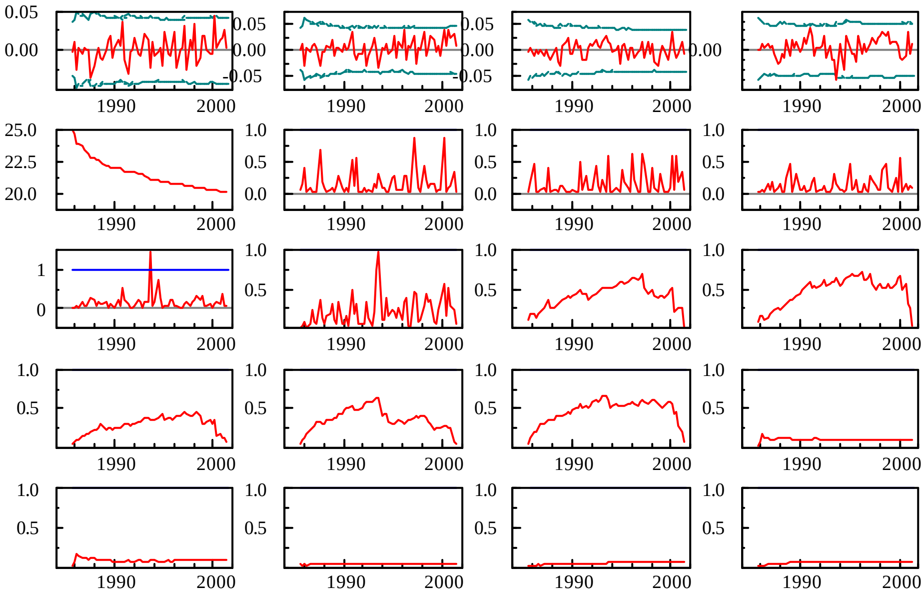

Figure 3: Recursive constancy statistics for the I(1) estimation of the production function

and an increase in capital per hour. The increase in capital per hour might seem counter-intuitive but we know that capital moves slowly (I(2)-ness of capital), suggesting that the adjustment will be done through a change in the number of hours[20]. In other words, the number of hours worked will go down. This implicitly says that labor demand should not be modeled as exogenous.

When the real rental price of capital is above its long-run value, production per hour will decrease at a rate of 35%, while capital per hour will decrease at a rate of about 70% per quarter, rather fast adjustment and in this case it is probably a combination of both a decrease in the capital stock and an increase in the number of hours. As a result, real wages have to increase (by 27%) as well.

Notice that the cointegrating vectors could have been derived in a less fancy way, just looking at the results of the ADF tests. First, we remember

[20] Of course, there could also be a labor hoarding e¤ect, a situation in which …rms cyclically hold ‡uctuating stocks of idle labor to smooth out the number of hours as output varies. But this e¤ect remains undetected in this model with a slow-adjusting capital.

Table 5: Cointegration statistics for the estimation of the production function per hour

r	0	1	2	3
λ		0.2277	0.1694	0.1114
Trace	51.160 *	27.648	10.752	
95%	49.6	30.5	15.2	

rank	6 highest roots of the companion matrix					
unrestricted	0.9043	0.8766	0.8766	0.8314	0.8314	0.7999
1	1.000	1.000	0.8733	0.8733	0.8294	0.8201
2	1.000	0.8774	0.8774	0.8429	0.8429	0.8278

that $(y - l)$ is trend-stationary. This implies that $\delta = 0$ in our system of equations. But then the second structural equation implies that $(k - l)_t$ has coefficient -1 and since $(w - p)_t$ is not trend-stationary, its equation is not identified.

Figure 4 shows the cointegrating vectors (panels 1 and 2) and the recursive graphics (panels 3, 4, 5) for this estimation of the production function. The first cointegrating vector corresponds to the production function and we see that its pattern is not affected by shocks to the Norwegian economy, which confirms that the trend in $(y - l)$ is not a stochastic trend, but a deterministic one. This finding further lends support to our results. Furthermore, the six implied over-identifying restrictions are not rejected, either calculated for the full estimation sample ($\chi^2(6) = 2.8567\ [0.8266]$) or recursively as shown in panel 5.

The results of Full Information Maximum likelihood (FIML) estimation, reported in table 7, are statistically acceptable and economically interpretable. They present the short-run dynamics for production per hour, capital per hour and real wages. The first equation says that positive changes in capital per hour decrease production per hour, an outcome which appears to conflict with production theory. But we know that changes in capital per hour are mainly changes in the number of hours, so that we can think of a positive change in capital per hour as a negative change in the number of hours. Then with a minus sign, we see that this leads to an increase in production per hour. The growth of production per hour is primarily affected by changes in the interest rate and then the growth rate of production per hour the quarter before, suggesting a low degree of persistence.

