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The Theoretical Framework and Methodology to Estimate the Farm Labour and Other Factor-Derived Demand and Output Supply Systems

ABSTRACT

This paper provides a conceptual framework for the estimation of the farm labour and other factor-derived demand and output supply systems. In order to analyse the drivers of labour demand in agriculture and account for the impact of policies on those decisions, it is necessary to acknowledge the interaction between the different factor markets. For this purpose, we present a review of the theoretical background to primal and dual representations of production and some empirical literature that has made use of derived demand systems. The main focus of the empirical work is to study the effect of market distortions in one market, through inefficient pricing, on the demand for other inputs. Therefore, own-price and cross-price elasticities of demand become key variables in the analysis. The dual cost function is selected as the most appropriate approach, where input prices are assumed to be exogenous. A commonly employed specification – and one that is particularly convenient due to its flexible form – is the translog cost function. The analysis consists of estimating the system of cost-share equations, in order to obtain the derived demand functions for inputs. Thus, the elasticities of factor substitution can be used to examine the complementarity/substitutability between inputs.

FACTOR MARKETS Working Papers present work being conducted within the FACTOR MARKETS research project, which analyses and compares the functioning of factor markets for agriculture in the member states, candidate countries and the EU as a whole, with a view to stimulating reactions from other experts in the field. See the back cover for more information on the project. Unless otherwise indicated, the views expressed are attributable only to the authors in a personal capacity and not to any institution with which they are associated.

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The Theoretical Framework and Methodology to Estimate the Farm Labour and Other Factor-Derived Demand and Output Supply Systems

Barbara Tocco, Alastair Bailey and Sophia Davidova*

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1. Introduction

This deliverable is part of Work Package 10, the objective of which is to provide a conceptual framework for the empirical analysis of labour markets. In order to analyse the drivers of labour demand in agriculture and the impact of policy on those decisions, it becomes important to develop a theoretical framework within which to study the impact of peculiarities in different factor markets upon the demand for labour. Therefore, it is necessary to acknowledge the interactions between the different factor markets in agriculture, as the optimum level of labour employed depends upon the demand for other inputs and on the output produced. Also the impact of policies and the conditions of factor markets need to be taken into account.

For instance, the capitalisation of CAP payments, both those of Single Farm Payment (SFP) or Single Area Payment Scheme (SAPS) and agri-environment, into land will likely reduce the relative price of both labour and capital. Consequently, it could be expected that farmers would substitute more labour and capital for land. However, the higher marginal cost of production due to the higher land values should see farmers scale back their output level and thus reduce their demand for labour and other factors. Whichever is the larger of these two effects will determine the direction and magnitude of the impact on the demand for, and earnings of, both labour and capital. Relative input factor prices do play a significant role in the determination of the demands for the various factors. Factors which influence relative prices will have an influence upon the factor mix in production and, conversely, factors which influence the composition of output will indirectly have an effect upon factor prices and resource allocation (Woodland, 1975). Other policies or peculiarities in factor markets which may have a non-trivial impact on the demand for farm labour also include the provision of a minimum wage legislation in agriculture and a low rural representation of the financial sector, reflecting the presence of credit constraints.

In general, factor market imperfections would be expected to drive a wedge between efficient and observed factor prices. This will have implications for the relative factor price, demand and earnings. In addition, public R&D policy could alter the relative marginal products of different factors of production (biased technical progress) which would also affect relative demand and in the long-run relative factor prices and earnings, and in particular farm labour earnings. Therefore, the objective of the paper is to develop a theoretically consistent analytical framework within which to study the farm labour and other factor derived demand and output supply systems. In particular, the estimation of factor substitution elasticities, the degree of capitalisation, and the share of land in total cost become key variables in this analysis.

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This conceptual framework forms the basis of devising the theoretical model and methodology for the empirical estimation of the derived demand for labour. For this purpose, the study includes a review of the theoretical background to primal and dual representations of production, with a brief discussion on the choice over different functional forms and related properties. Furthermore, a review of the empirical literature, which underpins the empirical estimation of derived factor demand systems, has also been undertaken. A dual cost function approach has been selected and therefore its functional form and specification are outlined in the last section.

2. The Derived Demand for Farm Labour

First of all, the demand for all factors of production, including labour, is a derived demand, as the demand for the factors of production is dependent on the demand for the outputs that they produce. Secondly, the empirical analysis of labour demand in agriculture requires a careful analysis of the drivers which affect the demand for the different factors, and the impact of policy on those decisions. A brief summary of the variables which affect the production process and need to be taken into account can be summarised in the following points:

a) The relative price of inputs, which does play a significant role in the determination of the demand for the individual factors of production.

b) The factors influencing the relative price of inputs, which have an influence upon the factor mix in production, in addition to:

c) Input market imperfections, which are expected to drive a wedge between efficient and observed factor prices;

d) Other input market interventions.

e) The factors influencing the output level and its composition, which have an indirect effect upon factor prices and resource allocation, and thus:

f) Output market imperfections.

g) R&D policy and biased technical progress, as public R&D policy could alter the relative marginal products of different factors of production, i.e. biased technical progress, which would also affect relative demand, and in the long-run relative factor prices and earnings.

The relationship between inputs and outputs in a production process is formalised by a production function, which is outlined in more detail in the next section.

