

Elasticities of Substitution and Factor Supply Elasticities in European Agriculture: A Review of Past Studies

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ELASTICITIES OF SUBSTITUTION AND FACTOR SUPPLY ELASTICITIES IN EUROPEAN AGRICULTURE: A REVIEW OF PAST STUDIES^{*)}

Klaus Salhofer^{**)}

I. Introduction

The Policy Evaluation Matrix (PEM) approach of the OECD (1999) is designed to test the feasibility of using standard partial equilibrium models in the tradition of Muth (1964), Floyd (1965), and Gradner (1987) and alike to numerous empirical applications (e.g. Hertel, 1989; Gunter et al., 1996; Salhofer, 1997) to evaluate the impacts of agricultural programs in regard to various policy measures including production, farm income, economic cost, trade, and environment. While doing so, the PEM approach faces at least three challenges: (i) to develop a model that represents the structure and nature of agricultural markets in a satisfactory way; (ii) to derive reasonable market parameters; and (iii) to obtain reliable policy measures (Bullock et al., 1999).

The study in hand tries to contribute to the two last challenges by (i) systematically reviewing past literature for values of key parameters of the PEM model and (ii) to suggest statistical procedures to deal with parameter uncertainty and hence derive more reliable policy measures.

More strictly speaking, this report has four objectives:

- a. Tabulate and compare estimates of elasticities of substitution and factor supply reported in past studies of agricultural adjustment in European countries - separately for crops and livestock commodities.
- b. Comment on the suitability of the available estimates for modeling the effects of agricultural policy changes as the PEM model attempts to do.
- c. Recommend plausible ranges of these parameters to use in policy simulations with the PEM crop and livestock models.
- d. Advise the OECD on appropriate statistical procedures for sensitivity testing to deal with parameter uncertainty.

Several online databases including AG-ECON, AGRIS and CAB Abstracts were utilized, to compile a bibliography of past studies which attempted to empirically estimate elasticities of substitution and factor supply. In addition, the two major European agricultural economic journals the European Review of Agricultural Economics (1973 – 1999) and the Journal of Agricultural Economics (1970 – 1999) were searched by hand. Subsequently, all relevant studies identified in these sources were searched for related sources.

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Because of rapid developments in quantitative methods, almost all of the studies included in this review were published after 1979.

The study is organized as follows: Based on past studies for Europe Section 2 and Section 3 derive averages of substitution elasticities and factor supply elasticities, respectively. Section 4 discusses alternative statistical (sampling) procedures for dealing with parameter uncertainty in economic models. The last section summarizes the results and comments on their suitability for modeling the effects of agricultural policy changes with the PEM model.

II. Elasticities of substitution

There are different measures of input substitutability proposed in the literature, e.g. the Hicksian direct elasticity, the Allen(-Uzawa) (partial) elasticity, the Morishima elasticity, and the shadow elasticity. However, the estimates reported in this study are Allen type elasticities of substitution since these are the ones needed as a parameter input in the PEM model.

Empirical estimates of input substitutability can be derived from studies estimating a production function, a profit function, or a cost function. In two of the 32 studies reported in Table 1 a production functions is estimated, in nine a profit function and in 21 a cost function. All studies report estimates for an individual EU country except Walo (1994) for Switzerland.

All, except two, cost function studies assume a translog form. Some of them do not report the Allen elasticities of substitution (AES) directly, but either only the estimation parameters or Hicksian type (output constant) factor demand elasticities.

The AES between factor i and j (σ_{ij}) can be derived from estimation results and/or from factor demand elasticities (η_{ij}) utilizing the following relations (Binswanger, 1974):

$$(1) \quad \sigma_{ji} = \sigma_{ij} = \frac{\eta_{ij}}{\alpha_j},$$

$$(2) \quad \eta_{ii} = \frac{\gamma_{ii}}{\alpha_i} + \alpha_i - 1,$$

$$(3) \quad \eta_{ij} = \frac{\gamma_{ij}}{\alpha_i} + \alpha_j,$$

$$(4) \quad \sum_j \eta_{ij} = 0,$$

and in some cases

$$(5) \quad \sum_i \alpha_i = 1$$

where γ_{ii} is the estimation parameter value of the variable $1/2(\ln w_i)^2$ with w_i being the price of factor i , and α_i is the factor or cost share of input i .

Table 1: Studies on factor substitution

Author(s)	Country	Farm type	Method	Data	No. Inp.	No. Outp.
Ball et al. (1997)	France	Agriculture	Profit	1985	3	7
Becker and Guyomard (1991)	France	Agriculture	Cost	1961-1984	4	1
	Germany	Agriculture	Cost	1961-1984	4	1
Bonnieux (1989)	France	Agriculture	Prod.	1959-1983	4	1
Boots et al.(1997)	Netherlands	Dairy	Profit	1973-1992	3	2
Boyle (1981)	Ireland	Agriculture	Cost	1953-1977	5	1
Boyle and O'Neil (1990)	Ireland	Agriculture	Profit	1960-1982	5	1
Fousekis and Pantzios (1999)	Greece	Agriculture	Cost	1953-1986	6	1
Glass and McKillop (1989)	N. Ireland	Agriculture	Cost	1955-1984	4	2
Glass and McKillop (1990)	Ireland	Agriculture	Cost	1953-1986	4	1
Guyomard (1989)	France	Cereals	Cost	1960-1984	4	1
Guyomard a. Vermersch (1989)	France	Cereals	Cost	1981	4	1
Hansen (1983)	Germany	Agriculture	Cost	1961-1979	3	1
Hemig et al. (1993)	Netherlands	Dairy	Profit	1970-1988	2	1
Higgins (1986)	Ireland	Agriculture	Cost	1982	4	3
Karagiannis et al. (1996)	Greece	Agriculture	Cost	1973-1989	7	1
Khatri and Thirtle (1996)	UK	Agriculture	Profit	1954-1990	5	3
Lang (1993)	Germany	Agriculture	Cost	1961-1989	4	1
McKillop and Glass (1991)	Ireland	Agriculture	Cost	1961-1985	4	2
Mergos (1988)	Greece	Livestock	Cost	1960-1981	4	1
Mergos and Karagiannis (1997)	Greece	Agriculture	Cost	1961-1993	2	2
Michalek (1988)	Germany	Agriculture	Cost	1960-1983	5	1
Millan (1993)	Spain	Agriculture	Cost	1962-1985	4	1
Neunteufel (1992)	Austria	Agriculture	Cost	1960-1989	5	1
Niendieker (1992)	Germany	Agriculture	Prod	1977-1987	4	1
Oude Lansink (1994)	Netherlands	Arable	Profit	1970-1988	3	1
Rossi (1984)	Italy	Agriculture	Cost	1961-1980	3	14
Rutner (1984)	Germany	Agriculture	Cost	1961-1980	3	1
Ryhänen (1994)	Finland	Dairy	Cost	1965-1991	4	1
Sckokai and Moro (1996)	Italy	Agriculture	Profit	1963-1991	3	6
Walo (1994)	Switzerland	Agriculture	Cost	1991	5	2
Witzke (1996)	Germany	Agriculture	Profit	1965-1992	3	2
Zeza (1987)	Italy	Agriculture	Profit	1960-1981	2	3