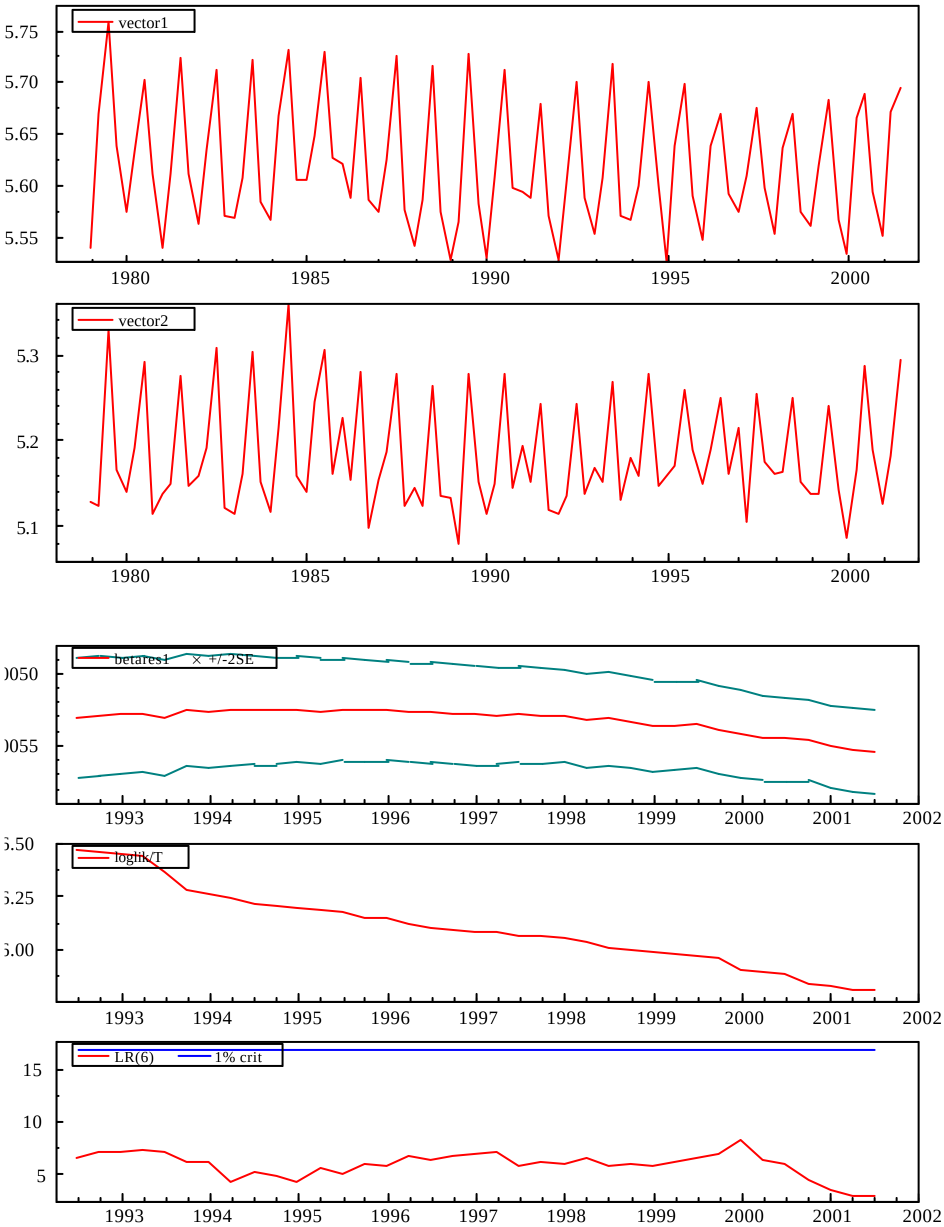

Figure 4: Cointegration vectors and recursive stability analysis for the production equation

Table 6: Equilibria and adjustment coefficients

Equilibria			
$eqcm1 = (y - l)_t - \underset{(0.0001)}{0.0055}t - 5.6004$			
$eqcm2 = (r - p)_t + (k - l)_t - 0.0055t - 5.1667$			
Feedbacks			
α_i	$(y - l)$	$(k - l)$	$(w - p)$
$i = 1$	$\underset{(-)}{0}$	$\underset{(0.0793)}{0.2732}$	$\underset{(0.1427)}{-0.4545}$
$i = 2$	$\underset{(0.0915)}{-0.3515}$	$\underset{(0.1403)}{-0.6969}$	$\underset{(0.1161)}{0.2701}$
LR test of over-identifying restrictions			
$\chi^2(6) = 2.8567$ [0.8266]			

The equation for production per hour is well specified and has a relatively small standard error (1.6%).

Secondly, positive past changes in production per hour increase capital per hour, whereas positive changes in real hourly wage costs depress it. And again, if capital is slow-moving the adjustment is done through an increase in the number of hours. The equation for capital per hour has a standard error of 2.3%.

Thirdly, increases in real wages are associated with positive changes in production per hour, negative changes in capital per hour and in the real rental price of capital. The equation for real wages has a standard error of 1.25%.

Finally, the diagnostic statistics for the system are given in the same table. All in all, there are no signs of mis-specification as the tests clearly show. The reduced model imposes 21 over-identifying restrictions, that are not rejected by the LR test ($\chi^2(21) = 15.766$, with p-probability 0.7827). All these outcomes suggest that the system of reduced equations is sound. The models track the (past) behavior of production per hour, capital per hour and real wages pretty well as can be seen in figure 5.

4.3.3 Dismissal of alternative specifications

Due to the well-known low power of the unit root test used which revealed the I(2)-ness of capital, we "jumped the gun" in Maih (2002) and estimated