3. Production Functions and Measurement Issues

The simplest and most common way to describe the technology of a firm is the production function, which summarises the production possibilities of the firm, depicting combinations of inputs and outputs that are technologically feasible. The production function can be simply defined as:

$$Y = f\,(L, K, M, \ldots) \tag{1}$$

Hence, the firm's output of a particular good produced at a particular time (Y) is a function of hours of labour input (L), capital usage or machinery (K), raw materials used (M), and other variables affecting the production process. In general, a production function shows the maximum amount of a good that can be produced using alternative combinations of inputs.

For simplicity, microeconomic theory begins any sort of analysis with a two-input production function, which depicts the maximum amount of the good that can be produced using alternative combinations of labour and capital. One of the key concepts in the empirical analysis of factor demand is the complementarity or substitutability of inputs, i.e. the degree to which a pair of factors substitute for one another to produce a given level of Y. Hence, the elasticity of substitution (σ) for the production function Y = f (L, K) measures the proportionate change in K/L relative to the proportionate change in the marginal rate of technical substitution along an isoquant, so that:

$$\sigma = \frac{percent\ \Delta\ (K/L)}{percent\ \Delta\ RTS} = \frac{d\ (K/L)}{d\ RTS} \cdot \frac{RTS}{K/L} = \frac{\partial\ ln\ K/L}{\partial\ ln\ RTS} = \frac{\partial\ ln\ K/L}{\partial\ ln\ f_L/f_K} \tag{2}$$

Although it is often convenient to assume that σ is constant along an isoquant (i.e. holding output constant), in real production processes with n inputs, it is likely that any changes in the ratio of two inputs will also be accompanied by changes in the use of other inputs. As some of these inputs may be complementary (or substitutes) with the ones being changed, to hold them constant would create a rather artificial restriction (Nicholson, 2005). Therefore, this parameter forms an essential component of input demand and production relationships, describing the extent to which changing factor prices influence input demand and hence optimal production techniques.

An important consideration to be made concerns technical progress: since methods of production may improve over time, it is essential that these improvements are captured in the production function framework. The simple equation would then be:

$$Y = A\ (t)\ f\ (L, K) \tag{3}$$

where changes in A over time represents technical progress (dA/dt > 0). In particular, the rate of growth in output can be broken down into two sub-components: growth attributed to changes in inputs and other residual growth (A) that captures technical progress. Hence, growth accounting can be used to estimate the relative importance of technical progress in determining the growth of output. This methodology, pioneered by Solow (1957), allows to measure the contribution of the different production factors to output growth and to indirectly compute the rate of technological progress (as residual) in the economy. Hence, the growth equation is:

$$G_Y = G_A + e_{Y,L}\ G_L + e_{Y,K}\ G_K \tag{4}$$

where $e_{Y,L}$ is the elasticity of output with respect to labour input and $e_{Y,K}$ is the elasticity of output with respect to capital input.

Moreover, it is essential to distinguish between neutral and biased technical change. Neutral technical change is a parallel movement of the isoquant inwards towards the origin, and it implies an equiproportional reduction in the quantity of all resources required to produce a given output and, *ceteris paribus*, leave factor ratios unaltered, or alternatively more output for the same level of resources (Ellis, 1993). It is neutral as it does not affect the combination of labour and capital used in production. Alternatively, if technical change is, for instance, biased in favour of capital and against labour the isoquant will be skewed inwards making it much steeper. The change of slope means that more labour is displaced for a given increase in capital than on the previous isoquant, so that the marginal rate of substitution of capital for labour increases between the two technologies. This biased technical change is capital-biased or labour-saving. Technical change bias is identified according to whether the income share of a factor rises, stays the same, or decreases, for constant factor proportions, i.e. with respect to the constant K/L ratio known as Hicks' neutrality. In order to estimate biases it is not possible to simply look at historical factor share changes, as the observed share changes have come about through both biased technical change and relative prices induced factor substitution. Thus, the problem is to understand to what extent the share changes have been due to biased technical change and to what extent to price changes. The substitution parameters of the production process have to be estimated before any biases can be measured (Binswanger, 1974b). Hence, in order to explain the direction of technical change, relative factor prices must be brought into the picture.

Empirical estimation in production analysis is based on two main approaches. The primal approach consists of specifying a functional form for the production function and then solving the cost minimisation problem. Essentially the firm is faced with the constrained minimisation problem, i.e. produce output with the minimal costs. In order to minimise costs, the firm should produce at that point on the isoquant at which the rate of technical substitution of labour for capital is equal to the ratio of the inputs' rental prices (w/r) (Johnson, 2005). From a mathematical point of view, the constrained optimisation problem can be solved through the Lagrange multiplier method. At the same time, profit maximisation requires that the firms hire each input up to the point where its marginal contribution to revenue is equal to its market price.

The first-order conditions of the cost minimisation problem, given the prices, lead to an implicit demand for inputs, which is contingent on the level of output being produced. Moreover, the production function approach is based on the physical quantities of inputs, which can be considered endogenous variables to the firm. Instead, in a more realistic setting, decisions on factor use are made according to factor prices, which are exogenous. Therefore, we will now turn the discussion to the dual approach.