Profit function studies usually do not report Hicksian (output constant) demand elasticities (η_{ij}), but rather Marshallian type demand and supply elasticities. Hence, to derive AES from profit function studies another step is necessary which converts Marshallian into Hicksian elasticities by

$$(6) \quad n_{ij} = \varepsilon_{ij} - \frac{\varepsilon_{yj}\varepsilon_{ip}}{\varepsilon_{yp}},$$

where ε_{ij} is the (Marshallian) elasticity of factor demand with respect to factor prices, ε_{yp} is the elasticity of output supply with respect to output prices, ε_{ip} is the elasticity of factor demand with respect to output prices, and ε_{yj} is the elasticity of output supply with respect to factor prices (Chambers, 1988, p. 135).

To derive AES from production function studies one needs the bordered Hessian of the production function (Chambers, 1988, chapter 1.7). However, the two production function studies reviewed, report the AES directly.

Most studies give estimates of the AES (or factor demand elasticities) for the agricultural sector as a whole rather than specific commodities (e.g. cereals, livestock) and should be interpreted in this way.

In accordance with the PEM model, the final objective of this section is to derive three aggregated AES: i) between land and other farm-owned inputs (labor and capital); ii) between farm-owned inputs and purchased inputs; and iii) between purchased inputs.

To derive the AES between land and other farm-owned inputs (labor and capital), as well as between farm-owned inputs and purchased inputs a first step is to calculate mean AES between the four very common categories land, labor, capital, and operating inputs. In addition, an attempt is made to divide operating inputs into crop inputs and animal inputs. Crop inputs are either typical factors used in crop production (mainly fertilizer, pesticides, and seeds) or operating inputs in studies of specialized crop farms. Similar is true for animal inputs (mainly feedingstuffs).

If studies distinguish between more than one operating input (e.g. crop inputs and animal inputs) elasticities of substitution involving the aggregated category operating inputs are derived by taking cost-share-weighted averages of the corresponding AES. For example, if a study distinguishes between crop inputs (C) and animal inputs (A) the AES between land (L) and operating inputs (O) is given by

$$(7) \quad \sigma_{LO} = \frac{\alpha_C \sigma_{LC} + \alpha_A \sigma_{LA}}{\alpha_C + \alpha_A}.$$

Hired labor is treated as an operating input. Hence, the category labor either includes only family labor (if a study distinguishes between family labor and hired labor) or total farm labor which is strongly dominated by family labor as reported in the next section.

If studies report results for several years (or periods) (e.g. Glass and McKillop, 1989, 1990; Lang, 1993) those with the most recent base year (period) are taken.

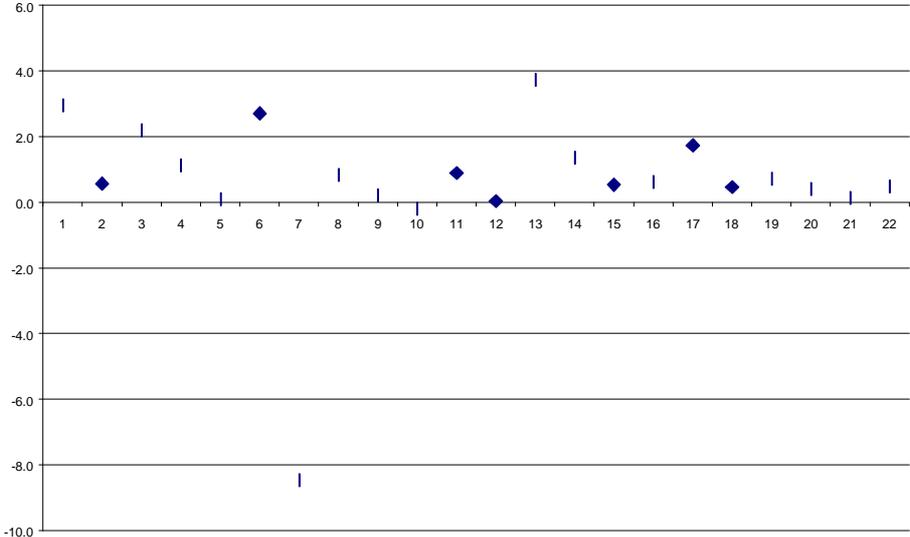
If studies report results for specific regions as well as an aggregate of those regions, the more aggregated numbers are preferred (e.g. Bonnieux, 1989; Millan, 1993).

If results for different models or different data (for the same country) are reported and the author identifies one of these results as superior those are taken (e.g. Michalek, 1988, p. 90). Otherwise, averages over all reported results are calculated (e.g. Ryhänen, 1994).