Table 7: Reduced model for the production function

$$\begin{aligned}
\Delta(y-l)_t &= \underset{(0)}{0.0144} - \underset{(0.0445)}{0.3203}\,eqcm2_{t-1} - \underset{(0.0548)}{0.471}\,\Delta(y-l)_{t-1} \\
&\quad - \underset{(0.0363)}{0.3544}\,\Delta(k-l)_{t-2} - \underset{(0.0506)}{0.2915}\,\Delta(k-l)_{t-3} + \underset{(0.0029)}{0.6372}\,\Delta(r-p) \\
&\quad + \underset{(0.039)}{0.2805}\,\Delta(r-p)_{t-1} + \underset{(0.0105)}{0.05494}\,CS_{t-2} + \underset{(0.0047)}{0.0179}\,id86q3 \\
&\quad + \underset{(0.0108)}{0.0377}\,id971(-2) \\
\Delta(k-l)_t &= \underset{(0)}{0.01547} + \underset{(0.0719)}{0.3051}\,eqcm1_{t-1} - \underset{(0.0854)}{0.6828}\,eqcm2_{t-1} \\
&\quad + \underset{(0.1)}{1.034}\,\Delta(y-l)_{t-2} + \underset{(0.116)}{0.3376}\,\Delta(y-l)_{t-3} - \underset{(0.0554)}{0.5008}\,\Delta(k-l)_{t-1} \\
&\quad - \underset{(0.087)}{1.218}\,\Delta(k-l)_{t-2} - \underset{(0)}{0.6305}\,\Delta(k-l)_{t-3} - \underset{(0)}{0.2521}\,\Delta(w-p)_{t-2} \\
&\quad - \underset{(0.0654)}{0.6551}\,\Delta(r-p)_{t-2} - \underset{(0)}{0.2761}\,\Delta(r-p)_{t-3} + \underset{(0)}{0.08504}\,CS_{t-2} \\
&\quad + \underset{(0)}{0.0586}\,id971(-2) \\
\Delta(w-p)_t &= \underset{(0)}{0.01175} - \underset{(0)}{0.4972}\,eqcm1_{t-1} + \underset{(0.131)}{0.3131}\,eqcm2_{t-1} \\
&\quad + \underset{(0.00266)}{0.9418}\,\Delta(y-l)_{t-1} + \underset{(0)}{0.7464}\,\Delta(y-l)_{t-3} - \underset{(0.28)}{0.556}\,\Delta(k-l)_{t-1} \\
&\quad - \underset{(0.188)}{0.5406}\,\Delta(k-l)_{t-3} - \underset{(0.0695)}{0.8194}\,\Delta(w-p)_{t-1} - \underset{(0.0827)}{0.2112}\,\Delta(w-p)_{t-2} \\
&\quad - \underset{(0.0687)}{0.4734}\,\Delta(w-p)_{t-3} - \underset{(0.0133)}{0.6637}\,\Delta(r-p)_{t-1} - \underset{(0)}{0.3625}\,\Delta(r-p)_{t-3} \\
&\quad + \underset{(0)}{0.057}\,id86q3
\end{aligned}$$

	$\Delta(y-l)$	$\Delta(k-l)$	$\Delta(w-p)$
$\hat{\sigma}$	0.016	0.0231	0.0125

System diagnostics

AR 1-5 test: $F(45,181) = 0.9321$ [0.5979]

Normality : $\chi^2(6) = 9.1605$ [0.1648]

Hetero: $F(204,233) = 0.6248$ [0.9997]

LR test $\chi^2(21) = 15.766$ [0.7827]

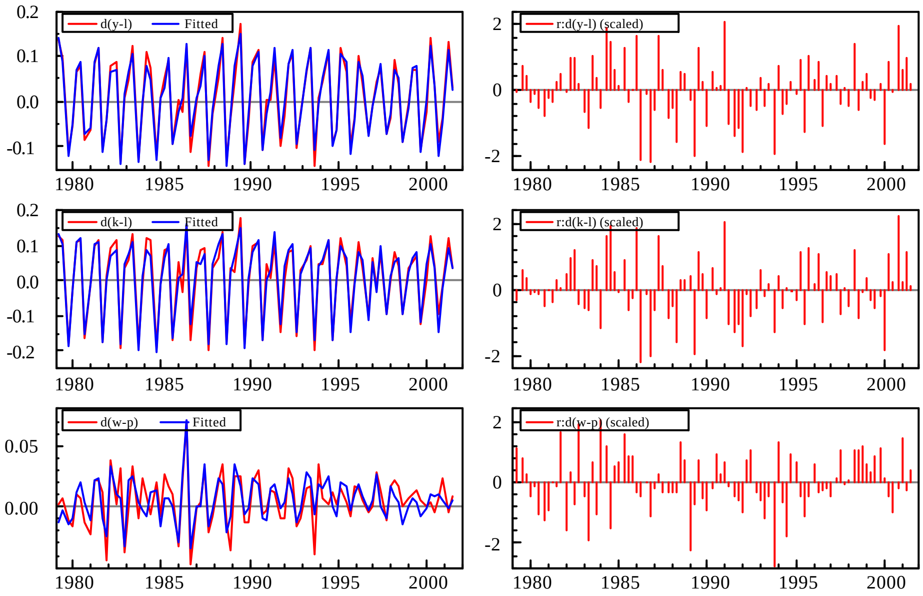

Figure 5: Graphical statistics for the …nal model of the production function

several other alternative models for the production function:

A model of production in a single equation framework Modeling production in a single equation in addition to unrealistically treating labor input as weakly exogenous still implies a more important role of capital than labor in the production process.

Estimation of the system in (6) This simultaneous estimation of the production function and the decision equations gives an unstable VEqCM, whose spurious results, due to di¤erent orders of integrations of the variables, cannot be interpreted.

4.4 Single-equation equilibrium correction model for labor demand

The long-run solution for labor demand was derived in equation (7). But we are also interested in the dynamics of the adjustment towards equilibrium. So we allow for capital to in‡uence labor demand at least in the short run. Having included capital as a potential factor in‡uencing labor demand, we are now in presence of two potential I(2) variables in the same equation. However, we leave an I(2) cointegration analysis for future research. Moreover, there's an intuitive argument why the number of workers could be I(1) instead of I(2): This is simply that if labor input measured in terms of hours cointegrate with production as found earlier, so should the number of workers because a high amount of production has to be satisfied by a high amount of working hours which can only come about if the number of workers is sufficient. Therefore if production is I(1), so should the number of workers. This might of course depend on the time frame. In the very long-run the number of workers can be considered as I(1). Juselius (1999) argues that the order of integration of a variable is not a general property of an economic variable but rather a convenient statistical approximation to distinguish between short, medium and long-run variation in the data.

We also model production as weakly exogenous. The reason for this is that production was found to be weakly exogenous for labor demand (number of hours, see (10)). Another argument can be provided. By their nature, services are non-storable, which suggests that all the services produced are consumed and again pointing to a demand-driven production. The econometric implication of these assumptions is that a labor demand equation can be estimated conditioning on production, capital, and the real rental price of capital.

