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Klaus Mohn

Modelling Regional Producer Behaviour
– A Survey

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Abstract

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Departing from theoretical principles of duality between production technology and costs, this study provides some suggestions on how to address regional aspects in empirical analyses of producer behaviour. Having established some general properties of the translog cost function, it is illustrated how dummy variable techniques may be applied to incorporate various regional technological characteristics into an integrated empirical model. The model is then used to illustrate and discuss different specifications of producer behaviour.

The first elements to be integrated in the regional framework are technological change, productivity growth, and spatial features. Different sources of regional productivity growth are discussed, and their measurement in the regional econometric cost function is then considered.

Second, the attention is drawn towards problems concerning measurement and modelling of regional labour demand. Regional labour markets have some special characteristics that require special attention. These include labour heterogeneity, differents forms of rigidity, and adjustment costs. The significance of these aspects is discussed within the dual approach to regional producer behaviour.

Third, regional investments and capital formation is introduced, largely motivated by the need for a framework to analyze regional producer behaviour in the long run. This provides a tool for empirical analysis of the links between public policy, investment incentives and the process of industrial localization.

Finally, the implications of sluggishly adjusting input demands are adressed within the regional cost function approach. As both labour and capital may be viewed as quasi-fixed, a dynamic approach is required for analyses of the different adjustment mechanisms. However, the technology of adjustment may also vary systematically from region to region. Two approaches are presented and compared in the treatment of dynamic factor demands.

Keywords: Regional producer behaviour, econometric modelling, cost functions.

JEL Classification: R30, D21, C50.

Sammendrag

Klaus Mohn

Modellering av regional produsentatferd – En litteraturoversikt

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Denne studien gjennomgår en del forslag til økonometrisk modellering av regionale aspekter i empiriske analyser av produsentatferd. Utgangspunktet er teoretiske prinsipper om dualitetsforholdet mellom produksjonsteknologi og kostnadsstruktur. Det illustreres hvordan dummyvariabler kan tas i bruk for å ivareta regional variasjon i ulike typer teknologiske karakteristika. Translog-modellen tjener som referanseramme for å kaste lys over ulike økonometriske spesifikasjoner av regional produsentatferd.

Først diskuteres teknisk framgang, produktivitetsvekst og regionale karakteristika. Ulike kilder til regional produktivitetsvekst blir gjennomgått, for deretter å bli inkludert i den regionale kostnadsfunksjonen.

Deretter fokuseres oppmerksomheten på problemer vedrørende måling og modellering av de regionale sysselsettingsmekanismene. Regionale arbeidsmarkeder har egenskaper som fortjener spesiell oppmerksomhet. Dette gjelder ulike former for heterogenitet, rigiditet og tilpasningskostnader. Disse aspektene diskuteres også innenfor den duale tilnærmingen til produsentatferd.

Regionale investeringer og kapitaldannelse bringes siden eksplisitt inn i analysen. Motivasjonen er et behov for et verktøy som kan benyttes for å analysere mer langsiktige forhold når det gjelder regional produksjonsvirksomhet. Resultatet er modeller som kan benyttes for å beskrive samspillet mellom offentlig politikk, investeringer og den kontinuerlige lokaliseringsprosessen med utgangspunkt i observerte data.

Til slutt ses produksjonsteknologi og faktoretterspørsel i et intertemporalt perspektiv, og dynamikk og justeringskostnader diskuteres innenfor rammen av regionale kostnadsfunksjoner. Ettersom tilpasningen av arbeidskraft og realkapital er kjennetegnet ved tregheter, trenges det dynamiske modellrammer for eksplisitte analyser av faktortilpasningen. I tillegg bør modellrammen tillate regional variasjon i forhold knyttet til justering og tregheter i faktormarkedene. To forskjellige tilnærminger presenteres og sammenlignes under behandlingen av dynamiske regionale faktormarkeder.

Emneord: Kostnadsfunksjoner, produsentatferd, regionaløkonomi, økonometri.

Contents

1. Introduction*

For most countries, the analysis of economic behaviour has an important, but somewhat neglected, *regional* dimension. Economic relations are likely not to be invariant to spatial characteristics. Therefore, empirical analyses of these problems should be of interest not only to economists who want insight regarding the general mechanisms of economic behaviour, but also because regionally unstable economic relationships have important policy implications. For example, the response of regional employment to economic policy measures will depend on the wage elasticity of labour demand, a parameter which may well vary over the regional dimension.

During the last years, the general activity in the Research Department of Statistics Norway has revealed an increasing interest in empirical studies of economic behaviour. The macroeconomic models now include econometric equations describing a great variety of behavioural relationships. Further, micro data has been applied to strengthen the tools of analysis for econometric investigation of microeconomic consumer and producer behaviour. The results of the micro-econometric research has proved useful, for isolated analysis of selected problems, as well as for the general macroeconomic modelling.

To some extent, this trend has had spill-overs also to regional economic analysis. In developing the regional model REGARD (cf. Mohn et al. (1994)), econometric equations are implemented to describe the industrial demand for labour, and to characterize the social and economic determinants of regional migration. Concerning producer behaviour, the estimated dynamic labour demand equations in REGARD has brought some new insights into the functioning of regional labour markets (see Mohn (1992, 1993)). During the formulation of REGARD, aggregate regional time series data were used to estimate error-correction models for labour demand, embodying an underlying stationary Cobb-Douglas technology. Both the quality of the data and the model specification leave room for significant

* I should like to express my gratitude to Tor Jakob Klette and Nils Martin Stølen, in particular, for extremely helpful comments to earlier versions of the study.

improvements. Thus, the limitations of this analysis still dominate, and the need for further research is urgent.

As for the microeconometric research activities in general, the role of future regional analyses of producer behaviour are twofold. First, this type of analysis may serve as a useful tool for partial investigation of selected regional problems. Examples are studies of regional employment, and optimal regional policies, concerning the real-world variety of regional input-specific taxes and subsidies. Second, this kind of studies can be useful in that they may illuminate mechanisms which are also reflected in macroeconomic relationships, but so far remain unexplained. For example, parts of the observed sluggishness in macroeconomic input demand may have explanations involving the regional dimension.

This study reviews some of the literature on regional analyses of producer behaviour, concentrating on the dual approach to the problem. To introduce the contents of the paper, let us ask what ideal requirements an appropriate empirical model of regional producer behaviour should meet?

First, to uncover as many sources as possible to regional variation in technological parameters, flexible functional forms should be brought into use. This will make it possible to address regional variation not only in partial output elasticities, but also in scale parameters and measures of substitution possibilities. Including second-order effects will further enrich the models with respect to the variety of economic effects. Restrictions on functional forms often tend to exclude regional variation in technological *flexibility*, an issue which is often held especially important in the literature on regional producer behaviour.

Second, to investigate regional differences in productivity, the models should incorporate some measure of technical change. A usual approach is to introduce a logarithmic linear trend function in the specification of technology, a technique that may well be applied also in a regional context. Implying a *constant* rate of technical change, this approach however puts certain restrictions on the process. To the extent that productivity reveals a cyclical pattern over time, the technology should therefore be specified to capture such cycles.

Third, the model should embody also long-term features of the structure of production, an important key-word being regional investments. Real capital as a variable input gives an improved description of long-term regional dynamics, since this will capture aspects of the industrial location process. Investment demand can be antagonised by investigating the effects of regional depreciation profiles, interest rates and regional economic policy upon the rental rates for capital equipment.

Fourth, both theoretical and empirical literature suggest that some inputs may be regarded as quasi-fixed rather than fully flexible. This kind of rigidity implies some form of adjustment technology in the process of tuning the input of different production factors. This element may also have a regional dimension. The argument is especially relevant for real capital and investments, but in the short run there are also reasons for treating labour inputs as quasi-fixed. When modelling regional production technology, the implications of imperfectly adjusting factor demand should be taken into consideration. It is therefore desirable to incorporate an adjustment technology into regional empirical analyses of production, making the production decision dynamic rather than static.

One single model cannot possibly include all the issues covered below. With, say, 5–10 regions it would soon grow untractable. In many cases it would also exhaust the number of degrees of freedom in the data set. However, the presented features should always be in the back of the head of the economist who wants to look closer at the empirical structure of cost and production in a regional context.

Depending on the availability of data, two different types of strategies should be held in mind. With data from the Norwegian regional accounts, one could estimate models for producer behaviour from aggregate regional time series data. However, some of the models to be presented will require a larger data set, and for these purposes one should seek to apply time series at the plant level. This kind of panel data is available for the Norwegian manufacturing industries through the manufacturing statistics time series data base at Statistics Norway. For other sectors, there will be problems involved if the data requirements extend the quality of the regional account statistics.

Chapter 2 introduces some basic concepts from the duality theory of cost and production. Characteristics of the preferred technical framework, the translog cost function, are presented in chapter 3. This part also include an illustration of how the technical framework might be utilized in a regional context, with an example concerning regional productivity growth. The next two chapters discuss regional aspects in the modelling of the labour market and the market for real capital, respectively. These inputs are the most basic and important inputs, also for regional analyses of the structure of production. The need for an appropriate description in regional analyses of productions technology is therefore most urgent for these production factors. This is in consonance with the modelling strategy for the macroeconometric models of Statistics Norway. The starting point has been to analyze the markets for labour and capital, whereas more recent approaches have treated the input of intermediate goods on a more disaggregate level[1]. Chapter 6 extends the analysis to allow for some intertemporal and dynamic problems, whereas chapter 7 offers some concluding remarks.

1 For an extensive treatment of the Norwegian market for electricity, see Bjerkholt et al. (1983). Olsen and Roland (1986) survey various approaches to modelling the demand for natural gas, whereas input substitution between different energy-bearers in Norwegian industries is analyzed by Mysen (1991).

2. Production theory and duality

2.1 Retrospect

The theoretical idea of the dual relationship between the cost function and the underlying production possibilities was first described by Shephard (1953)[2], but empirical descriptions of the structure of production by means of duality principles and an estimated cost function is a far newer concept. Some efforts were made in the early 1960s with simple and restrictive functional forms (see e.g. Nerlove (1963)), but it was not until the early 1970s that empirical applications of the duality principle really became popular.

The field experienced path-breaking progress when Diewert (1971) described how the structure of production may be represented through generalized flexible form cost functions, which in turn easily can be specified and estimated. Diewert's work included the first specification of the Generalized Leontief cost function. During the 1970s a number of generalized flexible functional forms were specified for econometric estimation, and today there is a variety of possibilities when economic is to be tested against economic theory by means of econometric methods. The available functional forms, to be presented closer below, include the Generalized Leontief, the Constant Elasticity of Substitution function, the Generalized Quadratic function, and the Transcendental Logarithmic function. This concludes the main advances from the 1970s, consisting of the recognition of duality principles of production, and the introduction of more flexible functional forms.

Before these improvements, empirically based models of regional producer behaviour had relied mainly on simple and restrictive functional forms, to the extent that input coefficients were allowed to vary at all. Labour demand functions consistent with a Cobb-Douglas production technology are also implemented in the regional model REGARD (Mohn (1993)). During the 1970s, the estimation of flexible functional forms introduced a variety of new possibilities in empirical

2 To a large extent Shephard (1953) has received credit for the application of duality in the economic theory of production, even though very similar phenomena were described for consumer utility and expenditure up to twenty years earlier (Hotelling (1932)).

analyses of producer behaviour, not only of productivity, but also for more general empirical studies of the economic processes of production. The properties of flexible functional forms may also be useful in the analysis of regional producer behaviour.

Regional analysts have already drawn extensively upon the new developments of empirical models of producer behaviour, applying more flexible functional forms, and to an increasing extent focusing on the dual side of the producer's optimization problem. Following this line of thought, Denny et al. (1981) and Denny and Fuss (1983) estimate generalized cost and input demand functions for manufacturing industries in Canadian regions. In a similar approach, Kim (1981) estimates the cost structure of the Canadian trucking industry, to investigate regional relative efficiency levels. More special aspects have also been put under focus in a regional context, exemplified by Luger and Evans (1988), who estimate dynamic factor demands for manufacturing industries in different US metropolitan areas to uncover regional effects originating in the dynamics of adjustment. Before we confine ourselves to this kind of models, let us have a brief look at the underlying general theory.

2.2 Theoretical underpinnings

Econometric analyses of the structure of production have to rely on some explicit functional form to describe technological parameters. Therefore a main headache has been to construct functional forms that don't impose too many restrictions on the economic parameters, and at the same time the functions should be easy to estimate. In the following, the duality principles of microeconomic theory of production will be applied to develop a simple and flexible tool for empirical analyses of producer behaviour[3].

To establish some mathematic tools, let $p = (p_1, p_2, \ldots, p_i, \ldots, p_n)$ denote the positive vector of input prices, and let $x' = (x_1, x_2, \ldots, x_i, \ldots, x_n)$ denote the transposed version of the non-negative row vector of inputs. Then let f be the production function for a single-product producer, describing the mathematical correspondence between inputs and maximum output.