Table 2 reports the average AES derived from the 32 reviewed studies. The number of observations varies between 5 and 25 and hence are of different statistical validity. The average AES vary between 0.1 and 2.9 with quite high standard deviations between 1.1 and 3.6. For example, the 22 observations of the AES between labor and variable inputs lie within the wide range of -8.5 and 3.7 with a mean of 0.6 , and a standard deviation of 2.3 . Hence, a 95% confidence interval would be between -3.9 and 5.1 .

Taking a closer look at the data reveals that in many cases the high standard deviations are caused by only a few outliers. This is illustrated in Figure 1 for the case of the AES between labor and variable inputs. 21 studies report AES between -0.2 and 3.7 while one reports a high negative elasticity of -8.5 . To eliminate these kind of outliers the following procedure is used: first, the mean and the standard deviation of all n observations except one observation i is calculated; second if the observation i doesn't lie within a range of two standard deviations from the calculated mean, it is canceled from the data set.

Figure 1: AES between labor and variable inputs for all 19 observations



Following this procedure for all estimated AES one can derive means and standard deviations as reported in Table 3. Obviously, without losing many of the observations (about 9%) the standard deviations become considerable smaller and are cut in half in many cases.

Table 2: Statistics of AES between land, labor, capital, and operating inputs (crop inputs, animal inputs)

	Land/ Labor	land/ capital	labor/ capital	land/ var. inp.	land/ crop inp.	land/ animal inp.	labor/ var. inp.	labor/ crop inp.	labor/ animal inp.	capital/ var. inp.	capital/ crop inp.	capital/ animal inp.
Observ.	12	12	21	12	5	5	22	13	12	25	14	13
Mean	0.5	0.3	0.9	1.4	1.5	2.9	0.6	0.7	1.2	0.6	1.1	0.1
St.Dev.	1.5	2.4	2.1	1.2	1.9	2.8	2.3	3.6	1.3	1.1	1.3	1.6
Min.	-2.5	-3.7	-2.7	-0.3	-1.7	-1.2	-8.5	-10.3	-1.1	-0.6	-0.6	-2.3
Max.	3.4	5.5	9.2	2.8	3.1	5.8	3.7	4.2	3.5	3.3	4.1	3.0

Table 3: Statistics of AES between land, labor, capital, and operating inputs (crop inputs, animal inputs), corrected for outliers

	land/ labor	land/ capital	labor/ capital	land/ var. inp.	land/ crop inp.	land/ animal inp.	labor/ var. inp.	labor/ crop inp.	labor/ animal inp.	capital/ var. inp.	capital/ crop inp.	capital/ animal inp.
Observ.	10	10	20	12	4	4	21	12	10	23	13	12
Mean	0.5	0.2	0.5	1.4	2.3	3.9	1.0	1.6	1.2	0.4	0.9	-0.2
St.Dev.	1.0	1.5	1.0	1.2	0.9	1.8	1.1	1.6	0.9	0.8	1.0	1.3
Min.	-0.4	-2.1	-2.7	-0.3	1.1	2.4	-0.2	-0.1	-0.5	-0.6	-0.6	-2.3
Max.	3.1	2.2	1.9	2.8	3.1	5.8	3.7	4.2	2.7	2.2	2.3	2.0

Table 4: Statistics of AES between land, labor, capital, and operating inputs (crop inp., animal inputs), corrected for outliers and weighted^{a)}

	Land/ Labor	land/ capital	labor/ capital	land/ var. inp.	land/ crop inp.	land/ animal inp.	labor/ var. inp.	labor/ crop inp.	labor/ animal inp.	capital/ var. inp.	capital/ crop inp.	capital/ animal inp.
Observ.	10	10	20	12	4	4	21	12	10	23	13	12
Mean	0.3	0.1	0.4	1.6	2.7	3.2	0.8	1.3	1.8	0.4	0.6	0.4
St.Dev.	0.5	1.4	0.9	1.1	2.0	1.4	0.9	1.1	0.9	0.8	0.9	1.2

a) Publications in international agricultural economic journals are weighted 25% higher; the publication year is weighted such that a publication in 1980 has 75% of the weight of a publication in 1990. The year for which the AES is calculated is weighted such that an elasticity for 1970 has 75% of the weight of an elasticity for 1980.

Based on Table 3 the average AES between farm-owned inputs (F) and purchased inputs (P), as needed for the PEM model, is derived by calculating a cost-share-weighted mean of the average AES between the mainly farm-owned inputs (land (B), labor (L), capital (K)) on the one side and the purchased operating inputs on the other side:

$$(8) \quad \sigma_{FP} = \frac{\alpha_B \sigma_{BO} + \alpha_L \sigma_{LO} + \alpha_K \sigma_{KO}}{\alpha_B + \alpha_L + \alpha_K},$$

where the cost shares are averages from those studies which assume land, labor, and capital as variable. To calculate average cost-shares the same procedure as discussed above is utilized to eliminate outliers.

The same procedures is used to derive the AES between farm-owned inputs and crop inputs as well as animal inputs, respectively. The standard deviations are derived in the same way. The results are reported in Table 5. The mean of the AES between farm-owned inputs and purchased inputs is one with a standard deviation of one. The AES between farm-owned inputs and the more specialized crop inputs are higher with higher standard deviations, but based on about half of the observations.

Table 5: Statistics of AES between farm-owned inputs and purchased inputs, and between land and other farm-owned inputs, corrected for outliers

	farm-owned/ variable inp.	farm-owned/ crop inp.	farm-owned/ animal inp.	land/other farm-owned
Observ.	55	29	26	20
Mean	0.9	1.6	1.4	0.4
St.Dev.	1.0	1.3	1.2	1.1

Similar, the AES between land and other farm-owned inputs is derived by calculating a cost-share-weighted mean of the average AES between land and labor and between land and capital.