But since we estimate an ADL model, this is not enough because we haven't said anything about real wages. From the tests of restrictions for the cointegrated VAR in table 6, we showed that the equilibrium equation for real hourly wage costs was not identified. This suggests that some extra information is needed for finding the determinants of those. For that reason we also treat it as weakly exogenous. Nymoen (1991) provides a more formal discussion of wage models for the Norwegian economy, which is beyond the scope this paper. We therefore don't pursue that discussion further.

We started the estimation of the labor demand equation with relatively long lags (7 lags) in all the variables, a time trend, three centered seasonal dummies and two impulse dummies id91q3 and id92q3. Reparameterized in an equilibrium correction, and after deletion of non-significant lags, we obtained the following long-run solution:

$$n^* = -5.5863 + 1.157y - 0.2249(wc - p) - 0.005t \qquad (11)$$

Equation (11) expresses the long-run level of employment as a positive function of demand (here production), a negative function of real wages and a negative function of technical progress. This equation should be interpreted in the light of (7). We see that the elasticity of substitution between the capital stock and the number of workers is 0.2249, which is significantly lower than unity, suggesting that a production function where inputs are the capital stock and the number of workers is not a CD. The degree of homogeneity of the underlying production function is 0.8316 ($\approx \frac{0.2249-1}{0.2249-1.157}$), which is also below unity implying that the assumption of constant returns to scale accepted earlier is not maintained when the labor input considered is the number of workers. Looking at the coefficient for the time trend, technical progress occurs at a rate of 0.645% ($\approx \frac{-0.005}{0.2249-1}$) per quarter, both suggesting that it has a very low impact on the efficiency of workers and supporting the idea of a low-productivity growth in the production of services. This outcome is in tune with the stylized facts of the literature on service economics[21]. Worth noticing as well, capital doesn't play any role in the demand for workers in the long run.

Looking at the short-run dynamics, we can see from table 8 that about 33% of an excess demand for labor in one quarter is recouped in the next quarter. Changes in the number of workers affect labor demand only after four quarters (a year) and the effect is positive. The short-run chief mover of labor demand seems to be capital: a 1% increase in the capital stock in the current period leads to an immediate increase in labor demand by 1.09%[22]. While current changes in the capital stock have a positive effect on the demand for labor, a noteworthy outcome is that their effect becomes negative after four quarters. This result indicates that while an increase in the capital stock for the current period will lead to an immediate increase in the demand for labor, the effect will be reversed after a year. Increases in real wages typically depress the demand for labor as expected.

All the diagnostics (see table 8) are favorable to the current specification, the standard error for the equation is rather small ($\hat{\sigma}$ = 0.5%) and as can be seen from figure 6, the model fits the data pretty well and its coefficients are fairly stable.

[21] It is often argued that productivity in the services grows more slowly than that of the manufacturing sector. But this idea also finds opponents like Baumol (1985) who claims that services are too heterogenous to lend themselves to such generalizations, and some services "to an extraordinary degree" permit innovation and productivity growth.

[22] As mentioned above capital doesn't play any role in the long-run. Its role is implicitly captured by production, following the derivation of the labor demand equation in (2). This feature is easily accepted by the data, and implies a separability between capital and labor in the production function.

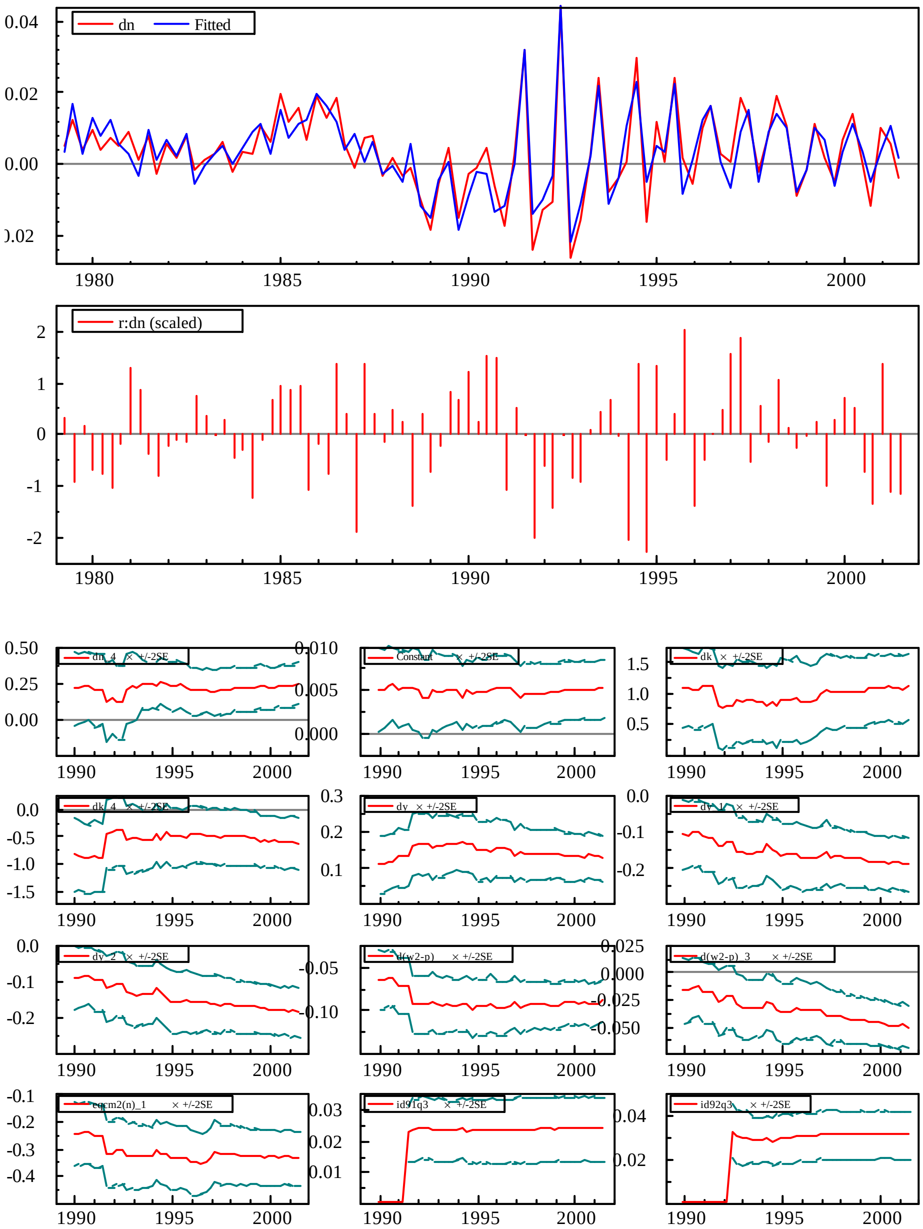

Figure 6: Fitted and residuals and recursive parameter estimates (+/- 2 s.e.) for the labor demand equation