Now, the maximum output (y) that can be produced with inputs x is given by the equation:

$$(1) \qquad y = f(x)$$

Strictly speaking, the production function is valid for an industry as a whole only if all production units characterized by optimizing behaviour. Thus, equation (1) may be thought of as a frontier function[4]. With competitive input markets the producer's optimization problem may be stated as a cost minimization problem,

3 For a more thorough exposition of the duality principles in microeconomic theory, see Diewert (1982). Jorgenson (1986) surveys the econometric applications, and Varian (1992) offers a textbook exposition on the subject.

whereby variable costs are minimized for a given amount of output and subject to a vector of exogenous input prices. The result is a restricted cost function, from equation given by:

(2) $c(p, y) = \min_x \{ px \mid f(x) \geq y \}$

Shephard's lemma permits the derivation of factor demand directly from the cost function of equation (2).

Let x^* represent the solution to (2) for given (p, y). Then x^* is unique and:

(3) $x^* = \nabla_p c(p, y)$

where the right-hand side represents the vector of partial derivatives of the cost function with respect to input prices. The duality principles of production further imply that *any* cost function which is positive, non-decreasing, and concave in factor prices represent an underlying technology which is well-behaved in neoclassical terms. More precisely, duality between production and costs means that if there exists a continuous, quasi-concave, monotone production function *f(x)*, then there will also exist a cost function *c(p, y)* with the following properties:

1) *c(p, y)* is a positive real-valued function defined for all positive prices *p* and all possible producible outputs. In addition *c(p, 0)* = *0*.

2) *c(p, y)* is non-decreasing in output and input prices.

3) *c(p, y)* is a continuous function in *y* and *p*.

4) *c(p, y)* is a concave function in *y* and *p*.

5) *c(p, y)* is a linear homogeneous function in *p*.

The practical implication of this insight is that all one needs to estimate various parameters of an arbitrary neoclassical production technology is to choose a nice cost function and estimate its parameters. However, these results depend crucially on the underlying assumptions concerning economic behaviour. First, one needs technical and allocative efficiency in all production units to secure that the cost function represents not only some establishments, but is valid for the whole

4 As an answer to this potential critique, the *best practice* approach has been developed to form an alternative approach, especially relevant for productivity analysis. The idea of the *best practice* approach is to measure the efficiency of each economic unit in terms of deviations from an established technological frontier. Farrell (1957) opened the field by estimating a non-parametric production frontier for british manufacturing industries. Later contributions are generalized, incorporate parametric as well as non-parametric methods, and both the primal and the dual side of the production problem serve as point of departure. For an early survey, see Førsund et al. (1980). Kopp and Diewert (1982) extends the framework to flexible cost functions, and Førsund (1992) represents a recent comparative application departing from the primal.

sample. Second, one is critically dependent on perfect competition in input markets to make sure that factor prices are exogenous to the producer.

2.3 The choice of aggregator function

Having elaborated on the theoretical properties of the cost function, we now turn briefly to the empirically related problem of appropriate measuring of costs. The exact composition of total costs must naturally be free to vary between production units and between different regions. This relates the problem of measuring costs to the more general problem of aggregation.

We will not elaborate on the problems concerning the *existence* of a consistent aggregate. For empirical analyses of these problems, the interested reader is referred to Berndt and Christensen (1974), Denny and Fuss (1977), Friedlander and Wang-Chiang (1984) and Kim (1986). Rather, we will illustrate some different possibilities of aggregation, given the existence of a consistent aggregate. We will first state the aggregator functions for the primal side of the producer's problem, leaving the implications for the dual to some comments towards the end of the chapter. With equation (1) as the point of departure, an output aggregate with no substitution resembles the Leontief production function, and for our purpose this may be written:

(4) $$y = \min(a x)$$

where a is the input requirement vector, and x is the vector of inputs. However, most empirical analyses of production allow for some degree of substitution. A simple way of introducing substitution possibilities is to weight the different types of inputs by some measure of productivity, say the sample average of the input-specific wage rates ($\overline{p}_i$):

(5) $$y = \sum_i \overline{p}_i x_i$$

As the $\overline{p}_i$'s are constant, the aggregate on the left-hand side of equation (5) may be normalized by division through $\overline{p}_i$, yielding:

(6) $$y^* = \sum_i p_i^* x_i$$

Equation (6) illustrates an underlying postulate of constant relative input prices, which is consistent with an assumption of perfect substitution between the different inputs. This assumption of perfect substitution is easily relaxed, for example by applying a constant elasticity of substitution (*CES*) aggregator:

(7) $$y = \left[\sum_i a_i x_i^{-\rho}\right]^{-\frac{1}{\rho}}$$

where $\Sigma_i a_i = 1$, and the elasticity of substitution (σ) between the different inputs is constant at $1/(1+\rho)$. For the special case described by homogeneous, constant substitution elasticities at unity, equation (7) reduces to the Cobb-Douglas aggregator function:

$$(8) \qquad y = \prod_i x_i^{a_i}$$

These different formulations of the production function, or the primal, all have their counterparts for the dual side of the producer's decision problem. A functional form with constant substitution elasticities is given by the Constant Elasticity of Substitution (*CES*) cost function. Following Fleck et al. (1971), the dual of the constant elasticity production function of equation (7) is given by:

$$(9) \qquad c(p, y) = \left[\sum_i b_i p_i^{1-\sigma} \right]^{\frac{1}{1-\sigma}} y$$

The *CES* cost function represents an improvement to the former less flexible forms, but still, it appears to be rather restrictive. The popularity of this functional form can be explained by its easy adaption to econometric formulations, and the fact that the elasticity of substitution is allowed to deviate from *1*. Further, the *CES* function nests some other well-known functional forms. The Cobb-Douglas cost function is the result when $\sigma \to 1$, and the fixed coefficient technology is covered by the special case where $\sigma \to 0$.

However, the fact that any positive, homogeneous, non-decreasing, concave function of input prices describes a well-behaved neoclassical technology has led to the development of more flexible functional forms. As for the *CES*-function, these are usually second-order approximations to an arbitrary underlying cost function[5]. The error terms in stochastic specifications can therefore be looked upon as consisting of terms of higher than the second order. Following Diewert (1971), and neglecting technical change, an example of a flexible functional form is given by a generalized version of the Leontief cost function:

$$(10) \qquad c\,(p, y) = \left[\sum_i \sum_j b_{ij} \,(p_i\, p_j)^{\frac{1}{2}} \right] y$$

This *Generalized Leontief* (*GL*) function offers a flexible framework for empirical analyses of production technology, and has been employed by Longva and Olsen (1983) in an applied general equilibrium model for the Norwegian economy (MSG). Brendemoen (1993) also applies this functional form in analyzing input demand for Norwegian transport sectors. The properties of the *GL* cost function will not be discussed in detail, as Diewert (1971) is quite exhaustive in this respect. However, we notice from equation (10) that the *GL* cost structure is

5 The CES cost function is a second order approximation of an arbitrary cost function for the two-factor case, and this functional forms will therefore suffice for production processes with less than three inputs.

reduced to the fixed-coefficient technology for the case where the off-diagonal elements of the matrix [b_{ij}] all equal zero. Econometric methods may be taken into use to test for the validity of this set of restrictions.

The international discussion literature has provided a number of other functional forms, and some of these are compared by Diewert and Wales (1987), who introduce two methods to secure that the flexible functional forms representing the structure of production costs also satisfy *global* curvature conditions. Diewert and Wales apply the translog function, the generalized Leontief function, the generalized McFadden function (Fuss (1978) and McFadden (1978)), and the generalized Barnett function (Barnett (1983)). Their findings are that the estimated elasticities are robust to the different specifications, suggesting that the choice of cost aggregator function is not critical to the econometric results.

Hopefully, the above discussion has illustrated that there are many alternatives when the choice of functional form is to be made. However, the variety is somewhat restricted once we require the cost function to allow for non-constant substitution possibilities. This leaves a subset of flexible functional forms, some of which has been mentioned above.

To illustrate some general aspects, we need a model which allow for more than two inputs. For the rest of this paper, the transcendental logarithmic (translog) cost function is therefore applied to illustrate the presented ideas concerning regional producer behaviour. This choice is made because the *translog function* meets all the important requirements to a flexible cost function, and because it has some advantageous properties regarding the readiness of interpretation of its parameters. However, the underlying ideas concerning economic behaviour are not at all critically dependent on this choice of functional form.

2.4 The translog cost function

By now it should be clear that empirical analyses of the structure of production may gain considerably by applying a flexible functional form. Over the last twenty years, this challenge has been met by the development of several generalized functional forms, a few of which were presented in the previous chapter. However, one important contribution still remains unmentioned. Christensen et al. (1971, 1973) suggested a second order approximation in the logarithms of $c(p, y)$. The result is the transcendental logarithmic cost function, or the *translog cost function*. Disregarding regional aspects and technical change, this function may be specified for a single-product producer as:

$$
\begin{aligned}
\ln c\,(p, y) = {} & \alpha_0 + \alpha_y \ln y + \sum_{i=1}^{n} \alpha_i \ln p_i \\
& + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \alpha_{ij} \ln p_i \ln p_j + \sum_{i=1}^{n} \alpha_{iy} \ln p_i \ln y \qquad (11) \\
& + \frac{1}{2} \alpha_{yy} \ln y^2
\end{aligned}
$$

where c, p and y again are total costs, input prices and the production level, respectively[6]. Equation (11) captures cross price effects (α_{ij}), factor augmenting scale effects, (α_{iy}) and neutral scale effects (α_{yy}). Further, it satisfies all the conditions of general neoclassical cost functions. Applying Shephard's lemma, input demand drops out from equation as input shares of total costs (s_i), since:

$$(12) \quad \frac{\partial \ln c}{\partial \ln p_i} = \frac{\partial c}{\partial p_i} \cdot \frac{p_i}{c} = \frac{p_i x_i}{c} \equiv s_i$$

giving for equation (11):

$$(13) \quad s_i = \alpha_i + \sum_{j=1}^{n} \alpha_{ij} \ln p_j + \alpha_{iy} \ln y$$

In practice, the cost level and the input shares are set simultaneously through the producer's decision problem, and this simultaneity should be acknowledged also in empirical models. This implies that the cost function in equation (11) and the factor demand equations in equation (13) make a simultaneous system of equations, and therefore corresponding techniques of estimation should be applied. Further, one of the factor share equations must be omitted to prevent from singularity in the estimated covariance matrix (because$\Sigma_i s_i = 1$). The conditions of neoclassical cost functions imply for the coefficients of the translog cost function in equation (11)[7]:

$$(14) \quad \begin{aligned} &\sum_{i=1}^{n} \alpha_{ij} = 0 \quad , \quad \sum_{i=1}^{n} \alpha_{iy} = 0 \\ &\sum_{i=1}^{n} \alpha_i = 1 \quad , \quad \alpha_{ij} = \alpha_{ji} \end{aligned}$$

The last restriction secures symmetry of cross price elasticities. Even this simple formulation of the translog-function is rich in economic effects, and at the same time it satisfies general conditions of neoclassical production theory. Some prospects of the translog cost function can be illustrated through a closer look at its properties.

First, observe that the translog cost function offers an excellent opportunity to test for Cobb-Douglas technology, which would imply constant shares of input costs.

6 For this function to be equivalent to the relation applying for multi-product producers, output aggregation must be possible. If not, all products will have to enter the cost function independently. Tests for aggregation whithin the translog-framework are described by Berndt and Christensen (1974), Denny and Fuss (1977), Friedlander and Wang-Chiang (1974), and Kim (1986).

7 The first restriction is equivalent to the condition posed on any neoclassical cost function of homogeneity of degree one in input prices.

The translog cost function may thus be said to nest the Cobb-Douglas structure of technology. The required restrictions for equation (11) to reduce to a Cobb-Douglas function cost are:

$$\alpha_{ij} = 0 \quad \forall \quad i\ ,\ j$$

$$\alpha_{iy} = 0 \quad \forall \quad i$$

Second, the elasticity of scale can be measured by examining the effects on the cost structure from an increase in the production level. Differentiating equation (11) with respect to the production level yields the following expression for the cost flexibility of the translog function:

$$(15) \qquad \varepsilon_{cy} \equiv \frac{\partial \ln c}{\partial \ln y} = \alpha_y + \sum_{i=1}^{n} \alpha_{iy} \ln p_i + \alpha_{yy} \ln y$$

The scale elasticity of production is usually defined as the percentile increase in output following a proportional increase in all inputs. The cost function in equation (11) provides a direct measure of the cost elasticity of scale, as illustrated in equation (15). However, an indirect measure is also easily obtained for scale elasticity of production. The duality principles of microeconomic producer theory implies that the effect of a production increase on the cost level is closely tied to the scale properties of the production function. If a general increase in the production level causes a less than proportional increase in costs, there must be increasing returns to scale. Defining the scale elasticity of production as Ω_y, and following Diewert (1982) we may therefore write:

$$(16) \qquad \Omega_y = (\varepsilon_{cy})^{-1}$$

Decreasing returns to scale now means that $\Omega_y < 1$ ($\varepsilon_{cy} > 1$), constant returns implies $\Omega_y = 1$ ($\varepsilon_{cy} = 1$), while increasing returns has the effect that $\Omega_y > 1$ ($\varepsilon_{cy} < 1$). Equation (16) illustrates the core of the dual relationship between costs and production. If a proportional increase in all input prices leads to an equivalent increase in total costs, then the cost flexibility is equal to *1*, and we have constant returns to scale. On the other hand, if the resulting increase in costs is less (more) than proportional, the production technology exhibits increasing (decreasing) returns to scale.