Finally, an attempt is made to account for the inhomogeneity of the reviewed studies with respect to the time period and area they cover as well as to their scientific quality. Since the final goal is to report AES for the EU as a whole, every observation is weighted by the share of agricultural production of the investigated country in total EU production in 1995 (Eurostat, 1997). Since Switzerland is not a member of the EU the study by Walo (1994) is given the same weight as a study for Austria, which is the most similar country in regard to the quantity and structure of production. Northern Ireland is given one fifth of the weight of Ireland what corresponds with the proportion of land between the two countries. Moreover, articles published in (more) international agricultural economic Journals (European Review of Agricultural Economics, Journal of Agricultural Economics, American Journal of Agricultural Economics and Agricultural Economics), in more recent volumes, and report elasticities for more recent base years are weighted higher. The results for a specific set of weights is reported in Table 4 and Table 6. The results are only slightly different compared to the unweighted results in Table 3 and Table 5. Different weights were tested without observing

significant changes in the results (except for AES with very few observations). Results for one alternative (more extreme) set of weights are reported in the Annex 1 in Tables A1.1 – A1.2.

Table 6: Statistics of AES between farm-owned inputs and purchased inputs, and between land and other farm-owned inputs, corrected for outliers and weighted^{a)}

	farm-owned/ variable inp.	farm-owned/ crop inp.	farm-owned/ animal inp.	land/other farm-owned
Observ.	56	29	26	20
Mean	0.9	1.4	1.7	0.2
St.Dev.	0.9	1.2	1.1	0.8

- a) Publications in international agricultural economic journals are weighted 25% higher; the publication year is weighted such that a publication in 1980 has 75% of the weight of a publication in 1990. The year for which the AES is calculated is weighted such that an elasticity for 1970 has 75% of the weight of an elasticity for 1980.

To derive the AES between purchased inputs a first step is to calculate mean AES between the four different categories of operating inputs. In accordance with the PEM model these categories are fertilizer, hired labor, other purchased inputs (including seed, pesticides, fuel, energy), and feed. If a study has only the category crop inputs it is treated like fertilizer. Results of these calculations are reported in Table 7. The same procedure as discussed above is utilized to eliminate outliers. The AES corrected for outliers are reported in Table 8. Given the small number of observations the results for the weighted AES were not very convincing and are hence not reported.

Finally, the AES between purchased inputs is derived by taking the mean of the means reported in column 1 to 6 in Table 6 and Table 7.

Table 7: Statistics of AES between purchased inputs

	fertilizer/ hired labor	fertilizer/ other purchased	fertilizer/ feed	hired labor/ other purchased	hired labor/ feed	other purchased/ feed	purchased/ purchased
Observ.	4	6	12	5	4	8	39
Mean	0.2	0.0	-0.5	1.3	0.3	1.5	0.5
St.Dev.	0.7	1.7	7.0	2.6	0.4	1.9	2.4
Min.	-0.8	-3.5	-14.4	-1.2	0.0	0.0	
Max.	0.8	1.3	14.8	5.6	0.8	4.7	

Table 8: Statistics of AES between purchased inputs, corrected for outliers

	fertilizer/ hired labor	fertilizer/ other purchased	fertilizer/ feed	hired labor/ other purchased	hired labor/ feed	other purchased/ feed	purchased/ purchased
Observ.	3	5	9	4	3	7	31
Mean	0.6	0.7	0.3	0.2	0.2	1.0	0.5
St.Dev.	0.2	0.4	1.4	1.0	0.2	1.5	0.8
Min.	0.3	0.3	-2.5	-1.2	0.0	0.0	
Max.	0.8	1.3	2.6	0.8	0.4	4.0	

In deriving plausible ranges of AES between farm-owned inputs and purchased inputs, between land and other farm owned inputs, and between purchased inputs for the EU the results reported in Table 5, Table 6, and Table 8 are utilized. The following observations are important: The AES between farm-owned inputs and the more specialized crop inputs and animal inputs are based on much fewer observations. The mean of the AES between farm-owned inputs and crop inputs as well as animal inputs are not significantly different from each other at the 99% significance level.

Given this, a plausible range of AES between farm-owned inputs and purchased inputs might lie between 0.3 and 1.5 with a base value of 0.9, for crop as well as animal production. A plausible range of AES between land and other farm-owned inputs might lie between 0.0 and 0.8 with a base value of 0.4. A plausible range of AES between purchased inputs might lie between 0.0 and 0.1 with a base value of 0.5.