Table 8: ADL estimation of labor demand

$$\begin{aligned}\Delta n_t = {} & \underset{(0.0017)}{0.0051} - \underset{(0.0509)}{0.3359}[n - n^*]_{t-1} + \underset{(0.0727)}{0.2381}\Delta n_{t-4} + \underset{(0.272)}{1.087}\Delta k_t \\ & - \underset{(0.235)}{0.6453}\Delta k_{t-4} + \underset{(0.0313)}{0.1235}\Delta y_t - \underset{(0.0366)}{0.1925}\Delta y_{t-1} - \underset{(0.0334)}{0.1886}\Delta y_{t-2} \\ & - \underset{(0.0121)}{0.0901}\Delta (wc - p)_t - \underset{(0.01)}{0.0512}\Delta (wc - p)_{t-3} + \underset{(0.0051)}{0.024}\, id91q3 \\ & + \underset{(0.0054)}{0.0311}\, id92q3\end{aligned}$$

Diagnostic statistics	
$\hat{\sigma}$ = 0.0049	AR 1-5: F(5,73) = 0.9812 [0.4352]
R^2 = 0.8456	ARCH 1-4: F(4,70) = 1.037 [0.3944]
DW =2.12	Normality: $\chi^2(2)$ = 0.683 [0.7107]
T=90 [1979Q1-2001Q3]	Hetero: F(20,57) = 0.705 [0.8045]
	RESET: F(1,77) = 0.0319 [0.8587]

5 Comparative performance through encompassing tests

Now that we have selected models that can represent output supply and labor demand behaviors for the Norwegian private services, it is important as a test to see whether our models can account for the results of rival explanations, in RIMINI, of the same phenomena, given that those explanations are also accepted by the data. This is a loose the definition of encompassing, and the minimum requirement for a model to be a useful contender is that it is non-dominated by its rivals. Encompassing can be conducted at three levels of analysis (see Hendry (1995, pp 509-511)): specification, mis-specification and selection, but here we focus on the first level. In order to nail down the discussion about the most appropriate specifications, several tests found in the literature can be used. However, we restrict ourselves to only few of them: the Cox (1961) test of variance encompassing (distributed $N[0;1]$); the Ericsson (1983) instrumental variables test of variance encompassing (distributed $N[0;1]$); the Sargan (1958) test for the restricted reduced form, which is implicitly defined by projecting the dependent variable on all the unmodeled variables encompassing test (another IV-based test $\chi^2(\cdot)$-distributed); and the traditional F-test, which tests whether each model encompasses their union. We use the notation, $M_1 \,\mathcal{E}\, M_2$, to say that model M_1 encompasses model M_2. We reestimate all

Table 9: Encompassing tests for the production function

	$(P_0)\ \mathcal{E}\ (P_4)$		$(P_4)\ \mathcal{E}\ (P_0)$	
Test	Distribution	p-val & p-prob	Distribution	p-val & p-prob
Cox	N(0,1)	-16.64 [0.0000]**	N(0,1)	-5.508 [0.0000]**
Ericsson IV	N(0,1)	8.066 [0.0000]**	N(0,1)	4.321 [0.0000]**
Sargan	$\chi^2(9)$	68.239 [0.0000]**	$\chi^2(7)$	43.811 [0.0000]**
Joint Model	F(9,73)	40.222 [0.0000]**	F(7,73)	12.625 [0.0000]**
$\hat{\sigma}_{P_0} = 0.0126$		$\hat{\sigma}_{joint} = 0.0055$		$\hat{\sigma}_{P_4} = 0.0078$

the models over the sample period 1979Q1-2001Q3.

5.1 Encompassing tests for the production function

The short-run model for production in RIMINI, estimated over 1978q1-1998q4, is the following:

$$\begin{aligned} \Delta y_t &= -3.090 - 0.799 y_{t-1} + 0.499 cp_t + 0.144 co_t \\ &\quad + 0.012 \ln(J - JJ + AF)_t + 0.335 k_{t-1} + 0.122 twtv_t \end{aligned} \tag{P_0}$$

The implementation of the test is not easy for the production function since our preferred equation was estimated in a system whereas the RIMINI production equation was estimated in a single-equation framework. In order to be able to perform the tests, we extract the equation corresponding to production per hour from our system and rewrite it as:

$$\begin{aligned} \Delta y_t &= const + 1 \cdot \Delta l_t - a_1 eqcm2_{t-1} - a_2 \Delta (y - l)_{t-1} \\ &\quad - a_3 \Delta (k - l)_{t-2} - a_4 \Delta (k - l)_{t-3} + a_5 \Delta (r - p)_t + a_6 \Delta (r - p)_{t-1} \\ &\quad + a_7 CS_{t-2} + a_8 id86q3 + a_9 id971(-2) \end{aligned} \tag{P_4}$$

where the coefficient for Δl_t is constrained to be equal to 1. This ensures that we have the same left-hand side variable. We reestimate (P_0), the RIMINI model, by adding the impulse dummy $id971(-2)$ to assuage the problems with the diagnostic tests. In the sample period analyzed the variable $\ln(J - JJ + AF)_t$ becomes insignificant.