4. Duality: Specifying Cost and Profit Functions

Over the last three decades there has been a movement from the 'primal approach', based on the production function, to the 'dual approach'. The latter offers a simple way of deriving input demand and output supply systems directly from the dual objective function. One of the advantages of the duality approach is the ability to accommodate a multiple output as well as a multiple input framework. As it was first shown rigorously by Shephard (1953), there exists a duality between production and cost functions, which implies that if producers minimise input costs then the cost function contains sufficient information to completely describe the technology (Woodland, 1975). Essentially a cost function can be simply defined as:

$$C = f\,(Y, w) \tag{5}$$

where cost (C) is a function of output (Y), which is predetermined, and of input prices (w). The advantages of specifying the cost function are that: a) the factor levels are now endogenous; 2. the input demand functions for the factors of production can be easily derived as the partial derivatives of the total-cost function with respect to the factor prices (Shephard's lemma). Because the output produced enters the total-cost function, input demand is contingent on that variable and this is why we refer as 'contingent' demand functions (Nicholson, 2005). Dividing these functions by the output level yields the input demand functions per unit of output, or the input-output coefficient functions. Hence, the demand equations do not represent a complete picture of input demand since they still depend on a variable that is under the firm's control. An alternative approach consists of specifying a profit function:

$$\Pi = f\,(p, w) \tag{6}$$

where the firm's profits (Π) depend only on the prices that the firm faces for inputs (w) and for output (p). In the process of profit maximisation the firm chooses levels of both output and inputs in order to maximise profits, subject to the exogenous prices of the inputs and the market price of the output produced. Since the profit maximising equations also imply cost minimisation, the first-order conditions in a profit-maximising process can be used to yield input demand functions (Hotelling's lemma), so that the demand for a particular input (as well as output supply) depends on the prices faced by the firm. In this sense, these input demand functions are 'unconditional' as they allow the firm to adjust its output to changes in prices (Nicholson, 2005).

An interesting question which has been investigated in several studies is the effect of a change in the price of an input on the demand for other inputs. For instance, if the market price of labour falls, there will not only be a change in the amount of labour demanded, but also a change in the amount of capital, as a new cost-minimising combination of inputs must be chosen. The total effect on labour due to a change in the wage can be decomposed into a substitution effect and in an output effect. The combined effects work in the same direction and increase the amount of labour hired in response to a decrease in the real wage. Hence, the inputs own-price elasticity of demand is negative. On the other hand, no definite statement can be made about the cross-price effects, i.e. how other inputs change in response to a price change in, for instance, labour. A fall in the wage will cause a substitution effect away from capital, as capital is relatively more expensive and thus less of it will be used in the production process. On the other hand, the output effect will cause more capital to be demanded as part of the firm's increased production plan. In general, the total effect on the demand for capital depends on whether these two inputs are complements or substitutes, so that the cross-price elasticities of demand are negative for complements and are positive for substitutes.

5. Functional Forms and Properties

A comprehensive review of traditional and popular functional forms used in production analysis has been carried out by Griffin et al. (1987), who identify twenty functional forms and categorise them according to their intrinsic properties. As recognised by these authors, "the researcher is never in a position to know the true functional form" so that the choice of a particular function is justified by the fact that it is more appropriate in comparison to others. Preferred functional form depends on a variety of things, including theory, underlying technology, research objectives and data (Anderson et al., 1996). More importantly, since functional forms are both data and model specific, and because the empirical estimates, including own-price elasticities, elasticities of substitution and returns to scale, are very sensitive to the choice of the functional form, it is fundamental to consider different functional forms and test their validity. However, since there is no absolute best functional form dominating the others *a priori*, knowledge of the production process under analysis may be helpful in selecting the most suitable form for the specific research objective.

First of all, some choice criteria must be considered. These include the maintained hypotheses implied by a certain function, statistical parameter estimation and data-specific considerations. Since the maintained hypotheses are assumed true, the choice of a particular functional form will render some of the hypotheses untestable (since they are maintained). As a general rule, we want to choose a parametric form for which some values of the parameters satisfy the restrictions required by theory. If our statistical tests do not reject some particular parametric restrictions, we may want to estimate the model imposing those restrictions as maintained hypotheses. If the hypothesis is true, the resulting estimates will generally be better than the unconstrained estimates. Conversely, if there is no clear theoretical or empirical basis for a maintained hypothesis, or if that particular property were the focus of the study, the unrestrictive functional form may be preferred. In general, and especially in the last 3 decades, 'flexible' functional forms are those in common usage, as they impose fewer prior restrictions upon the production relationships, and in particular they do not place prior restrictions upon the elasticity of factor substitution. Although these less restrictive functional forms are more desirable, they often require more information and thus may come at the expense of parameter estimation.