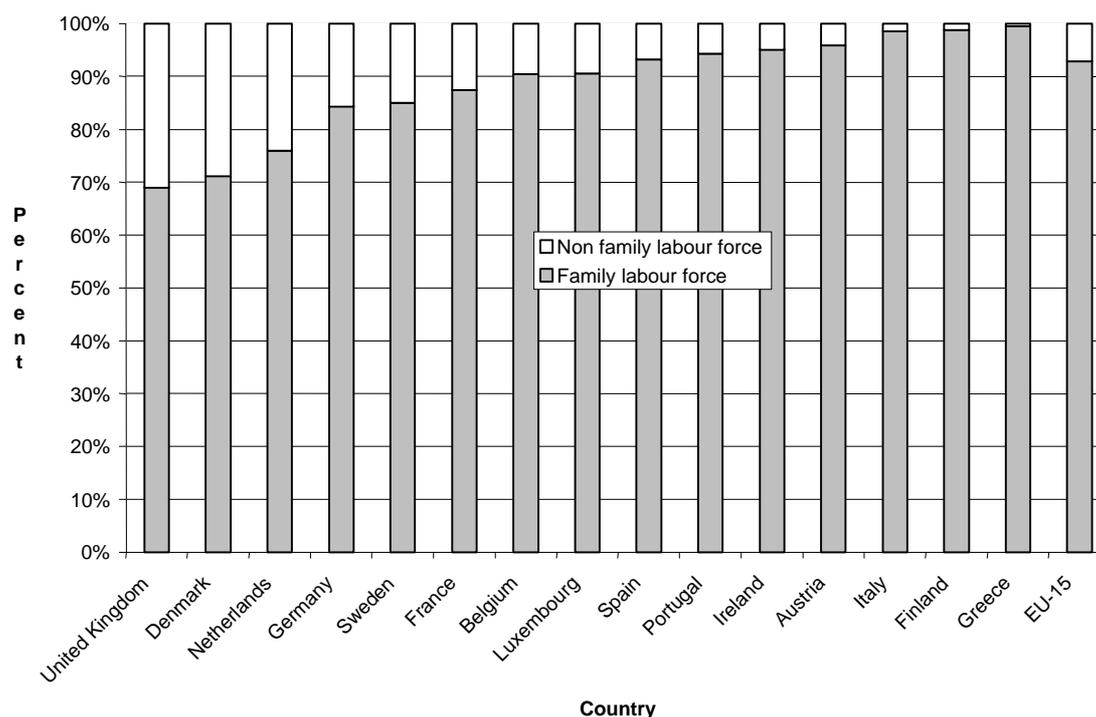
III. Factor supply elasticities

Following OECD (1999, pp. 29-33) elasticities for three different factors are derived: land, labor and purchased inputs.

i) Supply of labor

Though total farm labor comprises family labor and hired labor, the first one is with 93% of paramount importance in the EU (Figure 2). Moreover, all except one of the studies on on-farm labor supply in Europe discussed in this review are based on agricultural household models considering farm family labor only. Hence, the plausible range of values given at the end of this section is one for the own-wage elasticity of on-farm labor supply of the farm household, i.e. the percentage change of hours the farm family works on-farm with respect to a one percentage change in the shadow wage rate (or net return) of farm family labor.

Figure 2: Composition of the EU's agricultural workforce in 1997. Source: EUROSTAT



Labor decisions of farm families are often studied using household models (Becker, 1965, Huffman, 1980). There is a considerable amount of literature discussing labor allocation decisions of farm families based on household models and cross-section data especially for the United States (see Hallberg et al. (1991) for a good overview) and developing countries (e.g. Singh et al., 1986a), but also for Europe (Weiss, 1998a, 1998b). However, estimates of on-farm labor supply elasticities are scarce. Most of the empirical studies on farm household labor decisions for Europe analyze the influence of specific characteristics of farm holders, their families, and their enterprises on off-farm labor participation in a bivariate way (e.g. Corsi, 1993, 1994; Benjamin, 1994, 1995; Benjamin and Guyomard, 1994a, 1994b; Benjamin et al., 1994, 1996; Weiss, 1997; Woldehanna et al., 2000). Only a few studies discuss the determinants of hours worked off-farm (e.g. Gebauer, 1988; Pfaffermayr et al., 1992; Schulz-Greve, 1994; Daouli and Demoussis, 1995).¹

Schulz-Greve (1994) is a rare example of a study investigating also decisions about how many hours to work on farm. He derives estimates of the effect of a change in standard gross margins on on-farm labor supply. Based on his estimates and the assumption that standard gross margins per year divided by the hours worked on farm represents the shadow wage rate (net return) of farm family labor, one can derive own-wage elasticities of on-farm labor supply between 0.15 and 0.18 for men and between 0.07 and 0.10 for women for two distinct areas in Germany (Table 9).

Only a few studies actually derive own-wage elasticities of on-farm labor supply based on farm household models (Thijssen, 1988; Elhorst, 1994; Kjeldahl, 1995, 1996; Woldehanna, 1996). All four authors derive very similar elasticities in the range of 0.17 to 0.28.

¹ From this kind of studies one can derive elasticities of the effect of a change in the shadow wage rate of farm labor on off-farm labor supply or the effect of a change in off-farm wage rate on off-farm labor supply.

Table 9: Studies on on-farm labor supply

Study	Country	Farm Type	Elasticity	Comment
<i>Cross-section studies</i>				
Thijssen (1988)	Netherlands	Dairy	0.17	
Elhorst (1994)	Netherlands	Dairy	0.21	
Schulz-Greve (1994)	Germany	Agriculture	0.16	Men
			0.09	
Kjeldahl (1995, 1996)	Denmark	Agriculture	0.28	
Woldehanna (1996)	Netherlands	Arable	0.22	Household head
			0.27	Other family members
<i>Time-series</i>				
Cowling et al. (1970)	UK	Agriculture	0.50	

Woldehanna (1996) differentiates between household heads and other family members. He not only derives own-wage elasticities for these two groups, but also cross-wage elasticities between them. According to Woldehanna (1996, p. 234) a one percentage change in the shadow wage rate of farm labor of the household's head decreases the on-farm labor supply of other family members by 0.63% and a one percentage change in the shadow wage rate of farm labor of other family members decreases the on-farm labor supply of the household's head by 0.23%. Hence, a one percentage change of the shadow wage rate of farm labor of the household's head would decrease the on-farm labor supply of the whole family by 0.41% ($0.22 - 0.63$) implying a backward sloping labor supply curve (see Gasson and Errington, 1993, p. 124 for a discussion). According to Woldehanna (1996) even if the farm labor shadow wage rate of both groups would increase by one percent the net effect on on-farm labor would be negative.

The range of elasticities given in Table 9 for studies based on cross-section data and household models (0.09 – 0.28) is confirmed by similar results for non European countries. Singh et al. (1986b) report own-wage elasticities of on-farm labor supply between 0.01 and 0.45 for seven countries in Asia and Africa. Lopez (1984, 1986) estimates an own-wage elasticity of on-farm labor for Canadian farmers of 0.12.