The results for the encompassing tests are given in table 9 and (P_4) is our preferred equation. As emphasized in Hendry (1995, pp 518) and Hendry and Doornik (2001, pp 165), a model must variance-dominate its rival as a necessary condition for encompassing. That is because the better fitting-model clearly explains some aspects better than its rival. However, this is not a sufficient condition for encompassing, given that the rival model could still explain part of what the preferred model cannot. This is illustrated by the tests results, which show that the preferred equation has a lower standard deviation than RIMINI's, but doesn't encompass it in any of the tests. Nevertheless, the rejection of the hypothesis $(P_0)\ \mathcal{E}\ (P_4)$ is stronger than $(P_4)\ \mathcal{E}\ (P_0)$, looking at the p-values which are much smaller in the second case. We have argued that (P_0) doesn't have the structure of a production function, but that doesn't explain why it proves hard to beat on empirical grounds. In fact, the finding that production is likely demand-driven suggests that (P_0) expresses demand as a function of its components.

5.2 Encompassing tests for the labor demand equation

The current labor demand equation for private services in RIMINI was estimated over 1972q1-1998q4 and is as follows:

$$
\begin{aligned}
\Delta_4 nwtv_t = {} & -0.452 + 0.425\,\Delta_4 nwtv_{t-1} + 0.361\,[\Delta_4 nwtv_{t-1}(1 - sd89q4)] \\
& + 0.121\,\Delta cp_{t-1} + 0.170\,\Delta_2 cp_{t-2} + 0.061\,\Delta cp_{t-4} \\
& - 0.175\,\Delta\,[0.5\,(RS_{t-3} + RS_{t-4}) - 0.25\,\Delta_4 pytv_{t-3}] \\
& - 0.197 nwtv_{t-4} + 0.062 cp_{t-4} + 0.047\,(jf + co)_{t-4} \\
& - 0.053\,(w - cpi - zytv)_{t-4} + 0.028 id91q3 - 0.019 id92q2
\end{aligned}
$$

It doesn't take into account the self employed as we have done in our estimation of the labor demand equation. But the encompassing tests can only be done for the same left-hand side variable as mentioned earlier. Another problem is that the RIMINI model for labor demand was estimated with annual changes. In order to circumvent those problems, we modified the equation above as

$$
\begin{aligned}
\Delta n_t = {} & a_0 + a_1 \Delta n_{t-1} + a_2 [\Delta n_{t-1}(1 - sd89q4)] + a_3 \Delta cp_{t-1} \\
& + a_4 \Delta_2 cp_{t-2} + a_5 \Delta cp_{t-4} - a_6 \Delta\,[0.5\,(RS_{t-2} + RS_{t-1}) - \Delta pytv_{t-1}] \\
& - a_7 n_{t-1} + a_8 cp_{t-1} + a_9 (jf + co)_{t-1} - a_{10} (w - cpi - zytv)_{t-1} \\
& + a_{11} id91q3 - a_{12} id92q2
\end{aligned} \qquad (N_0)
$$

where nwtv is replaced by n, annual changes are transformed to quarterly changes, the level variables lagged for one period instead of four, the cost of capital adjusted to reflect a quarterly price.

In table 10, (N_1) represents our preferred labor demand equation. In the column for $(N_0)\ \mathcal{E}\ (N_1)$ we see that all the tests are significant, meaning

Table 10: Encompassing tests for the labor demand equation

	(N_0) " (N_1)		(N_1) " (N_0)	
Test	Distribution	p-val & p-prob	Distribution	p-val & p-prob
Cox	N(0,1)	-30.66 [0.0000]**	N(0,1)	-1.802 [0.0715]
Ericsson IV	N(0,1)	14.27 [0.0000]**	N(0,1)	1.618 [0.1056]
Sargan	$\chi^2(10)$	59.739 [0.0000]**	$\chi^2(11)$	7.7313 [0.7372]
Joint Model	F(10,67)	23.188 [0.0000]**	F(11,67)	0.67015 [0.7614]
$\hat{\sigma}_{N_0} = 0.0099$		$\hat{\sigma}_{joint} = 0.005$		$\hat{\sigma}_{N_2} = 0.0049$

that the RIMINI labor demand equation doesn't encompass our preferred equation. On the other hand, the column for (N_1) " (N_0) shows that our model for labor demand encompasses RIMINI's. The conclusion is that (N_0) is inferentially redundant and (N_1) remains undominated. And in addition, (N_1) parsimoniously encompasses (N_0) since it even explains the results of a joint model of both.

6 Concluding remarks

In concluding we would like to summarize our findings and then briefly evaluate them in a much broader perspective. Next, we will give a few directions for future research before closing down with a brief discussion of the implications of our results for policy-making.

The parameters of the Norwegian production function of services are not easy to estimate due to the sluggish movements of the capital stock and more specifically the role of capital in the production process is not clear. This however, doesn't mean that capital is unimportant. It seems reasonable to think of capital services as a function of labor input. Were this to be true, it would not be surprising to find that, controlling for technical progress, the production of services can almost entirely be explained by the amount of time workers spend working. In any case, the result that the supply process is labor intensive is strongly qualified and corroborates the stylized facts in the literature on services economics. Our findings also support the hypothesis of an exogenous production and consequently that of an endogenous demand for labor, the estimation of which shows that the elasticity of substitution between the number of workers and the capital stock is significantly lower than unity.