Third, the translog function may easily be applied to compute the elasticities of substitution between the different pairs of inputs. As they measure the proportionate change in relative factor use following a proportionate change in relative input prices, they may be thought of as a measure of technological flexibility. In a regional context, estimated elasticities of substitution may thus be used to test for regional variation in the degree of technological flexibility. It is often claimed that industries in agglomerated areas operate with a more flexible technology than more provincial regions. For an empirical application of such tests, see Luger and Evans (1988). With cost minimization ($f_i' = p_i \;\; \forall\, i$), the elasticity of substitution between input *i* and input *j* is defined by:

$$(17) \qquad \sigma_{ij} = \frac{d \ln \left(\dfrac{x_i}{x_j} \right)}{d \ln \left(\dfrac{p_j}{p_i} \right)}$$

Accordingly, the elasticity of substitution for input *i* and input (*j* (σ_{ij}) expresses the percentile change in relative input demand following from a change in relative input prices of one percent. With this common point of theoretical departure, economic theorists have provided several measures of elasticities of substitution[8]. For simplicity, we will however adhere to the main-stream practice, applying the *Allen-Uzawa* elasticity of substitution, defined by (Allen (1938), Uzawa (1962)):

$$(18) \qquad \sigma_{ij} = \frac{c\,(p, y) \cdot \dfrac{\partial^2 c\,(p, y)}{\partial\, p_i\, \partial\, p_j}}{\dfrac{\partial\, c\,(p, y)}{\partial\, p_i} \cdot \dfrac{\partial\, c\,(p, y)}{\partial\, p_j}}$$

Applied with the translog model in equation (11), this yields for the *Allen-Uzawa* partial elasticities of substitution[9]:

$$(19) \qquad \sigma_{ij} = \frac{\alpha_{ij} + s_i\, s_j}{s_i\, s_j} \qquad i \neq j$$

$$\sigma_{ii} = \frac{\alpha_{ii} + s_i^2 - s_i}{s_i^2} \qquad i = j$$

These measures of technological flexibility are symmetric, and are widely applied in general empirical studies of production.

Finally, observe that equation (19) implies for the cross-price elasticities (ε_{ij}) of our model:

8 Originally defined by Hicks (1932) for two inputs, different generalizations to the multifactor case has been provided by Allen (1938), Uzawa (1962) and Blackorby and Russell (1981). Chambers (1988) also offers a comparative discussion of the *Allen-Uzawa* and the *Morishima* elasticities of substitution. However, the debate on what measure to pick for a general description of the curvature of the technology still remains unsettled, two recent contributions being Blackorby and Russell (1989) and Frenger (1992).

9 See Berndt and Wood (1975).

(20) $\varepsilon_{ij} = \sigma_{ij} s_j$

Thus, the cross-price elasticity does not possess the symmetry properties of the *Allen-Uzawa* elasticities of substitution, except from in the two-input special case where $s_i = s_j$.

To summarize, the translog cost function is a flexible functional form which satisfies the requirements of neoclassical production theory. It is linear in all the parameters, and together with input demand equations it is easily estimated by appropriate simultaneous equations techniques. The richness in economic effects has made this functional form especially popular. Cobb-Douglas technology stand out as a special case, an may be tested for in empirical applications, and aspects like substitution possibilities and economies of scale are also readily uncovered.

3. Regional variation

3.1 Incorporating the regional dimension

There are at least two sets of reasons to be interested in the exact structure of cost and production in a regional context. First, analysis of spatial variation should always be of interest to researchers, as it may reveal economic features and technological characteristics which otherwise would be concealed. For example, the adjustment of production levels, input demand and investments are often claimed to take place in a sluggish manner. However, the list of plausible explanations for such rigidities is still far from exhaustive, and the geographical aspects of production and input demand should be examined more closely in this respect.

Second, regional factors matters for policy analysis, and the designers of economic policy will therefore take advantage of the implications of regional heterogeneity in production technology. As an example, it is an objective of the Norwegian government to preserve the spatial pattern of settling and employment. To this end, the tax system is formulated to stimulate investments, production, and employment in sparsely populated areas. Optimal design of this kind of regional policies requires knowledge of the structure of costs and production.

Traditional economic analysis assumes that the production functions are identical from one region to another. In other words they are regionally invariant. However, conducting regional analysis of the production decision, we may observe that production units localized in different parts of a country operate with different sets of production technologies. First, they may differ with respect to input combinations because some or all of the exogenously given variables exhibit regional variation. This goes for input prices, quality of inputs and outputs, production levels, or stocks of quasi-fixed factors. Second, there may be variation concerning the deeper, or structural, technological parameters. If the true structure of production (or costs) does not vary geographically, it is said to obey the strong geographical invariance assumption, whereas variation in a subset of the technological parameters implies fulfilment of the so-called weak invariance assumption (Luger and Evans (1986)).

There are also several ways of incorporating spatial features of the production technology in empirical analyses. First, a method is to incorporate regional infrastructure as a specific input in the production function. This approach is taken by Sasaki (1985) to estimate translog production functions for manufacturing industries in different Japanese regions. Regional attributes are calibrated as indices of density, scale of production, and market accessibility, and these variables are included in the estimation of a translog production function for nine manufacturing industries in Japan to uncover regional variation in total factor productivity. The results indicate that the variation in scale of production accounts for nearly half of the regional productivity differentials, whereas agglomeration and market accessibility explain about 25% each.

A second possibility is to estimate a general model separately for each region, leaving for the results to explain all regional variation in the structure of production. This is what Luger and Evans (1988) do when they estimate regional dynamic input demand functions for different metropolitan areas of the United States. A drawback of these methods is the requirement of a satisfying data set for each of the regions included. In disaggregated regional and sectoral approaches, this often proves to be a problematic point.

Third, dummy variables can be implemented to measure regional deviation from some reference technology. This improves the drawback of the second method, as the dummy variables technique allows estimation using a pooled data set and an integrated model, including all regions. Thus the technique may be applied on a sample where some of the regions are somewhat poorly represented and where the regional categories are unevenly distributed. In a regional context, one may therefore let one region serve as a point of reference, measuring all regional variation as deviations from the reference region's technology. However, the choice of reference region is not without consequences. The method allows bilateral comparisons between the "base" region and any other region, but cardinal differences between regions other than the reference region are not insensitive to the choice of reference region. These problems are discussed more detailed by Denny et al. (1981) and Denny and Fuss (1983).

To illustrate the idea of regional dummy variables in the cost function, let the general translog function's reduced representation be given by:

(21) $c = c\,(p, y)$

Appending dummy variables (d_r) for all regions but the reference region, technological differences can be described by means of regional shift parameters, operationalized by the introduction of dummy variables, or regional fixed effects. This gives a regional version of equation (21):

(22) $c_r = c_r\,(p_r, y_r, d_r)$

However, most empirical applications put restrictions on the model, assuming parts of the technology to be regionally homogenous. In the following we will apply different dummy variable strategies, some of which also allow regional variations in second order effects. Therefore, the technical models should be looked upon as points of departure, leaving for the econometric estimation to decide upon the exact choice of dummy variables. The principles of incorporating dummy variables in an integrated model for regional producer behaviour is applicable to a variety of flexible functional forms, but for simplicity of exposition we will still restrict ourselves to the translog cost function case.

3.2 Regional productivity growth in the translog cost function

When estimating regional cost functions, the multiplicity of economic effects is a result of various constraints and choices. First, the data set may place restrictions on the analysis because a full-blown model may exhaust the degrees of freedom. Second, the number of regions involved may also reduce the number of degrees of freedom, if all interaction terms were to be allowed. This is one of the reasons why regional variation mostly is limited to the first-order terms of the cost function (e.g. Kim (1981)). Finally, the scope of the analysis will influence on the number of restrictions placed upon the cost structure. Interaction terms connected to the trend variable are usually not included, unless productivity growth is one of the main aspects of concern.

In practice, most of these problems are related to the data availability. With aggregate regional time series data this will soon become a problem, and Daly et al. (1993) claim this to be the reason for not exploring the interaction between factor prices and technological progress in an analysis of regional investment incentives in Canada. However, the dilemma is usually resolved if data is available at the plant level. Panel data thus represents a powerful tool for analyses of regional producer behaviour, because it allows for the simultaneous analysis of a multitude of economic effects within a flexible framework.

With many regional effects and many regions, the translog model will easily grow difficult to handle. Below, we will therefore neglect all regional variation except from the effects connected to technical change. To focus on the aspects concerning regional variation, the possibility of multi-product producers will also be neglected. The presented model will therefore still be limited to the single-product case. Assuming that technical change can be described by an exponential time trend function, a flexible representation of the structure of production may be specified by the following translog cost function:

$$\begin{aligned} \ln c\,(p, y, d, t) &= \alpha_r^* + \alpha_y \ln y + \tfrac{1}{2}\alpha_{yy} \ln y^2 \\ &+ \sum_{i=1}^{n} \alpha_i \ln p_i + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} \alpha_{ij} \ln p_i \ln p_j + \sum_{i=1}^{n} \alpha_{iy} \ln p_i \ln y \qquad (23) \\ &+ \gamma_{tr}^* t + \sum_{i=1}^{n} \gamma_{itr}^* \ln p_i\, t + \gamma_{ytr}^* \ln y\, t + \tfrac{1}{2}\gamma_{ttr}^* \ln t^2 \end{aligned}$$

where:

$$\text{(24)}\quad \begin{aligned} \alpha_r^* &= \alpha_0 + \alpha_r\, d_r \\ \gamma^*_{\cdot\cdot r} &= \gamma_{\cdot 0} + \gamma_{\cdot\cdot r}\, d_r \end{aligned}$$

and where d_r represent provincial deviations for region r. This specification does not exclude the possibility of plant-specific fixed-effects, although these are not explicitly captured by equation (23). In the case of fixed effects, the constant term of equation (23) may be thought as consisting of three terms. The first is the common constant term for all units of the sample, the second is the regional shift parameter, and the third is a plant-specific dummy variable or the so-called fixed effect. With panel data, various coefficients of the cost function may be specified to vary over cross-sectional units, over time, and according to other exogenous variables. Thus, the procedure suggested above, where the coefficients of the model depend on location, is nothing but a special case of the universe of possibilities introduced by Hsiao (1986) in his monograph on econometric analysis of panel data. Even with panel data, a sensible point of departure is, however, to start with a simple case where for example the constant term is allowed to vary over region. More subtle regional economic effects can then be introduced at later stages.

Input demand equations are again obtained from the cost function as input shares:

$$\text{(25)}\quad s_{ir} = \alpha_i + \sum_{j=1}^{n} \alpha_{ij} \ln p_j + \alpha_{iy} \ln y + (\gamma_{it0} + \gamma_{itr}\, d_r)\, t$$

Observe that the optimal cost shares now depend on the regional degree of factor-augmenting technical change[10]. This illustrates how e.g. regional employment will be determined by region-specific productivity growth. Further, the model can be used for a more detailed investigation of the sources of regional variation in the degree of technical change. This can be seen by differentiating the cost function in equation (23) with respect to the trend variable t, producing for technical change:

$$\text{(26)}\quad \begin{aligned} \dot{T} &= (\gamma_0 + \gamma_r\, d_r) + \sum_{i=1}^{n} (\gamma_{it0} + \gamma_{itr}\, d_r) \ln p_i \\ &+ (\gamma_{yt0} + \gamma_{ytr}\, d_r) \ln y + (\gamma_{tt0} + \gamma_{tt}\, d_r)\, t \end{aligned}$$

Equation (26) describes how the cost frontier changes position over time, demonstrating also the possible sources of these changes; The two first elements on the right hand side of equation (26) represent first order pure (input and scale

10 However, the input shares are still independent of pure technical change, as in the previous mentioned Standard Time Trend Model.

neutral) technical change. The third element describes factor augmenting technical change, and the fourth effect illustrates how technical change may be caused by scale effects because the level of production varies over time. The last element of equation (26) embodies second order effects of changes in the trend variable itself, and will be zero if the *rate* of technical change is invariant to passage of time. One of this model's main advantages is its richness in economic effects. It introduces the possibility of regional differences in all the specified sources of technical change in an integrated framework. This increases the probability that observed regional variation in productivity growth will find its explanation in equation (26)

Following Kim and Sachisch (1986), the translog cost function in equation (23) can be used to calculate the growth in total factor productivity as:

$$(27) \qquad \dot{TFP} = -\dot{T} + (1 - \varepsilon_{cy})\,\dot{y}$$

where the rate of technical change ($\dot{T}$) is defined by equation (26), and ε_{cy} represents the elasticity of the cost function with respect to output, defined by:

$$(28) \qquad \varepsilon_{cy} \equiv \frac{\partial \ln c}{\partial \ln y} = \alpha_y + \alpha_{yy} \ln y + \sum_i \alpha_{iy} \ln p_i + (\gamma_{yt0} + \gamma_{ytr}\, d_r)\, t$$

Equation (27) illustrates how scale economies introduce a wedge between the rate of technical change and the growth in total factor productivity. The source of this effect is the change over time in the level of production, influencing both the rate of technical change and the elasticity of the cost function with respect to output.