A low range of the own-wage elasticity of on-farm labor supply is to some degree also confirmed by estimates of the cross-wage elasticity of off-farm labor supply, i.e. the elasticity of hours worked off-farm with respect to the on-farm shadow wage rate. If it is assumed that leisure is a normal good and inelastic, an increase in hours worked on-farm must decrease the hours worked off-farm at almost the same amount. Many studies report cross-wage elasticities of off-farm labor supply to be in a similar though negative range as own-wage elasticities of on-farm labor supply. Lass, Findeis and Hallberg (1991, p. 249) report estimates between – 0.28 and –0.43 for the US. For Europe Kjeldahl (1995, 1996) reports a cross-wage elasticity

of -0.03 . From Schulz-Greve (1994) one can derive a cross-wage elasticity for men between -0.23 and -0.07 and for women between -0.14 and 0.09 .²

Low or even negative own-wage elasticities of on-farm labor supply are also in line with numerous microeconomic household studies of labor supply for other sectors and social groups. For example Hansson and Stuart (1985) surveyed 28 studies on labor supply and calculated a median uncompensated wage elasticity of labor supply of 0.10 and a compensated wage elasticity of 0.25 . In a comparable effort Fullerton (1982) derived an uncompensated wage elasticity of 0.15 .

Furthermore, asking 464 economists about best estimates of economic parameters Fuchs et al. (1998) derive mean uncompensated (compensated) wage elasticities of 0.10 (0.45) for men and 0.22 (0.59) for women.

However, the own-wage elasticities of on-farm labor supply derived from household models cover only the effect of a change in the wage rate on the hours worked and not the effect of labor force moving into (out) of the sector. Hence, the aggregated (sector wide) labor supply elasticity can be expected to be higher than the individual supply elasticities based on household models. For example Kimmel and Kniesner (1998) found for a large random sample of US (not farm) households that a 1% increase in wage rates will reduce the hours worked by each employee by 0.5% , but will also reduce the number of employees by 1.5% . While the first number is comparable to the elasticities estimated in most cross section studies as reviewed by Hansson and Stuart (1985) or Fullerton (1982), the second number refers to the sectoral effect of a wage change. Using aggregated data of 22 OECD countries and simulation techniques Hansson and Stuart (1993) derive aggregated uncompensated wage elasticities of labor supply between 0.2 and 1.4 , and compensated wage elasticities between 0.96 and 2 .

More aggregated farm labor supply elasticities might be found in studies using time series data on labor supply and wage rates. However, as reviewed in Salhofer (1999) most of these studies on aggregated farm labor supply in developed countries date back to the sixties and seventies using simple estimation procedures and only Cowling, Metcalf and Rayner, 1970 report an aggregated elasticity for a European country. While Salhofer (1999) reports that family labor as well as hired labor supply elasticities estimated in these studies lie within a wide range of 0.03 and 2.84 with a tendency of being larger in the long run and for hired labor, Cowling, Metcalf and Rayner (1970) report an aggregated own-wage elasticity of labor supply of 0.5 for the UK.

*Given these findings, a plausible range of the own-wage elasticity of on-farm labor supply of farm families for Europe might be between 0.1 to 1 and a plausible base value might be 0.5 .*³

² Note that own-wage elasticities of off-farm labor supply are commonly estimated to be more elastic than own-wage elasticities of on-farm labor and cross-wage elasticities of off-farm labor supply. The mean of estimates of own-wage elasticities of off-farm labor supply reported in four studies for Europe is 1.16 (Pfaffermayr et al., 1992; Elhorst, 1994; Daouli and Demoussis, 1995; Kjeldahl, 1995, 1996).

³ Note that there might be a symmetry problem involved. Weiss (1997) reports that the impact of off-farm wages on the probability of switching from full-time to part-time farming is significantly different from zero, whereas there doesn't seem to be a significant relationship between off-farm wages and farmers decision to return to full time farming. In the same line one could argue that a decrease of on-farm shadow wage rates might bring family members to work part-time or even full-time off farm, but an increase in on-farm shadow wage rates doesn't have a likewise opposite effect.

ii) Supply of land

Elasticities of a change in land area allocated to a certain crop given a change in land prices, as needed for the PEM model, are not directly available from the literature. However, following Abler (2000) one can derive such elasticities indirectly by assuming that changes in product prices and hence returns are capitalized in land prices. In particular, it can be shown that the elasticity of supply of land to commodity i with respect to the rental rate on land for commodity j (ϕ_{ij}) is given by

$$(9) \quad \phi_{ij} = \frac{\alpha_{jB} \beta_{ij}}{\theta_{jB}},$$

where α_{jB} is the cost share of land for commodity j , β_{ij} is the elasticity of supply of land to commodity i with respect to the output price of commodity j , and θ_{jB} is the fraction of benefits from an increase in the price of commodity j that accrue as benefits to landowners (Abler, 2000, p. 5). Clearly, θ_{jB} is a number between zero and one and depends on the length of run one looks at. In the long run, θ_{jB} will be close to one. However, to derive relevant parameter values for the PEM model with a medium run horizon, values between 1/3 and 2/3 might be reasonable estimates. Following OECD (1999, p. 34) the cost shares of land for wheat, coarse grains and oilseeds are assumed to be 0.14, 0.18, and 0.18, respectively.

Table 10 summarizes the elasticity of supply of land to commodity i with respect to the output price of commodity j (β_{ij}) as reported in the reviewed studies, but aggregated for the three categories of crops (wheat, coarse grains, oilseeds) used in the PEM model (OECD, 1999).

Utilizing formula (10) average elasticities of supply of land to commodity i with respect to the rental rate on land for commodity j (ϕ_{ij}) are derived and reported in Table 11 and Table 12 for θ_{jB} is 1/3 and 2/3, respectively.

Based on these results a plausible range of own-price land supply elasticities might be between 0.1 and 0.4 with a base value of 0.25, and a plausible range of cross-price elasticities between 0.0 and 0.2 with a base value of 0.1 for all crops.

iii) Supply of purchased inputs

Supply of purchased inputs includes operating inputs like fertilizer, pesticides, fuel energy as well as investment goods like machinery and buildings. Estimates of such kind of supply elasticities are virtually absent from the literature. The only exceptions to our knowledge are Dryburgh and Doyle (1995) who estimate the supply elasticity of dairy machinery to be 1.9 for the UK and Salhofer (1997) who estimates the supply of fertilizer to be 1.2 for Austria.