The most common concerns in regards to maintained hypotheses include homogeneity, homotheticity, elasticity of substitution, and concavity. Linear homogeneity implies that when all the inputs in production double, the total output has to double, i.e. the production function is homogenous of degree one. For instance, a Leontief production function is linearly homogenous, whereas a Cobb-Douglas function requires that linear homogeneity must be imposed. For a homothetic production function the marginal rate of technical substitution remains constant as all inputs are increased proportionately. This implies that any change in the value of output will affect the optimum input levels proportionately as long as input prices are unchanged. Examples of homothetic production functions include the following: linear, Leontief, Cobb-Douglas. The flexibility of a functional form generally concerns the elasticity of substitution, and thus the marginal rate of technical substitution. Although the constant elasticity of substitution (CES) production function represents a much studied class of functional forms, such a maintained hypothesis might be undesirable in empirical work. Instead, more flexible functional forms allow the estimation of individual elasticities of substitution, i.e. the relative ease with which one input may be substituted for another. Since these functional forms also permit the estimation of substitution elasticities for systems with more than two factors of production they seem to be generally preferred: the two most commonly used are the generalised Leontief and the translog. Lastly, concavity implies that output increases at a decreasing rate as the level of inputs is increased. This property becomes important in the context of economic optimisation: only if the function is concave can input levels that maximise profits be computed from first-order conditions and can we consider the function to be well-behaved and thus yield downward sloping demand and upward sloping supply functions.

6. Review of Empirical Literature

This section of the paper is concerned with a review of the empirical literature which has made use of derived demand systems. This search is of particular importance because it will form the basis of devising the theoretical model and methodology for studying the derived demand for labour in agriculture. We have attempted to proceed with a systematic search from the JSTOR online archive, using specific key words, namely: 'demand for inputs', 'factors of production', 'system of demand equations', 'profit function', 'factor substitution', 'cross-elasticity of demand', 'elasticity of inputs', 'factor bias', 'technological change'. The empirical studies have been selected and categorised according to the objective function (whether a primal or dual approach was employed), the choice of the functional form, the type of data used (time-series versus cross-section) and the methodology employed (Table 1). As emphasised by Mundlak and Hellighausen (1982) differences in results across studies reflect formulation, statistical technique and sample coverage, and most importantly, results cannot be compared when different outputs and inputs are aggregated into different groups.

We are now interested in drawing some general conclusions from this review of empirical literature. First of all, the most frequently used functional forms in production analysis are those 'flexible' functional forms, which pose no *a priori* restrictions on substitution elasticities. In particular, as noted by Anderson et al. (1996), the three functional forms that have dominated the empirical production economics literature are the translog, generalised Leontief, and quadratic functions. Secondly, one of the key issues emerging from this literature concerns the mixed evidence on the complementarity/substitutability among inputs. The large body of literature seems to agree on the fact that capital and labour are substitutes in production, whereas instead there has been a strong support towards the complementarity of land and capital. Moreover, the majority of the studies, often due to data limitations, have treated hired and family labour as a single input, hence assuming their perfect substitutability. Conversely, Lopez (1984) differentiates labour into family and hired. As supported by his empirical findings, hired labour and operator labour appear to be net complements rather than substitutes and respond very differently to changes in input and output prices, with hired labour being more responsive to price changes than operator labour (almost totally inelastic). This would suggest that they should be treated as different inputs, as they perform specialised and diverse activities that cannot be easily interchanged.

Differences in the results have also emphasised the way in which technical progress is treated, as it becomes important to distinguish among neutral and biased technical change. For instance, several studies provide support for factor-augmenting technological change, and particularly for labour saving and capital-using technical change (Lianos, 1971; Binswanger, 1974a). In this regard, an interesting technique is the decomposition analysis, firstly employed by Kako (1978), which, as defined by the author, contributes to the understanding of "the extent to which changes in factor prices affect the derived demands for inputs and the contribution of technical change to the saving of scarce resources". The main findings confirm that technical change effects are negative for all five inputs, and those of scarce resources, land and labour, are larger than the technical change effects of the other inputs. As a consequence, the decline in the labour input is mainly attributable to labour-saving technical change, whereas the substitution of machinery for labour due to the change in machinery price is quite small.

Before proceeding with a more detailed discussion of the empirical results, we must bear in mind that the choice of a specific functional form entails some maintained hypotheses which are assumed to be true. Hence, the choice of a functional form should be in line with economic theory and some properties should be tested instead. For instance, Lopez (1980) rejects the hypothesis of constant returns to scale, implying that the underlying production technology is non-homothetic. On the other hand, the hypothesis of zero factor augmenting technical progress could not be rejected: the reduction in labour-capital ratio may be due to relative price and output expansion effect (economies of scale) rather than to biased technological progress.

Starting with those authors who relied on a primal approach, Lianos (1971) estimates an aggregate CES production function with two factors (capital and labour) from US time-series data. The estimation is based on a constant elasticity of substitution production function which assumed factor-augmenting technological change and constant returns to scale. His results would suggest that American agriculture is characterised by technological progress that is factor-augmenting, hence enhancing the productivity of capital with respect to labour. Hence, the elasticity of substitution and the increased marginal product of capital (relative to labour) have contributed to a decline in labour's relative share in US agriculture for the period 1949-68. Thirsk (1974) develops a three-factor model and examines the ease of substitution for different Colombian crops among different factor pairs, using cross-sectional data for the year 1968. The main results suggest a high elasticity of substitution between farm machinery and labour (close to 1.5) and conversely a negative elasticity of substitution between machinery and land, suggesting a complementarity relationship. Thus, the declining labour share in agriculture is consistent with an elasticity of substitution between labour and other factors greater than unity.