In spite of the variety of productivity-related economic effects offered by the translog framework, critical remarks can be registered in the literature. Observe first that the pure technical change in equation (23) is a linear function of the trend variable *t*, which implies that pure technical change is constant or changing at a constant rate. This implies that the model puts restrictions on the rate of pure technical change. This fact may cause the pure technical change part to dominate equation (23), leaving less room for factor and scale augmenting technical change. In addition, our model implies that the productivity growth is *monotonous* in the trend variable, leaving no room for productivity cycles. However, another characteristic of the standard time-trend model has caused even more critical remarks. From the cost function in equation (23) we see that *pure* technical change is no necessary prerequisite for any type of input-augmenting technical progress.

Baltagi and Griffin (1988) find these characteristics quite aggravating, and argue that input-augmenting technical change always should be accompanied by *pure* technical change. This is really a criticism against the flexibility of the translog model without restrictions, as this characteristic is caused by the absence of restrictions on the economic processes. Accordingly, Baltagi and Griffin (1988) presents a modified version of the translog cost function approach, where *any* type of technical change depends critically on the existence of pure technical change. This is in sharp contrast with the pure time trend model, where one may find both factor and scale augmenting technical change, but still no *pure* technical change.

With panel data for micro units, the translog model can be constructed to focus on regional variation related to arbitrary exogenous variables of the cost function. For example, one can add regional dummy variables to all effects where the level of production plays a role, to uncover whether regional scale effects vary over the regional dimension. Keeping the specification of equation (23), all regional variation in the scale elasticity is assumed to be connected to the trend variable, since the regional dummy variables are tied to the trend variable only. The same strategy may be applied for examination of regional variances in the input price elasticities of the variable inputs in the production process. To the extent that these input prices vary between regions, this variation should be utilized in the estimation. As an example, the above formulation could be employed to explore regional variation in the wage elasticity of labour demand. This kind of variation is important for the design of appropriate regional employment policies.

The complexity of the framework is, however, more limited if the data sources consist of aggregate regional time series. The reason is that a large number of regional dummy variables soon will exhaust the number of degrees of freedom in this case. One possibility with this kind of data is to test statistically for regional variation in the various economic effects, one by one (Mohn (1993)).

3.3 Productivity growth and regional characteristics

Hypotheses stating that the cost structure and the rate of productivity growth vary systematically, depending on variables which can be directly tied to the density of the region of location, are common in regional analyses of production technology. Such variation is usually explained by the idea that the location of production inevitably will have technological implications. Potential reasons for the hypothesized technological edge of certain regions are advantageous infrastructure, good interregional and international market accessibility, and nearness to important inputs.

The analysis of *regional* productivity differentials includes Kim (1981), who estimates a translog cost function for the Canadian trucking industry. Regional dummy variables are appended to all first order effects, and this allows for regional variation also in the rate of technical change. His main findings are that small firms compensate for their disadvantageous scale of operation by a higher degree of capital utilization, and therefore they seem to be competitive. Among the weaknesses of this paper is the lack of dynamics in the producer's decision problem, and the restriction of all regional variation to economic effects of the first order. Economic theory does not readily support this assumption, but as data sets usually do not provide the necessary number of degrees of freedom, this kind of restrictions often come in handy.

Evanoff and Israilevich (1991) is a recent contribution to the impact of public regulation, where the regional structure of production is estimated for U.S. commercial banks by means of a translog cost function. It is argued that banks located in regions with heavy regulations grow resilient to regulatory-induced distortions. Thus, the performance of these banks are better in simulations with regionally homogenous input prices.

Denny et al. (1981) utilize general indices of productivity that draw both on the intertemporal and the cross-sectional variation of their data set. Applied to data for Canadian manufacturing industries, their methods reveal significant regional productivity differentials. Garofalo and Malhotra (1989) combines the intertemporal and the interspatial perspectives in an analysis of productivity in U.S. manufacturing industries, but their reported variation in total factor productivity is close to negligible.

Denny et al. (1981) and Garofalo and Malhotra (1989) could be said to be directly nested by the general framework developed by Denny and Fuss (1983). These studies focus directly on the problem of measuring productivity growth, and are less concerned with general structural differences in production technologies between regions. Although Kim (1981) is estimating a strictly structural model, his measures of productivity differentials are strongly related to those of Denny and Fuss (1983)[11].

In addition, spill-over effects in R&D-activities are often associated with industrial location (see Jaffe (1989)). In short, plants localized in regions characterized by density and agglomeration are taken to possess an technological advantage to plants in other regions. In a macroeconomic context these ideas are stressed by Romer (1986) as important growth promoting factors. Romer's central concept is that of external returns to scale. This implies that the macro product function may be convex for a region as a whole, whereas the micro product function for each firm is quasi-concave. Because different parts of a country vary considerably with respect to market size, capital stock, and access to international markets, the concept of external returns to real capital should be of interest also in a regional context.

Lucas (1988, 1993) accounts for the theoretical mechanics of economic development, based on related ideas, but his focus is on human capital formation. As accumulated production may influence on the scale economies of the technology due to learning-by-doing mechanisms (Arrow (1962)), the concepts of external returns to scale and human capital formation are closely related[12].

11 See also Moomaw (1981), Beeson (1987), and Moomaw and Williams (1991). Larsen (1993) estimates rates of productivity growth in Norwegian industries on the national level, using data for the time-period 1970-1990.

12 Baldwin (1989) calibrates the growht effects of economic integration in Europe within a similar framework.

The relevance of these ideas in a regional context should be self-evident. The average level of education is not invariant to spatial characteristics, and also the propensity to take higher education varies over the regional dimension. Thus, both the stock of human capital and the formation of this kind of wealth are influenced by regional characteristics. The weakness of theories of external returns and economic growth is that at this stage they all lack convincing support from empirical analyses. However, Baldwin (1991) calibrates the gains from European integration, drawing on the ideas of Romer (1986).

Any variable suspected to influence upon the regional structure of cost and production may in principle be included in empirical versions of the translog model. This will also allow for econometric tests concerning the interaction between spatial features and regional productivity growth. This goes for all possible sources of regional variation, such as agglomeration variables, access to input and output markets, research activities, public regulations, and environmental variables. To illustrate this, we let this kind of variables be represented by the set of pseudo (quasi-fixed) inputs *v*, which are operationalizations of regional characteristics. This new set of variables is inserted into a standard translog cost function with technical change. The resulting generalized version of the regional model of producer behaviour is now summarized by the translog cost function:

(29)

$$\begin{aligned}\ln c(p, y, v, t) &= \alpha_r^* + \alpha_{yr}^* \ln y + \tfrac{1}{2}\alpha_{yyr}^* \ln y^2 + \sum_{i=1}^{n} \alpha_{ir}^* \ln p_i \\ &+ \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n}\alpha_{ijr}^* \ln p_i \ln p_j + \sum_{i=1}^{n}\alpha_{iyr}^* \ln p_i \ln y + \sum_{i=1}^{n}\sum_{k=1}^{m}\alpha_{ikr}^* \ln p_i \ln v_k \\ &+ \sum_{k=1}^{m}\beta_{kr}^* \ln v_k + \frac{1}{2}\sum_{k=1}^{m}\sum_{l=1}^{m}\beta_{klr}^* \ln v_k \ln v_l + \sum_{k=1}^{m}\beta_{kyr}^* \ln v_k \ln y \\ &+ \gamma_{tr}^* t + \sum_{i=1}^{n}\gamma_{itr}^* \ln p_i\, t + \sum_{k=1}^{m}\gamma_{ktr}^* \ln v_k\, t + \gamma_{ytr}^* \ln y\, t + \tfrac{1}{2}\gamma_{ttr}^* \ln t^2\end{aligned}$$

where:

(30)

$$\begin{aligned}\alpha^*_{..r} &= \alpha_{.0} + \alpha_{..r}\, d_r \\ \beta^*_{..r} &= \beta_{.0} + \beta_{..r}\, d_r \\ \gamma^*_{..r} &= \gamma_{.0} + \gamma_{..r}\, d_r\end{aligned}$$

The coefficients with subscript *0* are the economic effects applying for the reference region, the coefficients with subscript *r* are the regional shift parameters, and d_r are regional dummy variables.

This model allows for very many interactions between input prices, regional characteristics, and technical change. Some of the possibilities of the model are illuminated by an examination of the input demand functions. Differentiation of the cost function in equation (29) with respect to input prices yields for the demand for variable inputs:

$$(31) \qquad s_{ir} = \alpha^*_{ir} + \sum_{j=1}^{n} \alpha^*_{ijr} \ln p_j + \sum_{k=1}^{m} \alpha^*_{ikr} \ln v_k + \alpha^*_{iyr} \ln y + \gamma^*_{itr}\, t$$

This version of the brings in regional variation in the own and cross price elasticities of input demand, thereby introducing regional variation in the substitution possibilities between different factors of production. In addition, the cost shares may be influenced by regional characteristics v_k and their regional coefficients α^*_{ikr}. Also the scale parameter α^*_{iyr} is varying between regions in this model, and so is the degree of factor augmenting technical change γ^*_{itr}.

The influence from the pseudo inputs upon regional productivity growth is detected throught the derivation of technical change and scale economies, as the change in total factor productivity is still given by equation (27). The cost elasticity of scale ε_{cy} is given from equation (29) by:

$$(32) \qquad \frac{\partial \ln c}{\partial \ln y} \equiv \varepsilon_{cyr} = \alpha^*_{yr} + \alpha^*_{yyr} \ln y + \sum_{i=1}^{n} \alpha^*_{iyr} \ln p_i + \sum_{k=1}^{m} \beta^*_{kyr} \ln v_k + \gamma^*_{ytr}\, t$$

Equation (32) illustrates how the scale properties of the cost structure are influenced by all the variables of the translog cost function. However, we concentrate on the effects connected to the pseudo inputs representing regional characteristics. As an example, v_k may represent the regional level of research and development activities. To the extent that these activities interact with the level of production, the scale properties of the regional production technologies may be affected. The usual hypothesis is that R&D activities introduce positive external returns to scale, and that research regions therefore have a advantage connected to scale economies compared to other regions. This means that R&D activities reduce the marginal costs as the level of production rises, implying for equation (32) that $\beta^*_{kyr} < 0$. Moreover, the scale of production itself may have an effect on the cost elasticity of scale via the cost flexibility parameter α^*_{yyr}. Finally, observe that the level of production may interact with technical change via the parameter γ^*_{ytr}.

The rate of technical change ($\dot{T}$) is obtained by differentiation of the cost function with respect to the trend variable t, yielding:

$$(33) \qquad \dot{T}_r = \gamma_r^* + \sum_{i=1}^{n} \gamma_{itr}^* \ln p_i + \sum_{k=1}^{m} \gamma_{ktr}^* \ln v_k + \gamma_{ytr}^* \ln y + \gamma_{ttr}^* t$$

Equation (33) demonstrates how this model enables us to study the effects from regional characteristics upon the rate of technical change. Advantageous regional characteristics are expected to raise the rate of technical change, implying that the marginal effect upon costs is negative ($\gamma_{ktr}^* < 0$). However, only a combination of equations (32) and (33) will reveal the full impact from the regional pseudo inputs on the rate of productivity growth. Finally, the shadow cost (q_k) of a marginal change in the regional characteristics variable v_k can be computed from the cost function of equation 33 as:

$$(34) \qquad \frac{\partial \ln c}{\partial \ln v_k} \equiv q_{kr} = \sum_i \alpha_{ikr}^* \ln p_i + \beta_{kr}^* + \sum_l \beta_{klr}^* \ln v_l + \beta_{kyr}^* \ln y + \gamma_{ktr}^* t$$

Equation (34) illustrates how the total effect upon the structure of cost from a marginal change in the level of the regional characteristic variable v_k. This effect may depend on all the other variables of the model. Moreover, possible non-linearities between the level of the variables v_k and the level of total costs may be accounted for in the presented framework.

With less stringent methods related issues have been analyzed quite extensively in an empirical setting, applying the so-called Porter concepts (Porter (1990)). Industrial clustering is clearly seen as growth-promoting in a Porter analysis of the Norwegian economy (Reve et al. (1993)). On a more disaggregate regional level this kind of clusters are normally not big enough to ensure the full benefits of technological and productive spill-overs. Thus, Osland (1993) argues that the interregional and international networks to which local industries belong become even more important to the prospects for regional development. These works apply an alternative method, but really address very similar problems to the research commented above.

A fruitful approach for future empirical investigations would therefore be to integrate external returns to scale and/or the Porter concepts in a formal model for producer behaviour. To test empirically for these phenomena one should seek for a method to internalize the external scale economies. This can be done by introducing the region's total stock of real capital, or any other instrument for industrial clustering, as an independent exogenous cost factor in an econometric cost function, as illustrated above. This could also allow for the identification of estimates for the impact of external returns to scale. Further, using a flexible functional form, we would be able to describe also the accurate origins of these scale economies.

4. Regional labour markets

4.1 Regional demand for labour

There are two main reasons for being interested in the long run regional demand for labour. First, regional wages will be determined in a long-run equilibrium between labour supply and demand, and therefore regional wage formation will be influenced by the demand side of the labour market. However, unionized employment and other institutional arrangements may provide wage stickiness, implying that the supply of labour to a regional sub-sector is perfectly wage-elastic. In that case, the long-run demand for labour will be of interest for analyses of regional employment, whereas other aspects will have to be brought in to uncover the process of regional wage-formation. Interests concerning regional unemployment and general labour market development make up the second reason for being curious about regional demand for labour.