Our selection of the variables to include in our analyses, as well as the models used were entirely theory-based. We implicitly assumed that the theory is correct at the risk to see our results suffer from theory-dependence and induce evanescent evidence. There is very little in our theory that endows it with veracity so that the credibility of the equations presented depends on how credible the theory presented itself is. We didn't eschew from the theory when it came to empirical implementation just for the sake of having a good fit. Nonetheless, the models performed well and in some cases performed significantly better than their contestants in RIMINI, without being beaten in any criterion by any of them. With respect to the production function, we argued that production should be estimated in a system, but the superiority of system estimates over single equation methods is debatable. For instance, if our purpose is to predict production for given quantities of inputs, the single equation approach is likely to yield the best results. The results could be even better if demand-side variables are included just to increase the fit. This strategy seems not recommendable because in an extended sample the model can easily break down as we saw with RIMINI's production function of services. This result lends support to the idea that fit is not a sufficient criterion for importance. Nevertheless, Hendry (1995, pp 504) warns us that rejection is not final nor corroboration definitive.

A good deal of work remains to be done before one will fully understand all the mechanisms behind the production of services in Norway. If several arteries suggest themselves for future research, they all boil down to bridging the gap between economic theory conjecture and econometric modeling. The theory could be improved so as to allow a joint estimation of both the production function and the labor demand equation over the full sample available. But this, of course, passes by a good apprehension of the data and in particular better measures of both capital services and technical progress need to be constructed. Furthermore, since production is demand-determined, the model needs to be supplemented with a pricing equation reflecting monopolistic competition. Finally, the observation that employment increases much faster than it decreases suggests something of a nonlinearity, an asymmetric adjustment that could be handled by the plethora of nonlinear models developed in the literature[23].

Distinct but still related issues give an added impetus to furthering the study of the Norwegian supply of services. As mentioned earlier, the environment in which both policymakers and agents used to base their decisions

[23] See Van Dijk et al. (2001) for a survey of smooth transition autoregressive models.

has changed, to the extent that services are tradable, the years to come are likely to witness a …erce competition from service industries from abroad. One may want to see how far the …ndings presented here hold, to assess the extent to which Norwegian services are still sheltered from international competition and how fast that competition erodes the margins of domestic producers.

With respect to the policy implications, the most important question seems to be: how realistic are the equations presented and can they be used as a base for the formulation of economic policies? To this, we answer that the theory we used is sound, the estimates we got are both sensible and stable and the short-run and long-run dynamics are well characterized in our framework. While we haven't given conclusive answers to the problems we set out to solve, signi…cant progress has been made. For instance, if we haven't managed to explain the role of capital in the long-run, at least we know that labor plays a prominent role in the production process and therefore should be treated as such.

References

Acemoglu, D. (2001). Labor and capital-augmenting technical change. mimeo, MIT.

Antras, P. (2001). Is the u.s. aggregate production function cobb-douglas? new estimates of the elasticity of substitution. mimeo, MIT.

Arrow, K. J. (1962, June). The economic implications of learning by doing. The Review of Economic Studies 29(3), 155–173.

Arrow, K. J., H. B. Chenery, B. S. Minhas, and R. M. Solow (1961). Capital-labour substitution and economic e¢ciency. The Review of Economics and Statistics vol. 43 (3), 225–250.

Baumol, W. J. (1985). Productivity policy and the service sector. In Managing the Service Economy: Prospects and Problems, pp. 301–317. Cambridge University Press.

Berndt, E. (1976). Reconciling alternative estimates of the elasticity of substitution. The Review of Economics and Statistics 58(1), 59–68.

Biørn, E. (2000). Økonometriske emner. Oslo: Unipub forlag.

Blough, S. R. (1992). Spurious regressions, with ar(1) correction and unit root pretest. Mimeo, John Hopkins University.

Bodkin, R. G. and L. R. Klein (1967). Nonlinear estimation of aggregate production functions. The Review of Economics and Statistics 49 (1), 28–44.

Cox, D. R. (1961). Tests of separate families of hypotheses. In U. of California Press (Ed.), Fourth Berkeley Symposium on Mathematical Statistics and Probability, Volume 1, pp. 105–123.

Doornik, J. A. and D. F. Hendry (2001). Modelling dynamic systems using PcGive, Volume 2. London: Timberlake Consultants Ltd.

Durlauf, S. N. and P. C. B. Phillips (1988). Trends versus random walks in time series analysis. Econometrica 56 (6), 1333–1354.

Ericsson, N. R. (1983). Asymptotic properties of instrumental variables statistics for testing non-nested hypotheses. Review of Economic Studies 50, 287–303.

Ericsson, N. R. and J. S. Irons (1994). Testing Exogeneity. Advanced Texts in Econometrics. Oxford University Press.

Everaert, G. (2000). Balanced growth and public capital - an empirical analysis with i(2)-trends in capital stock data. Working paper 97, Faculty of Economics and Business administration, Ghent University.

Hamilton, J. D. (1994). Time Series Analysis. Princeton: Princeton University Press.

Harbo, I., S. Johansen, B. Nielsen, and A. Rahbek (1998, October). Asymptotic inference on cointegrating rank in partial systems. Journal of Business and Economic Statistics 16(4), 388–452.

Harrington, J. W. and B. Warf (1995). Industrial Location: Principles, Practice and Policy. Routledge.

Hayashi, F. (2000). Econometrics. Princeton: Princeton University Press.

Hendry, D. F. (1995). Dynamic Econometrics. Advanced Texts in Econometrics. Oxford University Press.

Hendry, D. F. and J. A. Doornik (2001). Empirical econometric modelling using PcGive (Vol. 1). London: Timberlake Consultants Ltd.

Heshmati, A. (2000). Productivity growth, e¢ciency and outsourcing in manufacturing and services industries. SSE/EFI Working Paper Series in Economics and Finance 394, Stockholm School of Economics.

Howells, J. (2000, August). Innovation and services: New conceptual frameworks. Discussion Paper 38, Centre for Research on Innovation and Competition (CRIC).

Johansen, S. (1988). Statistical analysis of cointegration vectors. Journal of Economic Dynamics and Control 12, 231–254.

Johansen, S. (1991). Estimation and hypothesis testing of cointegration vectors in gaussian vector autoregressive models. Econometrica 59 (6), 1551–1580.

Julius, D. (1998, November). In‡ation and growth in a service economy. Quarterly bulletin, Bank of England.