Vincent (1977) formulates a model of derived demand for primary factors of production (land, labour and capital) for Australian agriculture, using time-series for the period 1920-21 to 1969-70. The main findings would point at the fact that primary factor inputs in Australian agriculture have been largely unresponsive to changes in their relative prices. The elasticities of factor substitution are close to zero, implying very low technical prospects for substitution among primary inputs. The highest value is given by the capital-labour elasticity of substitution, followed by the labour-land elasticity, whereas land and capital appear to be complements. Moreover, efficiency growth (the annual percentage rate of factor augmentation) of land exceeds efficiency growth of labour which in turn exceeds efficiency growth of capital. Mundlak and Hellinghausen (1982) rely on an aggregate production function for the estimation of factor productivity in agriculture. Using a sample of fifty-eight countries, during the period 1960-1975, they assume that all countries have access to the same technology, although different countries use different production techniques. The choice of the implemented technique is determined by the state variables, which are resource endowments and represent the physical and economic environment within which the firms operate. The authors obtain a net positive effect of the state variables on output and positive production elasticities of the factors. The high share of capital (0.5) can be attributed to unobservable capital items such as human capital and infrastructure.

Most of the studies reviewed utilise a cost function, of which the most common functional form seem to be the translog cost function. Binswanger (1974a), using a single-output translog cost function with pooled-cross sections for thirty-nine US states, derives estimates of elasticities of derived demand and of elasticities of substitution for the US agricultural sector for the period 1949-1964. The results would suggest that technical change was non-neutral during the period of analysis and that it was labour-saving and machinery-using, with non-neutral regional efficiency differences. The Allen partial elasticities of substitution would imply complementarity of fertiliser and labour whereas the best substitutes are land and fertiliser; as expected, there is a small elasticity of substitution between land and labour whereas surprisingly machinery is a better substitute for land than for labour. In another study with the same functional form and the same data, Binswanger (1974b) focuses on measuring technical change biases with many factors of production in US agriculture. As a result, fundamental biases in innovation possibilities represented an important source of machinery-using bias in US agriculture. Moreover, very large changes in factor prices had a strong impact on the direction of technical change, as the large drop of fertiliser was accompanied by a strong fertiliser-using bias.

An interesting study is Kako (1978), which applies a translog cost function to Japanese cross-sections of farm-level data (for rice crops) over the period 1953-70. The author analyses the process of Japanese agricultural growth through a decomposition analysis of factor input demand. The main findings confirm that technical change effects were negative for all five inputs, those of scarce resources, land and labour, being larger than the technical change effects of machinery, fertiliser, and other inputs. Labour input declined mainly due to labour-saving technical change, whereas the substitution of machinery for labour due to the change in machinery price was small. On the other hand, the increase in the wage played an important role in decreasing the demand for labour (negative own-substitution effect) while increasing the input level of machinery, due to the quite high substitutability of labour and machinery (0.93). Moreover, the decline in the price of the fertiliser, the typical substitute for land, did not contribute much to the reduction of land input level.

A different approach is taken by Lopez (1980) who applies a Generalised Leontief cost function to Canadian time-series for the period 1946-77. The author estimates a system of derived demand equations for four inputs (labour, capital, land and structures, and intermediate inputs) for the Canadian agricultural production sector. The results point to the importance of relative factor prices in the determination of the demands for inputs. The hypothesis of constant returns to scale is rejected, implying that the underlying production technology is non-homothetic. Furthermore, the hypothesis of zero factor augmenting technical progress could not be rejected: the reduction in labour-capital ratio may be due to relative price and output expansion effect (economies of scale) rather than to biased technological progress. As emphasised by the author, when homotheticity is imposed, the output expansion effect on input shares is incorrectly attributed to biased technical change. Lastly, the Hicks-Allen partial elasticities of substitution are positive but quite small, so that all input pairs appear to be substitutes, with the highest degree of substitution occurring between labour and farm capital.

The application of a translog cost function in a multi-output context has been undertaken by Ray (1982) who analyses US agricultural production using time-series for the period 1939-77. The Allen-Uzawa partial elasticities of substitution would suggest that the degree of substitution between labour and capital is much smaller than between labour and fertilisers, consistent with the steady decline in labour use and the steep increase in fertilisers use; moreover the substitutability between labour and capital has declined over the period of analysis, whereas that between labour and fertilisers, or labour and feed, seed and livestock has increased. Furthermore, farm labour has the highest own-price elasticity of demand in absolute terms. In terms of the cross-price elasticities of demand, the steep increase in the user's cost of farm capital caused the demand for labour to be higher, moderating the out-migration of labour from farming. The annual growth rate of productivity is quite impressive with the rate of technical change around 1.8% per year. Since technological change neutrality was assumed, the possibility that technical change in US agriculture was biased was disregarded rather than tested.