This does not make analyses of labour demand less attractive, as regional employment is very important for the design of economic policy. Economists and practitioners who take interest in regional policy questions should therefore also be concerned with issues of labour demand, and regional differences in production technology in general. The effects of policy changes upon regional levels of production and employment depend critically on the structure of production, and this is not invariant to the regional dimension. On the other hand, estimating long-run labour demand equations directly tend to neglect some very important characteristics of the market for labour and human capital. More specifically, regional labour markets are usually characterized by imperfections, causing wage rigidity and sluggishly adjusting employment.

The demand for labour does not introduce additional aspects to the translog model framework presented in chapter 3, at least not in the basic long-run specification, and therefore it does not call for technical derivations in addition to those above. However, some reflections over the importance and relevance of labour demand analyses might be required. Before turning to the economic ideas outlined above, some relevant data and measurement problems are discussed in section 4.2.

Section 4.3 offers a discussion of regional labour market heterogeneities, whereas of regional labour market rigidities are addressed in section 4.4 and 4.5.

4.2 Measurement of labour inputs

To highlight some important perils in empirical labour market analysis, we shall look closer into some problems that may occur in the process of preparing labour market data for econometric estimation. First there are the problems of measuring and interpreting the number of man-hours and employees, respectively. Second, the measurement of the true costs of adjusting and paying the labour force may also prove difficult. Third, the aggregation of labour often involve pitfalls, as the labour force usually consists of heterogenous groups of persons.

These problems are discussed more extensively for the general case by Fallon and Verry (1988) and Hamermesh (1986), and will therefore only be reviewed briefly in this context. Some of the pitfalls introduced below have self-evident solutions, while others are more difficult to work out. Nonetheless, they should all be paid attention in discussions of data and measurement problems.

When measuring the input of labour, an important question concerns the unit of measurement: Should man-hours or number of employees form the basis for measurement? If the labour force is homogenous and all workers spend the same number of hours at work in every time period, the choice is naturally irrelevant. But heterogeneity with respect to number of hours worked in every time period makes the choice important. Thus, the distinction might be more important for disaggregate analyses of microeconomic units or regions, where the number of hours worked may vary considerably. On the other hand, analyses of macro-economic time series data is probably less sensitive to this choice, as the variation in number of hours worked per period is less in time series data.

Bergland and Cappelen (1981) discuss the problems of modelling the short-run demand for labour in a Norwegian context. They conclude that it is hard to find *one* model to fit data for all industries, calling for eclecticism in the choice of model. This conclusion is hardly applicable to the regional dimension, as it implies that different functional forms may have to be estimated for the same industry, depending on the region of location. Thus, practical reasons force us to rely on a simplified solution. However, Bergland and Cappelen (1983) do remind us that the problems of technological heterogeneity may reach further than to the actual magnitude of the estimated parameters.

Another possibility is, however, the case where the *dynamics* of labour demand and employment are explicitely at focus. In this case the distinction between man hours and employees is critical. The reason is that the dynamics might be quite different for these two different variables, although they are both measures of labour demand (cf. Nickell (1986)).

Stølen (1983) estimates macroeconomic labour demand equations for Norwegian manufacturing industries, using quarterly macroeconometric time series, and he also offers a discussion of the problems concerning the relationship between man-hours and employees. The labour demand equations are estimated using man-hours as the dependent variable, and the number of employees are then derived from independent econometric equations, under an assumption of quadratic adjustment costs. This method may also be applied in a regional context. Estimating regional demand functions for man hours, one may take account of regional variations in the technology of adjustment when estimating the dynamic relationship between man hours and number of employees.

Finally, the wage rate utilized in most analyses of labour demand represents an average of the hourly earnings in the production units of the data set. One problem with such measures of costs of labour is that the variation exposed might be a result of variation in the composition of a labour aggregate, or changes in the *normal* number hours worked per period. Regional variation in the composition of labour, and in the *normal* number of hours worked per period may thus prove problematic to handle.

Another problem is that the reported wage rates are usually average costs of labour. This makes it difficult to reveal the true cost of adding one extra unit of labour services to the already existing labour force. Marginal costs of labour will be affected by institutional features in the labour market, and these may vary considerably over between different units of production, as well as between different regions. For example, it is far more difficult to hire specialized labour in a thin provincial labour market than in a dense region.

4.3 Regional labour market heterogeneity

Implications for employment has been an important source of motivation of regional analyses of the structure of production. This has caused the labour market to be of special concern also in the specification of regional econometric models. There are several reasons why the labour market may need special treatment, but most of them imply some forms of rigidities. Theoretical literature has illustrated how the high degree of organization through trade unions may lead to market power on the supply side of the labour market (see Oswald (1985), Stiglitz (1986)). Trade unions offer protection against wage discrimination and unfair firing. These features give rise to both explicit and implicit *hiring* and *firing* costs, a cost aspect to be considered in addition to the directly observable cost of labour, namely the wage rate. In addition, new microeconomic theory of the labour market has stressed the problems of *mis-match* in the bilateral process of searching in the labour market (e.g. Sugden (1980)). Search theory is usually applied to the supply side of the labour market, but in a regional context, the search process becomes important also for the employers (Fluckiger and Hazari (1992)). See Snower (1993) for an extremely lucid overview over these ideas.

These new insights suggest that the adjustment of labour demand can not be described as momentary. Rather, empirical analyses of labour markets should submit to the suggested rigidities by incorporating some form of sluggishness. Further, these rigidities should be allowed to reflect also cross-sectional variation beteween regions. A reason for such an approach is the observation that the size and structure of the labour market is something that vary considerably over the regional dimension. Peripheral regions tend to represent labour markets which are spatially extensive, but small with respect to the number of employees. In addition provincial labour markets are normally more specialized and less differentiated than more centrally located areas (Neumann and Topel (1991)). These aspects suggest a higher degree of flexibility in highly agglomerated labour markets than in more provincial regions, an idea which has been discussed more extensively by Angel (1991) for the case of Silicon Valley.

Moreover, socio-demograpic characteristics of the labour force are vital to most employers. Thus, sex, age, and education are important factors that may create heterogeneity in the input of labour. Over the last years, Norway has experienced a significant increase in the enrollment rates for higher education. This will most probably have effects on the relative wages for different types of labour, and the seemingly most likely consequence is that relative wages for highly educated people will fall. With some degree of flexibility in labour demand, the result is substitution towards highly qualified labour. Whether the labour market will respond to this change force by a sufficient increase in the hiring of highly educated employees is, however, still an open question.

It should be recognized that such changes, both on the supply and the demand side of the labour market, may have expressive regional implications. Human capital formation may have positive effects on the regional rates of economic development, as long as education and knowledge can be applied in an efficient manner in the production side of the economy.

When designing policy measures, the recognition of regional labour market heterogeneity may have significant implications. Standard macroeconomic estimates of technological parameters are usually established as bench-marks when policy measures are constructed to stimulate regional employment. Macroeconomic estimates will be dominated by dense, central regions, as these regions have the largest weight in the macroeconomic time series. If technological parameters vary over different regions, national estimates may be systematically biased. To give an example, regional empirical analyses of manufacturing industries in Norway suggest that labour demand may be somewhat more wage elastic in agglomerated regions than in more provincial districts (see Steen (1991) and Mohn (1993)). This implies that the necessary measures required to reduce wage costs, and thereby raise regional employment, are more extensive out in the districts than pure macroeconomic estimates would suggest.

4.4 Adjustment and employment

Some possible implications of sluggishness adjustment for regional labour demand may be illustrated in a simple quasi-dynamic theoretical framework. We look at a cost-minimizing producer to whom the costs of adjustment are observable. If z is a vector of non-negative fixed inputs and h is the adjustment costs faced by the producer, a short-run restricted cost function may be derived by:

$$(35) \quad c(p, \Delta x, y, z) = \min_{x, \Delta x} \{ p x + h(\Delta x) \mid y \geq f(x, z) \}$$

producing disequilibrium demand equations for variable inputs:

$$(36) \quad \frac{\partial c}{\partial p_i} = x_i^* (p, \Delta x, y, z) + \sum_j \frac{\partial h}{\partial x_j} \frac{\partial x_j}{\partial p_i}$$

where $x_i^*(\cdot)$ represents input demand in the absence of adjustment costs. Ignoring cross-price effects, with rising adjustment costs ($h' > 0$) and falling input demand ($\partial x_i/\partial p_i < 0$), the last term of equation (36) will be negative. It is thereby demonstrated how the costs of adjustment may place a distortion on equilibrium labour demand, causing another employment level than in a perfectly adjusting labour market. From equation (36) we may also conclude that both price elasticities and elasticities of substitution may differ between the short-run disequilibrium and the long-run stationary solution. However, the structure of these differences are not available in this simple theoretical model.

To make further conclusions, the adjustment cost technology needs a discussion. Clearly, total costs of adjustment must be rising in the rate of adjustment. Further, it is widely acknowledged that there may be cost elements of the adjustment technology that will tend to cause some form of increasing returns, at least for low rates of adjustment. Thus, some forces may tend to reduce the marginal costs of adjustment as the adjustment activities increase. On the other hand, according to the standard literature of the area (cf. Nickell (1986)), there should also be forces that make the adjustment costs rise at the margin, and we will assume that these forces dominate. This gives a convex relationship between adjustment and adjustment costs. This convex relationship need not be identical over the regional dimension. As different regions make up different markets for labour inputs, the adjustment technology may well vary over the regional dimension. We shall return to this point in chapter 6, where different specifications of dynamic factor demands are outlined.

On a general level, the idea of partial adjustment suggests that marginal costs of labour force adjustment will be relatively high if adjustment takes place at a relatively extensive rate, because of the convex adjustment cost technology. This means that in plants experiencing relatively many and large exogenous shocks, the negative deviation from equilibrium employment will be correspondingly large (cf. Granger (1986))[13]. Examples of exogenous shocks are given by shifts in wage expectations and general shocks in product demand. This kind of shocks are likely to vary systematically across regions. For example, some introductory studies of Norwegian manufacturing industries suggest that provincial districts are more

13 An intuitive interpretation for this result lies in the idea that costs of adjustment may tend to crowd out the wage expenses, as the marginal costs of adjustment introduces a additional cost element in connection with the input of labour. The result is reduced employment.

exposed to exogenous shocks than densely populated and agglomerated regions (see Mohn (1993)). This makes it especially important to consider regional variation also in the adjustment technology.

The discussion above suggests that the rate of adjustment depends on the magnitude of local exogenous shocks relative to some equilibrium relationship for labour demand. Neumann and Topel (1991) claim this kind of ideas to contribute to the explanation of regional differences in unemployment rates in the US. They argue that unemployment rates are high in areas that are relatively specialized in industries exposed to demand shocks. However, this kind of shocks may vary systematically over different regions, also within the same industry (Mohn (1993)). Thus, the level of regional employment will be negatively correlated with the diversification of the economic base.

5. Real capital and regional investments

5.1 Why bother about regional capital formation?

In general, theoretical and empirical analysis of investments and capital formation has had a prominent role for a long time, both for microeconomic and macroeconomic purposes. The main reason seems to be the belief that the level of investments is closely related to the general level of economic activity, and to the growth potential of the economy. In the short run the connection runs mainly through the demand-pull effects from the sales of investment goods. In the long run, investments contribute to higher production and income via the supply side of the economy, by increasing the total stock of real capital.

These effects will of course be as valid on a geographically disaggregated level. This leaves many potential sources of concern for regional investment behaviour. Generally speaking, regional analysis is useful for two reasons. First, the conclusions from regional economic investigations may be useful for their own sake. That is, they may improve the understanding of the functioning of the spatially disaggregated economy, an aspect which is important for the design of regional policies. Second, analyzing economic behaviour on a disaggregate level may also contribute to the general understanding of macroeconomics. The determinants of regional capital formation represent an excellent example in this respect.

Macroeconomic studies of investment demand are often forced to rely on the time series variation in the variables involved. This restricts the scope of the analysis, as important variation in the underlying economic stocks and flows tends to be aggregated away. Allowing room for the regional dimension may unfold interesting effects, as many of the major determinants of investment vary systematically from region to region. To mention one of these, the tax system of Norway is consciously and explicitly constructed to make investment opportunities vary according to the location of the production unit.

Arguments concerning profitability, net value and investment behaviour, however, extends further than to intersectoral distribution of investment, and may therefore be especially relevant in a spatial context. Changes in regional variation in profits are likely to cause structural changes also in the general regional industrial structure. These changes takes place through investment demand and industrial location, and therefore they have implications also for regional employment. An empirically-based description of the technological structure will provide an explanation of the nature of these changes. The evolution of regional employment over time is therefore critically dependent on the spatial distribution of investments and real capital.

However, the stock of real capital has implications also for the short-term decision problem of the producer. This corresponds to the textbook-case where real capital is fixed, whereas labour and intermediate inputs are free to respond to changes in factor costs. Accordingly, the below exposition will therefore also present a version of the translog cost model with so-called quasi-fixed factors. Towards the end of the chapter the determinants of rental rates and the long-run decision problem will be discussed. But before we turn to the problems of modelling capital formation and the long-run structure of cost and production, let us start out with some reflections concerning the formal distinction between the short and the long run.