A few studies assume elasticity values rather than estimating them. For example Trail (1979) assumes the supply elasticity of capital to be 3 while Abler and Shortle (1992) assume the supply elasticities of capital and chemicals to be perfectly elastic. Clearly, the supply elasticity crucially depends on the length the time horizon.

Based on the short to medium run orientation of the PEM model as well as on the results from the very few observations reviewed here, it might be plausible to assume that the elasticity of supply of purchased inputs is in a wide and elastic (but not perfectly elastic) range between 1 and 5 with a base value of 3.

Table 10: Studies on the elasticity of land supply with respect to output prices

Study	Country	Commodity	Own-price	Cross-Price	With
Burton (1992)	UK	Wheat	0.30	-0.20	Barley
				-0.21	Oilseed
		Barley	0.21	-0.11	Wheat
				0.03	Oilseed
		Oilseed	0.53	-0.27	Wheat
				-0.54	Barley
Jensen and Lind (1993)	Denmark	Cereals	0.36	-0.18	Rapeseed
		Rapeseed	1.28	-2.38	Cereals
Ibanez Puerta and Perez Hugalde (1994),	Spain	Wheat	0.57	-0.57	Coarse Grains
		Coarse Grains	0.69	-0.69	Wheat
Guyomard et al. (1996)	France	Wheat	0.33	-0.11	Coarse Grains
				0.00	Oilseed
		Coarse Grains	0.68	-0.36	Wheat
				-0.02	Oilseed
		Oilseed	0.23	-0.12	Wheat
				-0.03	Coarse Grains
O. Lansink a. Peerlings (1996)	Netherlands	Cereals a. Oilseeds	1.01		
Oude Lansink (1999a)	Netherlands	Cereals a. Oilseeds	0.26		
Oude Lansink (1999b)	Netherlands	Cereals a. Oilseeds	1.86		
Boyle and McQuinn (2000)	Ireland	Barley	0.02	-0.02	Wheat

Table 11: Average land supply elasticities assuming $\theta_{jB} = 0.333$

	wheat	coarse grains	oilseeds
wheat	0.25	-0.17	-0.06
coarse grains	-0.12	0.26	-0.04
oilseeds	-0.05	-0.10	0.25

Table 12: Average land supply elasticities assuming $\theta_{jB} = 0.667$

	wheat	coarse grains	oilseeds
wheat	0.13	-0.11	-0.03
coarse grains	-0.06	0.13	-0.02
oilseeds	-0.03	-0.05	0.12

IV. Statistical procedures for sensitivity testing

The PEM approach is designed to evaluate the impacts of agricultural programs in regard to various policy measures including production, farm income, economic cost, trade, and environment. Obviously, the value of the policy measure derived crucially depends on the model's parameters. Therefore, given a significant uncertainty about parameter values, as discussed above, a likewise dubiety about policy measure can be assumed.

More formally, let $\mathbf{y} = (y_1, \dots, y_n)$ be a vector of policy measures (e.g. y_1 is production, y_2 is farm income, etc.), let $\mathbf{x} = (x_1, \dots, x_m)$ be a vector of policy instruments (e.g. x_1 is market price support, x_2 is direct payments, etc.), let $\mathbf{b} = (b_1, \dots, b_z)$ be a vector of parameters (e.g. b_1 is the AES between farm-owned inputs and purchased inputs, b_2 the farm labor supply elasticity, etc.), and Let $\mathbf{f}(\cdot) = (f_1(\cdot), \dots, f_y(\cdot))$ be a vector of functional relations describing the economic system as well as some method to derive policy measures (Bullock et al., 1999). In the case of the PEM such a system of equations is for example described in OECD (1999, pp. 21-22). Then, policy measures \mathbf{y} are in a functional relationship with policy instruments and parameters:

$$(10) \quad \mathbf{y} = \mathbf{f}(\mathbf{x}, \mathbf{b}).$$

Assuming some specific functional form of the relations describing the economic system, a given set of policy measures of e.g. farm income, and a specific policy change to be simulated, the derived values of the policy measure depend solely on the assumed parameter values. However, since there usually is some uncertainty about parameter values it is more reliable to assume a distribution for each parameter value rather than specific values, implying a distribution for each policy measure. Let, $\boldsymbol{\phi}(\mathbf{b}) = (\phi_1(b_1), \dots, \phi_z(b_z))$ be a vector of distributions of parameters and let $\boldsymbol{\theta}(\mathbf{y}) = (\theta_1(y_1), \dots, \theta_n(y_n))$ be a vector of distributions of policy measures. Then

$$(11) \quad \boldsymbol{\theta}(\mathbf{y}) = \mathbf{f}(\mathbf{x}, \boldsymbol{\phi}(\mathbf{b})),$$

To derive a distribution of a specific policy measures $\theta(y_i)$, more than one method are available. Here, we distinguish between three different categories in regard to what kind of information about the distributions of parameter values is needed: i) methods based on actual data; ii) methods based on an econometric estimation result; and iii) methods based on parameter values taken from the literature.

A sampling method based on actual data is bootstrapping (Efron, 1979; Freedman and Peters, 1984). To derive a distribution for each parameter one needs a data set A to econometrically estimate them. However, instead of running one regression and deriving one set of parameters \mathbf{b} , one would create a large number T of new data sets A^1, A^2, \dots, A^T from the original data set by resampling either from the empirical error distribution (e.g. Kling and Sexton, 1990; Graham-Tomasi et al, 1990) or from the data set directly (e.g. Jeong et al. 1999, 2000) and use these T data sets to estimate T parameter sets. Substituting these T parameter sets into Equation (12) one can derive T values for each policy measure and form a distribution $\boldsymbol{\theta}(\mathbf{y})$.