Ali and Parikh (1992) examine the relationships among different inputs in response to changes in input prices, distinguishing among tractorised and non-tractorised plots in Pakistan. The authors employ a translog cost function applied to Pakistani farm-level data for the agricultural year 1987-88. Since the issue of agricultural mechanisation and labour displacement is of great importance in densely populated developing countries with high unemployment, the authors investigate the impact of tractor use on human labour and animal power. The results suggest that human labour and tractors are substitutes so that mechanisation has labour-saving effects; the hypothesis that tractors could enhance the situation for labour absorption through an increase in productivity and cropping intensity is not supported. Animal labour (bullocks) and human labour are also substitutes, and the same hold for tractors and bullocks which compete for the same types of operations. Lastly, O'Donnell et al. (1999) estimate a system of flexible input demand equations for US agriculture, derived from a translog cost function. The demand equations for labour, capital and materials are estimated for ten farm production regions, using pooled-time series and cross-sections for the period 1960-93. Main results would suggest that labour and capital are complements in production whereas all other input pairs are substitutes and that there is a slight variation in technical efficiency across states.

Looking at the studies which relied on a profit function, Lopez (1984) employs a multi-output Generalised Leontief functional form to estimate a system of factor demand and output supply responses for Canadian agriculture.

Using Canadian cross-section for the year 1971, the author firstly tests the hypothesis of non-joint production between crops and animal outputs in agriculture and cannot reject it, and secondly verifies empirically the hypothesis of perfect substitutability between hired labour and operator labour. The last hypothesis is particular important as several studies, also due to data limitations, have treated hired and operator and family labour as a single input, hence assuming their non separability. The results would suggest that hired labour and operator labour appear to be net complements rather than substitutes and that they respond very differently to changes in input and output prices, with hired labour being more responsive to price changes than operator labour (almost totally inelastic). Hence, they should be treated as different inputs, as they perform specialised and diverse activities that cannot be interchanged. Shumway and Alexander (1988) estimate supply equations for five outputs and demand equations for four inputs in ten agricultural production regions of the US, using annual time-series for the period 1951-82. They employ a Normalised Quadratic profit function to assess the differences in the responses across US regions to market stimuli, governmental interventions and changing technology. There is an extreme diversity across regions in terms of own-price elasticities, with hired labour exhibiting the greatest variation. The same results hold for cross-price elasticities, with regions differing in their responsiveness to market stimuli and governmental intervention, as also supported by the output supply elasticities with respect to diversion payments. In addition to this, technology changed considerably over the period of analysis rejecting the Hicks-neutrality hypothesis.

Lastly, Huffman and Evenson (1989) employed a multi-output Normalised Quadratic profit function with US repeated cross-sections in forty-two states over the period 1949-74. The authors present estimates of supply and demand elasticities for US multiproduct cash grains farms and place particular emphasis on the input and output bias effects caused by research, extension, and farmers' schooling. Important results would suggest that biases effects of agricultural research in favour of fertiliser and against farm labour are consistent with the induced innovation hypothesis. Moreover, the estimated shadow values have positive values for public crop research and farmers' schooling, with social return of 62% and 15% respectively, whereas private crop research and extension are slightly negative.

Table 1 . Review of Empirical Literature

Study	Objective	Data	Functional form	Methodology
Lianos (1971)	investigates the sources of the decline in labour's relative share in US agriculture for the period 1949-68	US time-series: 1949-68 Source: various annual issues and reports from Agricultural Statistics and Farm Labour (USDA)	CES production Function	direct least squares and two-stage least squares
Thirsk (1974)	develops a three-factor model and examines the ease of substitution for different Colombian crops among different pairs of the factors	Colombian cross-section of crop farms: 1968 Source: Colombian Land Reform Agency (INCORA)	production function	ordinary least squares (OLS) and generalised least squares (GLS)
Vincent (1977)	formulates a model of derived demand for primary factors of production for Australian agriculture	Australian time-series: 1920-1 to 1969-70 Source: Powell (1974)	production function	full-information maximum likelihood (FIML) with instrumental variable estimates (IVEs)
Mundlak and Hellinghausen (1982)	estimate factor productivity in agriculture on a sample of fifty-eight countries	repeated cross-country (fifty-eight countries): 1960, 1965, 1970, 1975 Source: FAO, World Tables, ILO Yearbooks, Buringh et al. (1975)	production function	principal components and multiple comparisons
Binswanger (1974a)	derive estimates of elasticities of derived demand and of elasticities of substitution for the US agricultural sector	US cross-section of states: 1949, 1954, 1959, 1964 Source: US Census of Agriculture, various agricultural statistics (USDA), Griliches (1964), Filchelson (1968)	Translog cost function	restricted generalised least squares (RGLS)
Binswanger (1974b)	measures technical change biases with many factors of production applied to US agriculture	US cross-section of states: 1949, 1954, 1959, 1964 Source: US Census of Agriculture, various agricultural statistics (USDA), Griliches (1964), Filchelson (1968)	Translog cost function	restricted generalised least squares (RGLS)
Kako (1978)	analyses the process of Japanese agricultural growth through decomposition analysis of factor input demand	Japanese cross-sections of farm-level data: 1953-70 Source: Annual Survey of Rice Production Cost (Ministry of Agriculture and Forestry)	Translog cost function	full information quasi-maximum likelihood estimator (FIQML)
Lopez (1980)	derive input demand equations for the Canadian agricultural production sector	Canadian time-series: 1946-77 Source: several Statistics Canada publications, CANSIM data files, Danielson (1975)	Generalised Leontief (GL) cost function	full information maximum likelihood (FIML)
Ray (1982)	analyses US agricultural production in a multi-output context	US annual time-series: 1939-77 Source: various publications from US Department of Agriculture and US Department of Commerce	Translog cost function	joint generalised least squares (GLS)
Ali and Parikh (1992)	examine the relationships among different inputs in response to changes in input prices on tractorised and non-tractorised plots in Pakistan	Pakistani farm-level data: 1987-88 Source: sample survey in the North West Frontier Province (NWFP) of Pakistan conducted by the Institute of Development Studies in Peshawar (Pakistan)	Translog cost function	seemingly unrelated regression (SUR)
O'Donnell, Shumway, Ball (1999)	estimate a system of flexible input demand equations for US agriculture and derive estimates of elasticities of input demand and technical efficiency for the ten farm production regions	US pooled-time series and cross-sections: 1960-93 Source: US Department of Agriculture (USDA)	Translog cost function	Markow chain Monte Carlo (MCMC) methods to estimate a seemingly unrelated regression (SUR) system of input demand functions
Lopez (1984)	estimates a system of factor demand and output supply responses for Canadian agriculture	Canadian cross-section: 1971 Source: Canadian agricultural and population censuses	Generalised Leontief (GL) profit function	
Shumway and Alexander (1988)	estimate supply equations and demand equations in ten agricultural production regions of the US	US annual time-series: 1951-82 Source: Economic Research Service (ERS) and Agricultural Statistics (USDA)	Normalised Quadratic profit function	constrained nonlinear least squares
Huffman and Evenson (1989)	present estimates of supply and demand elasticities for US multiproduct cash grain farms and estimates of input and output bias effects caused by research, extension, and farmers' schooling	US repeated cross-section for cash grains farms in forty-two states: 1949-74 Source: various issues from US Department of Agriculture, US Department of Commerce, US Department of Labour	Normalised Quadratic profit function	ordinary least squares (OLS) and seemingly unrelated regression (SUR)