Juselius, K. (1999). Models and relations in economics and econometrics. Journal of Economic Methodology 6(2), 259–290.

King, R. G., C. I. Plosser, J. H. Stock, and M. W. Watson (1991, September). Stochastic trends and economic ‡uctuations. American Economic Review 81(4), 819–840.

Krusell, P., L. E. Ohanian, J.-V. Ríos-Rull, and G. L. Violante (1997, September). Capital-skill complementarity and inequality: A macroeconomic analysis. Research Department Sta¤ Report 239, Federal Reserve Bank of Minneapolis.

Lee, K., M. Pesaran, and R. Pierse (1988). Aggregation bias and labor demand equations for the u.k. economy. Working Paper 492, UCLA.

Maih, J. (2002, August). Modeling production and employment in the norwegian private services. Master's thesis, Department of Economics, The University of Oslo.

Miozzo, M. and L. Soete (1999, August 30 to September 2). Internationalisation of services: A technological perspective. Paper prepared for the 3rd International Conference on Technology Policy and Innovation.

Nymoen, R. (1991). A small linear model of wage and price in‡ation in the norwegian economy. Journal of Applied Econometrics 6(3), 255–269.

Patterson, K. (2000). An Introduction to Applied Econometrics: A Time Series Approach. Macmillan Press Ltd.

Phillips, P. C. B. (1986). Understanding spurious regressions in econometrics. Journal of Econometrics 33, 311–340.

Roach, S. S. (1991, September-October). Service under siege - the restructuring imperative. Harvard Business Review, 82–91.

Romer, D. (2001). Advanced Macroeconomics. McGraw-Hill.

Sargan, J. D. (1958). The estimation of economic relationships using instrumental variables. Econometrica 26, 393–415.

Tsurumi, H. (1970). Nonlinear two-stage least squares estimation of ces production functions applied to the canadian manufacturing industries, 1926-1939, 1946-1967. The Review of Economics and Statistics 52 (2), 200–207.

Van Dijk, D., T. Teräsvirta, and P. H. Franses (2001). Smooth transition autoregressive models - a survey of recent developments. SSE/EFI Working Paper Series in Economics and Finance 380, Stockholm School of Economics.

A Data description and variable list

The data are quarterly seasonally unadjusted for the period 1979(1) to 2001(3). For all variables, lower case letters denote the natural logarithm of the upper case variable. The real variables have base year 1997.

Y : Real Production. Output in private service production, fixed base year prices. Mill. NOK. RIKMOD sectors 06 and 12. Source: Quarterly National Accounts (QNA).

K : Capital stock. Stock of fixed capital in private service production, fixed base year prices. Mill. NOK. RIKMOD investment sector 06. Source: NA, KVARTS. Macro:

L : Labor input. Man-hours by employees and self-employed in private service production. Including overtime and absence from work due to vacation, sick leave etc. Also influenced by calendar effects. Mill. hours. RIKMOD sectors 06 and 12. Source: KVARTS.

N : Employment. Total employment (employees and self-employed) in private service production. 1000 persons. Sum RIKMOD sectors 06 an 12. Source: KVARTS.

W : Hourly wage costs. Hourly wage costs in private service production. NOK. RIKMOD sectors 06 and 12. Source: KVARTS.

P : Output Price. Nominal price of output in the private service production, computed as the ratio of $LXTV$ over Y $\left(P = \frac{LXTV}{Y}\right)$.

R : Nominal rental price of capital $\left(= \frac{LXTV - W \cdot L}{K}\right)$, where $LXTV$ is the output in private service production at current prices (Mill. NOK. RIKMOD sectors 06 and 12. Source: QNA.)

$\hat{W}$: Estimated quarterly wage costs per employee. The following demarche was used to construct a series for $\hat{W}$. The total wage cost supported by the private service sectors in one quarter is $W \cdot L$. But $L = N \cdot FHTV$, where $FHTV$ is the average number of hours worked by each employee during a quarter. So we can write $W \cdot L = (W \cdot FHTV) \cdot N = \overline{W} \cdot N$, where $\overline{W}$ is the average quarterly wage costs per employee. If $FHTV$ were exogenous and independent of N, one could simply use it to calculate $\overline{W}$ and then use this series to estimate the labor demand equation. However, $FHTV \equiv \frac{L}{N}$. So we have to correct for a potential endogeneity problem by finding a proxy $\widehat{FHTV}$ for $FHTV$. Fortunately we have a series NH, which is the normal number of working hours for blue and white collar workers in the manufacturing sector. We assume that this number of hours will not be very different from the one in vigor in the private services or put differently, the number of working hours in the private services will hover around NH. Therefore, we calculate $\widehat{FHTV}$ as the fitted value from an ADL regression of $FHTV$ on a constant, centered seasonal dummies and present and past values of $NHM = 0.012 \times NH$, since NH is given in terms of the number of hours per week and $FHTV$ is expressed in terms of 10^3 hours[24]. We then compute $\widehat{W}$, the implied proxy for $\overline{W}$, as $\widehat{W} = W \times \widehat{FHTV}$.

Other transformations For any variable X_t, $x_t = \log(X_t)$; $\Delta x_t = (x_t - x_{t-1})$; $\Delta^2 x_t = (\Delta x_t - \Delta x_{t-1})$

[24] The equation was estimated over the sample 1967Q2-2001Q3 and the following solution obtained:

$$\begin{aligned}\widehat{FHTV} = & -\underset{(0.0678)}{0.1943}FHTV_{t-1} + \underset{(0.0476)}{0.3104}FHTV_{t-3} + \underset{(0.0635)}{0.4309}FHTV_{t-4} \\ & +\underset{(0.0632)}{0.2911}FHTV_{t-5} + \underset{(0.164)}{0.7747}NHM_t - \underset{(0.17)}{0.6544}NHM_{t-2} \\ & -\underset{(0.0049)}{0.03877}CS_{t-2}\end{aligned}$$