5.2 Long-run and short-run cost functions

Some technical reflections may illuminate the distinction between the short run and the long run even better. Let $r = (r_1, r_2, \dots, r_l, \dots, r_L)$ represent the vector of input prices of the quasi-fixed factors (z), including real capital. Together with the previously defined notation, and following Slade (1986), four distinct types of cost functions now illustrate the differences between long-run and short-run production technology. The first is the long-run total-cost function:

$$(37) \qquad c = \min_{x,\,z} \{ p\,x + r\,z \mid y = f(x, z, t) \} = c(p, r, y, t)$$

where all inputs are assumed to be variable. The resulting cost function have input prices, the production level, and technical change as its arguments. This is the cost function of producer in long-run equilibrium, and all the marginal products of all inputs are equal to the price of the input in question. The second cost function is the short-run restricted cost function, or variable-cost function:

$$(38) \qquad vc = \min_x \{ p\,x \mid y = f(x, z, t) \} = vc(p, z, y, t),$$

restricting quasi-fixed factors to a predetermined level. This corresponds to the situation resulting from a short-run optimization problem, whereby input of intermediate goods and labour are free to adjust, whereas the real cap stock is kept constant. The third cost function measures total costs of producing at level y when some factors are fixed:

$$(39) \qquad uc = vc(p, z, y, t) + r\,z = uc(p, r, z, y, t)$$

Equation (39) may thus be thought of as a disequilibrium total-cost function or short run cost function, as it measures the short-run *total* costs of production, including costs of quasi-fixed factors. Finally, a *fictitious* shadow cost function may be constructed to account for the cost that would be incurred in addition to the short-run costs if the prices of the fixed factors adjusted to make the observed levels optimal:

$$(40) \qquad c^* = vc\,(p, z, y, t) + \lambda z = c^*\,(p, z, y, t)$$

Applying Shephard's lemma, we see that $\lambda = -\nabla_z vc$. In the long-run equilibrium, marginal variable costs of quasi-fixed factors are equal to marginal total costs, which again are equal the price of the quasi fixed factors:

$$\lambda = -\nabla_z vc = r$$

implying that $c = c^* = vc + \lambda z = vc + rz$. These properties have been used by Slade (1986) to construct statistical tests for the validity of long-run cost minimization hypothesis on the basis of Monte Carlo simulations (cf. also Conrad and Unger (1987)).

The distinction between the short run and the long run production technology is also combined with Norwegian data by Olsen (1983), who estimates generalized Leontief cost functions for Norwegian industries to be implemented in a specialized version of the macroeconometric model MODAG. These specifications allow for short-run effects, for a given amount of quasi-fixed inputs, as well as long run effects, implying the appropriate adjustment of all inputs.

Let us look closer at a version of the translog cost function which allows for quasi-fixed inputs, normally thought of as real capital in the short-run. Let $z = (z_1, z_2, \ldots, z_k, \ldots, z_m)$ represent the vector of quasi-fixed inputs. Neglecting technical change, the corresponding translog formulation of the cost structure is given by:

$$\ln c\,(p, y, z) = \alpha + \alpha_y \ln y + \tfrac{1}{2}\alpha_{yy} \ln y^2 + \sum_{i=1}^{n} \alpha_i \ln p_i$$

$$(42) \qquad + \tfrac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} \alpha_{ij} \ln p_i \ln p_j + \sum_{i=1}^{n} \alpha_{iy} \ln p_i \ln y + \sum_{i=1}^{n}\sum_{k=1}^{m} \beta_{ik} \ln p_i \ln z_k$$

$$+ \sum_{k=1}^{m} \beta_k \ln z_k + \sum_{k=1}^{m} \beta_{ky} \ln z_k \ln y + \tfrac{1}{2}\sum_{k=1}^{m}\sum_{l=1}^{m} \beta_{kl} \ln z_k \ln z_l$$

Equation (42) illustrates how the short-run cost structure is conditional on the level of the quasi-fixed inputs. This kind of specification may therefore be applied to the short-run decision problem of the producer, or the case where the real capital stock is exogenously given, whereas variable inputs are free to respond to changes in input prices. With a panel data set for micro units, the procedures of chapter 3 may be employed to describe regional variation in the estimated parameters.

Factor demands, still in terms of cost shares, are given by:

(43) $$s_i = \alpha_i + \alpha_{iy} \ln y + \sum_{i=1}^{n} \alpha_{ij} \ln p_j + \sum_{k=1}^{m} \beta_{ik} \ln z_k$$

whereas the short-run shadow-price of the quasi-fixed inputs can be derived similarly as:

(44) $$\hat{p}_k = \beta_k + \beta_{ky} \ln y + \sum_{i=1}^{n} \beta_{ik} \ln p_i + \sum_{l=1}^{m} \beta_{kl} \ln z_l$$

For the case of real capital as a quasi-fixed input, these shadow prices indicate the magnitude of the marginal costs of not having adjusted the stock of real capital according to the optimal long-run level.

5.3 Regional user costs for real capital

In modelling real capital formation and investments, standard theory imply the reliance on some assumption that real capital in the long run will be directed towards industries and regions with a relatively high profit rate. This idea has characterized models of investment behaviour since Jorgenson (1963) introduced the neoclassical model of investment. However, the explicit formulations of the links between profitability and investment have taken different styles. Following Jorgenson (1963), the models of investment were gradually refined, incorporating explicit dynamics and adjustment cost (e.g. Eisner and Nadiri (1968)). The Q theory of investment (Tobin (1969)) related investment expenditures to the ratio of the financial value of the firm to the replacement cost of its capital stock. However, robust to all these formulations, whether static or dynamic, is the conclusion that investment expenditures are positively related to some measure of profitability[14].

To illustrate these links, we shall illustrate the neoclassical ideas of investment in a simple technical framework. The below exposition draws on Luger (1986), who estimates the impact on regional investments from the tax system via the regional depreciation profiles. With corporate taxes at a rate m, depreciation at a constant geometric rate δ, inflation at a rate π, and depreciation allowances u, the price (q) of an arbitrary asset may be written:

14 Chirinko (1993) offers an extensive review of modelling strategies, empirical results, and policy implications concerning investment behaviour. Having explored an impressive amount of empirical literature, he concludes that business fixed investments seem to be far more sensitive to changes in quantity variables than in price variables.

$$(45) \qquad q = \int_0^\infty g_0 (1 - m) e^{-\delta t} e^{-r(1-m)t} e^{\pi t} dt + qmu$$

assuming perfectly competitive markets. The first term on the right-hand side of equation (45) is the after-tax profit flow (g_0) discounted by the after-tax return to lenders. The second term is the discounted value of depreciation deductions, with u as the exogenous depreciation allowance. Solving by integration, Luger (1986) now gets for the rental price of cap services:

$$(46) \qquad \frac{g_0}{q} = [\, r(1-m) - \pi + \delta \,] \left[\frac{(1-mu)}{(1-m)} \right]$$

Equation (46) represents the general neoclassical investment rule, with linear taxes and geometric depreciation. It implies the equation of marginal discounted profits to the rental price of capital services. However, as we are concerned with implications concerning the regional dimension, a first step is to consider the variables of equation (46) which are likely to vary according to the location of production.

First, the tax system has a design which make tax rates vary significantly between industries, but also between regions within a country. Regional policies are often formulated to stimulate investment, employment, and production in sparsely populated areas. Norway may be characterized as a geographically extensive and sparsely populated country, at least by European standards. Together with a political concern for the provincial districts, this makes regional policy measures especially relevant in Norway, although the ideas naturally also have validity in a more general context. Second, the Norwegian tax system also comprises regionally differentiated possibilities for depreciation deductions. Third, producers may set aside capital in special funds, and the terms at which this takes place vary from region to region, a characteristic which is not included in equation (46). Thus, the Norwegian tax system is an important source of regional variation in the user costs of capital.

There are also regional variables *not* under public control which may affect the extent of regional investment. According to the new macroeconomic theory, financial market distortions and asymmetric information may cause regional variation in the interest rates[15]. Further, the rate of inflation will affect the investment decision, and this variable is also neglected in the simple model above. Nonetheless, public policy is likely to be a very important manipulator of regional incentives related to investments and capital formation.

According to the above discussion, empirical analyses of investment behaviour should include the problem of determining regional rental rates of real capital. As

15 For a survey of the literature on financial structure and macroeconomic activity, see Gertler (1986).

we have seen, rental rates of capital are determined mainly by capital prices, costs of finance, depreciation rates, and regional public policies. A reasonable point of departure is the establishment of some national reference for user cost of capital wti, from which regional deviations then could be measured. A recent empirical work by Holmøy et al. (1993) looks promising in this respect. In a neoclassical framework, historical rental rates for capital are constructed for a number of Norwegian industries over the period 1970 to 1990. Regional deviation from this national reference can be computed by taking account of economic policy and differing depreciation profiles because of regional variation in the combination of different types of capital equipment.

5.4 Discussion of other contributions

A relevant question when testing the hypothesis of regional homogenous investment behaviour is whether firms in different regions face the same terms of trade in capital markets. Over the last years, contributions to microeconomic investment theory have focused increasingly on how investment behaviour relates to factors like financial structure, and credit access. One conclusion from this literature is that the terms on which credit is offered depend on the project-information available to the lender. Thus, an intimate relationship between creditor and debtor is associated with favourable contracts. The availability of intimate information regarding borrowers and their projects is probably more usual in sparsely populated areas than in the cities. This suggests that the terms of observed credit contracts should vary systematically from region to region, thus also affecting investment behaviour.

One influential hypothesis in this literature has been that investment is positively related to the firm's net worth. The reason is that net worth is used by lenders as a proxy for collateral, and thereby for the default risk of the investment projects. Econometric methods and panel data has been taken into use to test this hypothesis. Deverux and Schiantarelli (1992) estimate investment functions for a panel of U.K. firms, whereas Johansen (1994) employs related techniques in an investigation of Norwegian manufacturing industries. Both these works report a negative relationship between investment and the debt ratio[16]. To the extent that financial structure vary systematically over the spatial dimension, these are aspects which may also contribute to the explanations of regional variation in investment behaviour and production technology.

In spite of the new microeconomic contributions, the traditional view still tends to be that competitive and unregulated capital markets provide the most efficient resource allocation. Accordingly, public regulation may cause rationing in the credit markets, especially if the government puts restrictions in the form of credit ceilings. This is thought to have been the case in Norway until the deregulation policies of the middle 1980s. This has caused problems for the treatment of capital formation in the Norwegian macroeconometric models. To the extent that credit

16 See also Hubbard (1990), which is a selection of conference papers on the area of asymmetric information, corporate finance, and investment.

was rationed prior to 1985 because of the government's credit policy, market mechanisms are likely to have had less influence on the intersectoral and interregional distribution of investments.

Neoclassical theories of investment may therefore not be appropriate to explain the evolution in real investments in Norway, at least not prior to 1985. Therefore, capital formation is seen in isolation from other inputs in the macroeconometric models MODAG and KVARTS. The demand for variable inputs is then conditioned on the amount of real capital, as in traditional short-run approaches. Accordingly, econometric models of investment in Norway should at least open for the possibility of a change of investment regime during the last 15 years. The simplest way of doing this is to introduce simple time dummies to test for the stability of the constant term.

However, with panel data techniques, far more sophisticated methods are also applicable (cf. Hsiao (1986)). One possibility is for example to let the parameters of the econometric model be time-dependent, and test statistically whether they have been stable over time. Panel data also allows us to utilize the cross-section variance between the production units involved. This reduces the necessity of bringing in periods prior to the liberation of the capital markets, thus escaping the most serious problems concerning historical negative rental rates.

The tax system is said to be neutral if the difference between the private and the social rate of return is the same for all businesses (see Biørn (1984, 1985a), Jorgenson and Yun-Kim (1989)). Variation in depreciation rates over production units and industries may thus produce a wedge between the private and the social rate of return that varies between different firms and activities, making the tax system depart from neutrality. Luger (1986) claims that depreciation policies in this way may have regional as well as sectoral dimensions. In the same way as depreciation policies create wedges between effective taxes in different production activities, it creates variation in effective tax rates over the regional dimension. Having efficiency and welfare implications, this adds an additional dimension to the discussion of neutrality in the tax system (see also Gerber and Hewitt (1987)).

Luger (1984) focuses on the employment effects from investment incentives, estimating different models for U.S. manufacturing industries. It is claimed that the employment effects from improving investment incentives may prove minimal. This is because the improved investment incentives crowd out more jobs via the substitution effects than they create via the accompanied increase in production. These conclusions find support also in a recent work by Daly et al. (1993), who estimate a long-run translog cost functions to evaluate the regional effects on employment from a regional investment tax program in Canada. The investment incentives program in question have increased the production level as planned, but the reduced cost of capital has also skewed the capital-to-labour ratio through input-substitution. On impact, the effect on employment has therefore been minimal. Daly et al.(1993) argue that employment subsidies would be far more effective, because the implied shift towards labour in this case would have reinforced the effects of increased production.

This kind of analyses has not yet been undertaken using regional data from Norwegian industries. The absence of demand for such analyses is also puzzling, as much of the regional bias of the Norwegian tax system is concentrated on investment incentives, such as subsidized finance and accelerated depreciation allowances[17].