7. Functional Form and Specification

An interesting question which has been investigated in several studies is the effect of a change in the price of an input on the demand for other inputs, and therefore the estimation of the elasticities of factor substitution. Specifically, the main focus of our empirical work is the effect of market distortions in one market, through inefficient pricing, on the demand for other inputs. Therefore, own-price and cross-price elasticities of demand become the key variables in the analysis, so that a 1% increase in the price of, for instance, hired labour (or an equivalent distortion in the same market), will most likely cause a reduction in the hired labour demanded, but also lead to an increase (or reduction) in the demand of other inputs.

In terms of objective function, a dual cost function is preferred, as input prices are more likely to be exogenous. Hence, our main assumption is that firms operate in a competitive market, so that farmers see prices as exogenous signals and, as rational economic agents, are price takers. In this model we adopt a single-output cost function with five variable inputs: labour (family and hired), land, capital equipment and materials (seeds, fertilisers, feed, etc.)[1]. In the dual system input prices are used, and thus revenue and expenditure data from the FADN (cross sections) are aggregated over one output and five inputs. In addition to this, aggregated country level data, indices of prices of Agricultural Products and Means of Production tables can be accessed through the Eurostat. The selection of European Member States shall be based upon specific factor market studies and differences in market imperfections, so that interesting contrasting cases can be explored.

Useful candidates for our empirical work is the class of flexible functional forms which, as previously mentioned, do not place *a priori* restrictions upon substitution elasticities. In particular, a flexible function f is one that has enough parameters that it can approximate an arbitrary twice continuously differentiable function, *f**, to the second order at an arbitrary point x* in the domain of *f* and *f**. A commonly employed specification form and particularly convenient in this context is the Translog (Transcendental Logarithmic) cost function, which can be specified as:

$$\ln C\ (Y,w) = \ln \alpha_0 + \sum_{i=1}^{n} \alpha_i \ln w_i + \frac{1}{2} \cdot \sum_{i=1}^{n}\sum_{j=1}^{n} \gamma_{ij} \ln w_i\ ln\, w_j + \alpha_Y \ln Y + \frac{1}{2}\ \gamma_{YY}\ \ (\ln Y)^2 + \sum_{i=1}^{n} \gamma_{iY} \ln w_i \ln Y \qquad (7)$$

where C is total cost, Y is total value of output, and w_i are factors' prices (in our case: family labour, hired labour, land, capital equipment and materials). The analysis consists in estimating the system of cost share equations, in order to obtain the derived demand functions for inputs X_i. The cost shares equations (S_i) are obtained by logarithmically differentiating equation (7) with respect to input prices and subsequently from Shephard's Lemma (Berndt, 1991):

$$\frac{\partial \ln C}{\partial \ln w_i} = \frac{w_i}{C} \cdot \frac{\partial C}{\partial w_i} = \frac{w_i X_i}{C} = S_i = \alpha_i + \sum_{j=1}^{n} \gamma_{ij} \ln w_j + \gamma_{iY}\ \ln Y \qquad (8)$$

where

[1] In order to capture some of the heterogeneity inherent in farm labour it may be necessary to differentiate labour into family and hired. The dualistic labour structure and the different qualities associated with the two forms of labour have often been neglected in the literature and a single labour input has commonly been used. An exception is Lopez (1984), who instead tests the hypothesis of perfect substitutability and finds that hired and family labour are net complements and respond differently to changes in prices, suggesting that they should be treated as two different inputs.