It is widely recognized that the degree of capital utilization plays an important role, especially for the short-run production process. Most empirical analyses of producer behaviour are based on an assumption that capital services are proportional to the capital stock, and the capital stocks are used to approximate the flow of services. However, this assumption is violated as soon as the producers do not operate with optimal capital stocks. Epstein and Denny (1980) and Kim (1988) go about this problem by approaching the flow of capital services directly, leaving out the capital stock of their cost functions.

In a macroeconomic setting, Lesteberg (1979) and Cappelen and von der Fehr (1986) estimates rates of capital utilization in Norwegian industries, drawing on different varieties of the so-called Wharton index. This approach utilizes a simple proxy for potential production, and calibrates the rate of capacity utilization as actual production relative to potential production. To the extent that adjustment of the capacity responds sluggishly, such corrections should also be undertaken for the capital stock in the short-run input demand functions.

Until now, the notion of investment and real capital has been discussed within a static framework. However, the treatment has revealed that many features of the producer's demand for capital are characterized by a sluggish response to exogenous changes. To capture rigidities of capital and investment, a dynamic model is required. Between the somewhat narrow static formulation discussed above, and the fully specified dynamic model to be presented below, there is an intermediary alternative. That is to incorporate costs of adjustment in the static model. However, the limitations of this model in describing the path from the short-run to the long-run equilibrium may necessitate a truly intertemporal formulation. These issues are treated more explicitly in chapter 6, where different specifications are outlined to take explicit account of the regional dynamics of production technology and factor demand.

17 Torsvik (1989) argues that the puzzle may be resolved in a game-theoretic framework, because labour subsidies introduce problems of precommitment and time-consistency in the government's policy plans, which can be avoided by offering investment grants.

6. The regional dynamics of factor demand

6.1 Production technology and time

In chapter 3 we saw how the passage of time may cause shifts in the level of technology, a notion referred to as neutral technical change. This is one of the simplest interactions between production technology and the intertemporal dimension. The concept of time introduces a lot of other problems to deal with in the modelling of production technology. First, because the producer's foresight is imperfect, she will have to form expectations concerning future prices and sales (see Svendsen (1993)). As these expectations are typically uncertain, the resulting estimates has to be corrected for risk. Second, some commodities have intertemporal characteristics from nature. Real capital must be accumulated over time, it depreciates over time, and the input to production is measured as the flow of capital services per unit of time. More generally, inputs and outputs may pass through vintage profiles, during which their value appreciates in the beginning of their lifetime, before depreciation dominates in later periods.

Further, the market mechanism often function in a sluggish manner, suggesting that the process of adjustment should be incorporated explicitly. This is often seen as especially relevant for the capital market, as real capital goods are typically lumpy, making the investment process irregular and typically not smooth. Even capital goods that may be sold piece by piece are difficult to trade because markets for used capital equipment are non-present, or at best imperfect. Consequently, the investment decision has certain characteristics which call for the explicit formu-lation of forward-looking behaviour. To explain investment, the producer problem should therefore be modelled as a dynamic optimization problem.

In many respects, the labour market has similar characteristics. In chapter 4 we touched upon the measurement problems concerning man-hours versus the number of employees. To the producer this will typically introduce an intertemporal dimension to the problem, as the number of man-hours worked per period can be adjusted in the very short run, whereas the number of employees involve other types of adjustment costs. Rigidities of the labour market have also been the theme of a vast *theoretical* literature, but less has been done to offer empirical support to the theories by applying econometric methods of producer behaviour[18].

The implications of sluggishly adjusting input markets have been treated in various ways in the empirical literature on the area, but there is a main distinction between two groups of approaches. The first group is mainly concerned with the intertemporal dimension as seen from the producer's point of view. These works view the producer's optimization problem as truly dynamic. Consequently, they model intertemporal object functions and adjustment cost functions. The results from this kind of approach provide information on the costs of adjustment, and how these interact with the general structure of cost and production. Pindyck and Rotemberg (1983a,b) introduced methods for estimation of dynamic factor demands of this kind, and their methods are applied in a regional context by Luger and Evans (1988). Although methods are very explicit in modelling the cost of adjustment technology in a dynamic setting, the empirical results are *conditional* on the imposed adjustment cost function.

The second group originates in the statistical theory of dynamic modelling, especially time series modelling (Anderson and Blundell (1982)). The aim of these analyses is to describe the data-generating process, and they are not so worried about the intuitive connections to economic behaviour. Accordingly, these authors estimate generalized dynamic system of equations, where no explicit assumptions are made regarding the technology of adjustment. This leaves us with a flexible framework, where all dynamic properties are determined through the procedures of estimation. An example of this methodology is represented by the error-correction model (cf. Engle and Granger (1987)). The error-correction model is usually applied with macroeconomic time series data, but may also be used in the estimation of general dynamic specifications of microeconomic relationships, where panel data forms the empirical basis for estimation. We shall review both of these approaches more closely below.

6.2 Dynamic optimization and costs of adjustment

In a stochastic environment with adjustment costs, Pindyck and Rotemberg (1983a) assume that economic agents maximize the sum of expected discounted profits, which can be shown to imply minimization of the expected sum of discounted costs. Together with factor demand equations, the optimal path towards the long run equilibrium is solved, using also the first order conditions for the quasi-fixed factors, the so-called Euler equations. Applying a flexible functional form this enables Pindyck and Rotemberg (1983a) to estimate short-term as well as long-term technological parameters. The factor demands of Pindyck and Rotemberg (1983a) are derived from the following cost minimization problem:

$$(47) \qquad \min_{\{z\}} = E_t \left[\sum_{\tau = t}^{\infty} \Phi_{t\tau} \left\{ c\,(p_\tau, z_\tau, y_\tau) + r_\tau z_\tau + h\,(\dot{z}_\tau) \right\} \right]$$

18 For a review of the literature on dynamic labour demand modelling, see Nickell (1986). Dynamic models of capital formation and investment behaviour are surveyed by Chirinko (1993).

where E_t is the expectations operator taken at time t conditional on all future input prices and production, and $\Phi_{t\tau}$ is the discount factor applied at t for income accruing at τ:

$$(48) \qquad \Phi_{t\tau} = \frac{1}{1 + \psi_{t\tau}}$$

The real interest rate from t to τ is given by $\psi_{t\tau}$, reflecting the producer's preferences over intertemporal allocation of resources. The adjustment cost technology is represented by the function h, expressing the extent at which adjustment of quasi-fixed factors influence on operating costs. For variable inputs, this minimization problem gives as first order conditions:

$$(49) \qquad \frac{\partial c}{\partial p_t} = x_t$$

which represent input demand functions as described by Shephard's lemma. Let us now consider the effect on expected profits from installing another unit of the quasi-fixed factors. The traditional savings in variable costs would result, as the stock of quasi-fixed factors grow. However, additional costs would incur through the rental price of the quasi-fixed factors and through the adjustment costs. But in an intertemporal setting, the producer would also have to consider the effects on costs from the timing of the installing of quasi-fixed factors. These effects should all be uncovered by investigating the first-order conditions for the quasi-fixed factors.

Letting $\Phi_t \equiv \Phi_{t\,t+1}$, the first-order conditions with respect to quasi-fixed factors are represented by their Euler equations, describing the progression of these factors on the path towards the long run equilibrium:

$$(50) \qquad \frac{\partial c}{\partial z_t} + r_t + \Phi_t \frac{\partial h\,(\dot{z}_t)}{\partial z_t} - E_t \left[\Phi_t \frac{\partial h\,(\dot{z}_{t+1})}{\partial z_t} \right] = 0$$

Equation (50) represents the net effect on expected costs from an additional unit of the quasi-fixed factor, and it is stated that this should sum up to zero. The first term is the saved variable costs from installing quasi-fixed factors, the second is the rental price effect, and the third is the current adjustment cost. The last term is however additional to the models surveyed above, and describes the expected discounted cost savings from installing the quasi-fixed factor now, rather than in the future. In the long run, it must also be true:

$$(51) \qquad \lim_{\tau \to \infty} E_t \, \Phi_{t\,\tau} \left[\frac{\partial c}{\partial z_\tau} + r_\tau + \frac{\partial h}{\partial z_\tau} \right] = 0$$

Equation (51) states that the further into the future the producer look, the nearer should the stocks of quasi-fixed factors be to the quantities demanded in the absence of adjustment costs.

Pindyck and Rotemberg (1983a) specify a quadratic adjustment cost technology (h):

$$(52) \qquad h = \tfrac{1}{2}\,\beta\,\dot{z}_t^2$$

and for the cost function they use a translog form as follows[19]:

$$(53) \qquad \begin{aligned} \ln c\,(p\,,y\,,z\,) &= \alpha_0 + \alpha_y \ln y_t + \tfrac{1}{2}\,\alpha_{yy} \ln y_t^2 + \alpha_t\, t \\ &+ \sum_i \ln p_{it}\left[\tfrac{1}{2}\sum_j \alpha_{ij} \ln p_{jt} + \sum_l \alpha_{il} \ln z_{lt} + \alpha_{iy} \ln y_t + \alpha_i\right] \\ &+ \sum_l \ln z_{lt}\left[\tfrac{1}{2}\sum_m \theta_{lm} \ln z_{mt} + \theta_{ly} \ln y_t + \theta_l\right] \end{aligned}$$

Following equations (52) and (53), the first order conditions for flexible factors may now be equipped with the following parameters from the cost function:

$$(54) \qquad s_{it} = \alpha_0 + \sum_j \alpha_{ij}\, p_{jt} + \sum_k \alpha_{ik} \ln z_{kt} + \alpha_{iy} \ln y_t$$

And for the Euler equations we yield:

$$(55) \qquad \frac{c_t\, s_{kt}}{z_{kt}} + r_t + \beta_k\, \dot{z}_{kt} - E_t\left[\Phi_t\, \beta_k\, \dot{z}_{kt+1}\right] = 0$$

The cost function and the first-order conditions now make a system of regression equations that can be used to estimate technological parameters no matter what functional form the specifications may take. Using three-stage least squares, Pindyck and Rotemberg (1983a) estimate the cost function together with the first-order conditions (54) and (55), omitting one of the input share equations to prevent singularity of the estimated covariance matrix. This procedure provides estimates of short-run as well as long-run elasticities, depending on whether the stocks of quasi-fixed factors are adjusted to their optimum or not. Moreover, the results may create the basis of tests investigating if and how the hypotheses of quasi-fixed factors are supported by the data set.

19 Observe that this specification restricts possible technological innovation to *neutral* technical change at a *constant* rate.

Luger and Evans (1986) have adopted the framework of Pindyck and Rotemberg (1983a,b) to test different geographic invariance assumptions in the production technology of U.S. manufacturing. With only one variable factor, their technology specification is represented through a single input requirement equation, together with the Euler-equations for the quasi-fixed factors. Their results confirm that important technology parameters expose regional variation. First, the coefficients of the adjustment cost functions are significant for half of the cases investigated. Second, the marginal costs of adjustment vary over region in a way that can be explained using density arguments. Third, technical change and *TFP*-growth also differ between the two metropolitan areas under investigation. Fourth, estimated scale elasticities suggest that the effects of output increases varies over region for three of the four industries analyzed. Finally, substitution elasticities differ by location in most cases, illustrating that the isoquants of the technology are not invariant to the geographic dimension.

6.3 The error-correction model

Another approach to dynamic modelling of producer behaviour is more concerned with finding the appropriate technical formulation for the evolution of the data-generating process. According to this line of thought, the point of departure should always be an examination of the joint distributions of the involved variables, followed by the formulation of generalized dynamic models. However, recent contributions have concentrated increasingly on the error-correction formulation to represent the data-generating process. The error-correction approach sees changes in the dependent variables as depending on changes in the independent variables in addition to a so-called error-correction term. The error-correction term is estimate for the lagged deviation from the underlying equilibrium relationship.

The error-correction approach may be utilized within the full-blown translog framework. A recent example is given by Friesen (1993), who tests different dynamic specifications of factor demand in U.S. manufacturing industries. She concludes that the error-correction model has properties which make it dominate the other specifications, although it can not solve all the puzzles of dynamic specification. Lindquist (1993) estimates a dynamic translog cost structure for the Norwegian primary aluminium industry on the national level. Her results are also in favour of the error-correction specification.

This section is devoted to an application of the error-correction approach to a dynamic singular input demand system. An important assumption of the following exposition is that exogenous shocks in productivity and input prices cause deviations from the equilibrium input demand, and that producers respond to these deviation through continuous adjustment, or error-correction. One of the producer's problem must then be to decide on how large part of the equilibrium-error to be adjusted in each period, given information about the adjustment technology and the optimal long-run employment rule.

Letting x_{it} and x^*_{it} represent the observed amount of input and optimal factor demand, respectively, Nickell (1985, 1986) illustrates that the partial adjustment mechanism:

$$(56) \qquad \Delta x_t \equiv x_{it} - x_{it-1} = \lambda \left[x^*_{it-1} - x_{it-1} \right]$$

is supported by a wide class of dynamic optimization problems. The expression in the brackets may be thought of as a deviation from the underlying structural equilibrium, or an *equilibrium error*. Thus, our approach draws quite heavily on the error-correction models applied with time series data to analyze the economics of macroeconomic employment (e.g. Jenkinson (1986), Flaig and Steiner (1989) and Matthes and Schulze (1991)). As x^*_{it} in equation (56) is unobservable, we need a proxy for the deviation from the equilibrium labour demand. Following Engle and Granger (1987), an estimate for the *equilibrium error* (ecm_{it}) may be obtained by computing the difference between the observed amount of input and the amount which is optimal according to the estimated version of some equilibrium labour demand function. Thus, the change in the demand for production factors should depend on the change in the dependent variables, in addition to the lagged distance from some underlying structural relationship. This is equivalent to specifying the input demand functions as error-correction models, where the growth in the dependent variable depends both on current growth rates and lagged levels of the dependent variables.

As illustrated in chapter two, one of the equations of the simultaneous system has to be skipped during the estimation, to prevent singularity in the estimated covariance matrix. We remind that this is still the case. Factor demand will be represented by its share in total costs in the following, to remain consistent with the translog cost function approach. Now consider an equilibrium demand function for variable inputs, where the shares in variable costs (s_{it}) depend on the prices of variable inputs (p_{it}), on quasi-fixed factors (z_{lt}), and an exponential trend (t):

$$(57) \qquad s_{it} = \alpha_i + \sum_j \alpha_{ij} \ln p_{jt} + \sum_l \beta_{il} \ln z_{lt} + \gamma_{iy} \ln y_t + \delta_{it}\, t$$

A general stochastic formulation of the error-correction model for the above input demand function may be written:

$$(58) \qquad \dot{s}_{it} = a_{0i}\, \dot{y}_t + \sum_j a_{1ij}\, \dot{p}_{jt} + \sum_1 a_{2il}\, \dot{z}_{lt} + \sum_j \lambda_j\, ecm_{jt-1} + u_{it}$$

where dotted variables represent growth rates in per cent, u_{it} is empirical noise, and where the error-correction mechanism ecm_{it} is defined by:

$$(59) \qquad ecm_{jt} = s_{jt} - \left[\alpha_j + \sum_k \alpha_{jk} \ln p_{kt} + \sum_l \beta_{il} \ln z_{lt} + \gamma_{jy} \ln y_t + \delta_{jt}\, t \right]$$

Observe that this specification neglects lagged differences of all variables. General specifications of the error-correction model for time series data include both these transformations of the variables of the model. However, Nickell (1981) discusses some problems of panel data estimation of dynamic models with fixed effects. More precisely, Nickell (1981) concludes that the estimated variances of the parameters will be inefficient if the lagged dependent variable is included in this kind of models. This is the reason for excluding the lagged change in s_t in equation (58).

In general formulations of the error-correction model, lagged changes in the explanatory variables should also be included. This is done by Lindquist (1993), but she rejects this general model in favour of a simplified version which is very similar to that of equation (58). However, one should be careful not to draw general conclusions from the case study of Lindquist (1993). The choice of independent variables should rather be a result of repeated estimation. In our example, lagged changes in explanatory variables are excluded mostly for simplicity of exposition.

The error-correction coefficient in equation (58) is given by λ_{ij}. This magnitude measures the share of the deviation from the long-run equilibrium which is adjusted in every period. Thus, it also captures some of the sluggishness of the dynamic process. According to the above discussions, the error-correction coefficient should be allowed to vary over the regional dimension. This may be accomplished by applying regional dummy variables, as described in chapter 3.

In principle, all the coefficients of equation (58) may actually vary from region to region. Therefore, when estimating the model, the point of departure should be a general econometric formulation where as many as possible of the parameters are allowed to vary between regions. During the stepwise approach of the preferred estimated model, insignificant regional dummies should then be left out. This will provide us with an estimated model where regional variation in the parameters is gradually revealed through repeated econometric procedures. Mohn (1993) offers a simplified approach, estimating dynamic regional labour demand equations which are consistent with Cobb-Douglas production technology.

There are mainly two methods of estimating the error-correction model. First, there is the two-step approach advocated by Engle and Granger (1987). The first step involves the direct estimation of a structural relationship like the one in equation (57). An estimate for the error-correction mechanism is then derived for all units of the data set according to equation (59). In the second step, the estimated error-correction mechanism is inserted as a predetermined variable in the dynamic specification of equation (58), and this equation may next be estimated by standard econometric procedures.

A second method of estimating the error-correction model is to include both changes and lagged levels in a general specification like equation (58), and then to estimate the error-correction equation directly. With a generalized simultanous specification like equation (58), this involves a large amount of restrictions, because of the cross-interaction terms of the error-correction matrix. To illustrate the procedure, we therefore assume that all the off-diagonal elements of the error-correction matrix equal zero, implying that:

$$\lambda_{ij} = 0 \quad \forall \quad i \neq j$$

Under this assumption, the error-correction model of equation (58) may be specified directly as:

$$\begin{aligned} \dot{s}_{it} &= a_{0i}\,\dot{y}_t + \sum_j a_{1ij}\,\dot{p}_{jt} + \sum_l a_{2il}\,\dot{z}_{lt} \\ &\lambda_i\, s_{it-1} + b_{0i} + \sum_j b_{1ij}\,p_{jt-1} + \sum_l b_{2il}\,z_{lt-1} + b_{3i}\,y_{t-1} + b_{4i}\,t + u_{it} \end{aligned} \tag{61}$$

Specified in this way, the error-correction model implicitly embodies an underlying structural relationship of the kind represented by equation (57). That is: All structural properties of the labour demand can be derived from an estimated version of the dynamic error-correction model. The long-run relationship is defined as a situation where the changes in the involved variables all approach zero, leaving us with a relationship in the levels of the variables involved. This implies that the error-correction model is reduced to an equation from which the long-run coefficients of equation (61) may readily be derived as:

$$\alpha_{0i} = -\frac{b_{0i}}{\lambda_i} \qquad \alpha_{ij} = -\frac{b_{1ij}}{\lambda_i} \qquad \beta_{i1} = -\frac{b_{2il}}{\lambda_i}$$

$$\gamma_{iy} = -\frac{b_{3i}}{\lambda_i} \qquad \delta_{iy} = -\frac{b_{4i}}{\lambda_i}$$

Regional variation in economic behaviour may be introduced by letting the parameters of the error-correction model vary between regions. As mentioned above, special concern might have to be paid to regional variation in the sluggishness of the adjustment process. This implies a formulation where the error-correction coefficient is allowed to vary between regions. However, when estimating this kind of model for regional analyses, as a point of departure, one should allow for regional variation in as many as possible of the effects involved, to let the data set reveal the significance of such variation through the procedures of consecutive estimation.

The error-correction model represents a flexible model framework, where short-run dynamics may be separated from the underlying structural relations. The estimated coefficients thus embody both short-term effects from exogenous shocks, as well as the long run impact. Further, the error-correction model offers a plausible description of the sluggishness which often characterize the data-generating process behind economic time series. However, there are pitfalls involved. The main problem is that the error-correction model does not offer a proper *behavioural* interpretation of the relationship between the error-correction mechanism and the structural model, or the long-run relationship. This leaves many interesting questions concerning economic behaviour unsettled.

First, the literature on error-correction and cointegration has so far not come up with explanations what the error-correction coefficient really tell us about economic behaviour, although Granger (1986) makes a well-intended attempt. Granger (1986) suggests that the error-correction coefficient might be a positive function of the deviation from the long-run equilibrium, thus varying between different production units (and/or between regions). This is supposed to reflect an idea that economic agents located near the long-run equilibrium devote less resources to adjustment than units completely astray. This is one of several ideas which desperately want further research.

Second, the error-correction approach is not explicit with respect to the *costs* of adjustment, or the costs of error-correction. A intuitive assumption would be that firms that have to devote resources to adjustment somehow had less resources left for productive activities. If shocks and rigidities were aspects connected to labour markets only, whereas markets for other variable inputs were more perfect, one might also believe that firms to some extent would substitute labour for other variable inputs. Mohn (1993) touches upon these problems, allowing for regional variation in the error-correction coefficient of dynamic labour demand equations. This variation is assumed to reflect regional variation in exogenous shocks, an in the sluggishness of the employment process. The impact of the exact form of the error-correction mechanism also calls for further research. The general error-correction literature so far offers no answers to these important problems concerning producer behaviour and employment.

Third, there might be good reasons to be interested in the interaction between cost structure, rigid labour markets, and the process of technical change and productivity growth. If labour markets are sluggish to respond to exogenous changes, and the production process is characterized by continuous shocks in actual demand and input prices, the costs of employment adjustment are likely to be high. Based on a hypothesis that these costs of adjustment crowd out R&D-expenses, it could be tempting to investigate to which extent the costs of adjustment give rise to regional variation in the rate of technical innovation. The presented error-correction model is still not very generous in offering possibilities for research into this kind of problems.

7. Concluding remarks

This study has reviewed some of the economic literature concerned with empirical analyses of regional producer behaviour. We have seen that the duality principles of microeconomic theory implies that the technology of production is completely characterized by an estimated version of the cost function. Further, these duality principles of cost and production imply that *any* cost function which meets certain requirements will represent a well-behaved neo-classical technology. This may make the theoretical framework look simple and straight-forward. However, there are still lots of problems and pitfalls. First, there are important methodological questions involving measurement and econometric problems. Second, there are problems concerning the choice of mathematical specification of real-world economic phenomena. The general conclusion from this part of the study is that the simplicity of some of the technical models may block for proper descriptions of real-world phenomena. On the other hand, a sophisticated technical model may easily suffer from the lack of proper data, and with a disaggregated regional dimension it may also grow untractable.

Until now, regional analyses of producer behaviour in the Research Department in Statistics Norway have been conducted with the purpose of implementation in regional macroeconometric models. This means that the data has consisted of a limited number of aggregate regional time series. This kind of data has been extracted from the regional economic accounts at Statistics Norway, an important data source also for future analyses. This study suggests that considerable gains can be achieved through a transition to panel data, where these are available. Applying time series information for micro units and corresponding econometric methods will offer an explosion in the number of possible extensions. To increase the understanding of regional variations in the structure of production and cost, one should therefore incorporate also the cross-sectional variation of the data set in empirical analyses of regional producer behaviour. This kind of data is available at the regional level through the manufacturing statistics time series data base at Statistics Norway. For manufacturing industries, a powerful data source is at hand, also for analyses of regional producer behaviour.

Chapter 2 discussed the choice of functional form. To be able to address aspects concerning regional variation in technological flexibility, the chosen functional forms should allow for regional variation in the elasticities of substitution. For illustrative purposes of the most general cases, the translog cost function has been chosen as the empirical specification of the underlying cost structure. However, the CES cost function will do in cases with less than three inputs. For the two-factor case, this functional form also represents a local second-order approximation to an arbitrary neoclassical cost function. Still, the translog functional form proves an appropriate specification for regional analyses of input demand systems with more than two variable factors of production.

The discussion in chapter 3 acknowledges the fact that there may be spatial features affecting the structure of cost and production, especially through regional variation in the rate of productivity growth. Some of these regional characteristics can be related to ideas within the literature on so-called new growth theory. Regional attributes that may contribute to the explanation of regional productivity differentials include agglomeration variables, access to input and output markets, research activities, public regulations, and environmental variables. Variables may be constructed to account for the variation in these endowments, and such measures should be included in future studies of regional producer behaviour, at least when the focus is on productivity growth.

The labour market is usually looked upon in terms of national estimates of labour demand and supply. Further, demand for labour is too often characterized under the assumption of homogenous employees, neglection important socio-economic characteristics of the plant-specific labour force. Sex, age, and education are examples of characteristics which make the labour force heterogenous. Regional analyses of labour demand in Norway should at least look closer into the demand for different skills and different levels of education. This could help us to understand the responsiveness of labour demand to changes in the educational composition of the total labour force.

The economic behaviour underlying real capital formation in Norway has been difficult to describe empirically on the basis of historical data. This is due to the fact that Norwegian markets for capital were regulated until the middle of the 1980s. To the extent that panel data for micro units is available to analyze investment demand for the period after 1985, real capital should be included as a variable input, allowing for changes in the costs of finance to be reflected in the rates of business fixed investment spending. As the time series data base of manufacturing industrires acquires more years of observation, this will be a preferrable strategy. On the other hand, empirical analyses of regional producer behaviour may still have to rely on aggregate time series data including many years of public credit controls and negative rental rates for real capital. In this case, it may still be the best solution to model investment demand in an ad hoc manner, and make demand for variable inputs contingent on the existing stock of real capital.

The regional dynamics of input demand is important when it comes to quasi-dynamic inputs like real capital. However, following the theoretical literature on labour market rigidities, there are empirical studies that also suggest that labour is a quasi-fixed factor of production. The degree of sophistication in the dynamic modellling will have to depend on how subtle the analysis of other aspects is set up. If dynamic modelling is chosen primarily because it can improve the econometric specification in terms of statistical diagnostics, the error-correction model will suffice. However, this approach does not offer a proper *behavioural* interpretation of the relationship between the incorporated dynamics and the structural model, or the long-run relationship. If the focus is at dynamic economic behaviour, one should therefore submit to more explicite formulations of the producer's intertemporal decision problem.

As mentioned in the introduction, models incorporating all these features soon grow very complicated. For many cases, one therefore has to rely on simplified specifications, including the most important subset of the aspects above. For rough predictions of aggregate measures for production, input demand and employment, this may suffice. Still, the disclosure of subtle details behind regional economic producer behaviour will also require a more complex technical framework.

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