$$C = \sum_{i=1}^{n} w_i X_i \ , \qquad S_i \equiv \frac{w_i X_i}{C}, \qquad \therefore \sum_{i=1}^{n} S_i = 1 \tag{9}$$

Since the cost shares sum to unity only n-1 of the share equations need to be estimated. The complementarity/substitutability between inputs can be examined through the Allen partial elasticities of substitution (AES), for comparison with other empirical work, and the Marshallian price elasticities of factor demands, in order to consider the inter-market spillovers. Based on the translog functional form, we can compute the AES from:

$$\sigma_{ij} = \frac{\gamma_{ij} + S_i S_j}{S_i S_j}, \qquad i \neq j \tag{10}$$

$$\sigma_{ii} = \frac{\gamma_{ii} + S_i^2 - S_i}{S_i^2}$$

The cross-price and own price elasticities of demand are given by:

$$\epsilon_{ij} = S_j \sigma_{ij} \ , \qquad i \neq j \tag{11}$$

$$\epsilon_{ii} = S_i \sigma_{ii}$$

The cost function requires the validity of some properties, namely symmetry, homogeneity and curvature conditions, in order to be consistent with economic theory, which can be ensured by imposing some parameter restrictions. First of all, the symmetry condition is required in order to ensure the equality of the cross-partial derivatives, so that:

$$\gamma_{ij} = \gamma_{ji} \ , \qquad i \neq j \tag{12}$$

The function also needs to satisfy the condition of homogeneity of degree one in input prices, which implies that:

$$\sum_{i=1}^{n} \alpha_i = 1, \qquad \sum_{i=1}^{n} \gamma_{ij} = \sum_{j=1}^{n} \gamma_{ji} = \sum_{i=1}^{n} \gamma_{iY} = 0 \tag{13}$$

Moreover, the translog cost function should be checked to ensure it is monotonically increasing, i.e. the function must be an increasing function of the input prices: this requires that the fitted shares (S_i) are all positive. Concavity restrictions (strictly quasi-concavity) in input prices can be tested by ensuring that the Hessian matrix (the matrix of partial elasticities of substitution, σ_{ij}) is negative semi-definite. Lastly, satisfying global curvature conditions are important and need to be checked at each point[2]. The flexibility of this functional form implies that the constant returns to scale need not be imposed. Instead, specific features of the technology, such as the degree of returns to scale and homotheticity, can be tested by examining the estimated parameters. Thus, if production does not exhibit constant returns to scale then the function may also be non-homothetic. If that's the case, a change in the optimal level of output (output market effect) may affect factor markets

[2] Violation of curvature properties is one of the problems encountered with flexible functional forms. If we need to impose curvature restrictions we can move to a Normalised Quadratic function as this would not compromise the flexibility form.

differentially. The analysis could also be extended to test the hypothesis of zero factor augmenting technical progress: i.e. to check whether technical change is neutral or biased.

8. Conclusion

This paper has developed a conceptual framework for the analysis of the derived demand for labour in agriculture. The theoretical background, based on a review of the primal and dual approaches in production theory, and the empirical literature constitute the basis for the theoretical framework to estimate the farm labour and other factor derived demand and output supply systems. The choice of the functional form is strictly dependent on the research objectives and on the properties entailed by the technology. In order to analyse the drivers of labour demand in agriculture, and account for the impact of policies on those decisions, it necessary to acknowledge the interactions between the different factor markets in agriculture. The main focus of our empirical work is the effect of market distortions in one market, through inefficient pricing, on the demand for other inputs. Hence, the functional form puts forward is the dual translog cost function, which is a flexible form and allows the examination of the complementarity/substitutability between inputs, through the estimation of the elasticities of factor substitution. The methodological procedure and the functional form related properties have been set out for the empirical analysis of farm labour and other factor derived demand.

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Comparative Analysis of Factor Markets for Agriculture across the Member States

245123-FP7-KBBE-2009-3

The Factor Markets project in a nutshell

Title	Comparative Analysis of Factor Markets for Agriculture across the Member States
Funding scheme	Collaborative Project (CP) / Small or medium scale focused research project
Coordinator	CEPS, Prof. Johan F.M. Swinnen
Duration	01/09/2010 – 31/08/2013 (36 months)
Short description	Well functioning factor markets are a crucial condition for the competitiveness and growth of agriculture and for rural development. At the same time, the functioning of the factor markets themselves are influenced by changes in agriculture and the rural economy, and in EU policies. Member state regulations and institutions affecting land, labour, and capital markets may cause important heterogeneity in the factor markets, which may have important effects on the functioning of the factor markets and on the interactions between factor markets and EU policies. The general objective of the FACTOR MARKETS project is to analyse the functioning of factor markets for agriculture in the EU-27, including the Candidate Countries. The FACTOR MARKETS project will compare the different markets, their institutional framework and their impact on agricultural development and structural change, as well as their impact on rural economies, for the Member States, Candidate Countries and the EU as a whole. The FACTOR MARKETS project will focus on capital, labour and land markets. The results of this study will contribute to a better understanding of the fundamental economic factors affecting EU agriculture, thus allowing better targeting of policies to improve the competitiveness of the sector.
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Partners	17 (13 countries)
EU funding	1,979,023 €
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SEVENTH FRAMEWORK PROGRAMME