To derive a distribution of parameter values based on already existing econometric estimation results there are two different ways: i) classical linearization; and ii) the Krinsky-Robb procedure. For both methods the information needed are estimates of the parameters and of the associated variance-covariance matrix. The classical linearization method uses first-order Taylor series expansions to derive the variance of a policy measure by knowledge of the variances and covariances of the parameters (Hausmann, 1981; Kealy and Bishop, 1986;

Bockstael and Strand, 1987). Obviously this method becomes less and less tractable with an increasing number of parameters. Beside, the appropriateness of such a procedure depends, of course, on the nature of the non-linearity between the policy measure and the parameters and has been criticised for that reason (Graham-Tomasi et al., 1990; Kling, 1991; Krinsky and Robb, 1991).

Krinsky and Robb (1986, 1990, 1991) and Adamowicz, Graham-Tomasi, and Fletcher (1989) (Further references are Adamowicz, Fletcher and Graham-Tomasi (1989) and Alston et al. (1998)) discussed how one can estimate a distribution of policy measures by knowledge of their means, variances and covariances and the assumption that they are distributed normally. First, a great number T of parameter sets ($\mathbf{b}^1, \dots, \mathbf{b}^T$) is drawn randomly from the multivariate normal distribution of the parameters. Second, by substituting the T parameter sets into Equation (12) one can derive $\theta(\mathbf{y})$.

If the parameter values are actually distributed normally the bootstrapping procedure and the Krinsky and Robb procedure should yield the same results. Clearly, the advantage of the Krinsky-Robb procedure is that it is computationally cheaper, while bootstrapping is theoretically more accurate.

However, for many policy analysis models, like the PEM model, it is neither within the scope of the study to derive the needed set of parameters independently, starting from raw data, nor are estimation results (including a variance-covariance matrix) for exactly such a parameter set available from some other study. Rather, parameter values have to be taken from different sources with only means (and sometimes standard deviations) available.

Very recently, Davis and Espinoza (1998), Griffiths and Zhao (1999), Davis and Espinoza (1999), Salhofer (1999), and Zhao et al. (2000) discussed how to derive a distribution of a policy measure in such a situation. Based on Bayesian inference they suggest to derive a subjective distribution of the parameters from all prior information available such as published econometric estimates, expert surveys, theoretical restrictions or correlations among parameters as well as modeller's subjective judgement (Zhao et al. 2000, p. 85).

Hence, following this approach the PEM model could use the parameter ranges and base values suggested above, assume some distribution within these ranges, take a large number T of random draws from these distributions and derive distributions of policy measures by running T simulations with T different parameter sets.

Usually with only a few point estimates available from the literature review one will assume either a normal distribution around the mean of the assumed range or a uniform distribution.⁴ In many cases, one can expect that both distributions will result in similar means, while the variance will be larger in the case of a uniform distribution (e.g. Sinabell et al. 1999).

This procedure is exemplified by means of a model, similar to the one used in the PEM approach, of the Austrian bread grains sector before EU accession based on Salhofer (1997, 1999).⁵ In this model the Austrian bread grains sector is modelled by a log-linear, three-stage vertically-structured model. The first stage includes markets of agricultural input factors (land, labour, capital goods, operating inputs) used for bread grains production. At the second stage, input factors of the first stage are used to produce bread grains assuming a CES

⁴ Zhao et al. (2000) also discuss a hierarchical distribution.

⁵ A graphical depiction of the model is given in Annex 2, Figure A.2.1.

technology. The first and the second stage are linked by the assumption that agricultural firms maximise their profits. At the third stage the produced quantities of bread grains are used for food production, animal feed, and exports. Firms which process food combine bread grains with other input factors of capital goods and industrial labour assuming a CES technology. Again, the second and the third stage are linked by the assumption that food industry firms maximise their profits.

For illustration purposes the effect of joining the EU in 1995 on farm income is simulated. For simplicity the introduction of compensation payments and set-asides are neglected. Rather, we concentrate on the effect of the 50% decrease in bread grains prices.

The model has 17 parameters. The parameter values used and their ranges are reported in Annex 2 Table A.2.1. For simplicity it is assumed that the seven factor shares and the two demand elasticities are known with no (or little) uncertainty. However, for the six factor supply elasticities and the two elasticities of substitution plausible ranges rather than point estimates are presumed. Since little is known about the mean, a uniform distribution is taken. A distribution of the change in farm income, caused by the price reduction, is derived by randomly drawing 800 values for each parameter from their distribution and simulate 800 times the change in the policy regime.

Figure 3 illustrates the results using a Kernel Density Function. Given the 50% decrease in prices bread grains farmers on average loose € 96 million with a minimum of € 88 million and maximum of € 107 million. Furthermore, one can create probability intervals Griffiths and Zhao (2000). For example in 90% of the 800 simulations (i.e. in 720 simulations) the decrease in farm income is between € 102 million and € 90 million.

To examine the sensitivity of the estimated policy measures to changes in individual parameters Zhao et al. (2000) suggest to regress the randomly drawn parameter sets against the calculated policy measure. Because of the complicated nature of the underlying relationship they suggest a quadratic functional form of the regression model. However, here we show that also simpler linear or log-linear models can give helpful insights.

The results of such regressions are illustrated in Table 13. The high R^2 shows that the assumed linear and log-linear relationships between the policy measure (change in farm income) and the parameters fit the data well. As would be expected, the elasticities at the farm level have a significant influence on farm income while the elasticities at the food industry level have not. In the case of the linear regression an increase in the elasticity of substitution by 0.1 units (e.g. from 1 to 1.1) will reduce the estimated cost of farmers by € 3.7 million. To be able to run the log-linear regression the negative signs of the changes in farm income have to be converted. Therefore, a one percentage increase in the elasticity of substitution will reduce the estimated cost of farmers by 4.1 %.

The regression results in Table 13 offer two interesting features. First, they show to which elasticities the policy measures react most sensitive. Second, based on the estimated coefficients one could calculate the change in farm income (for a 50% price decrease) for a specific parameter set without actually needing to run the simulation model again.

Figure 3: Kernel Density function of farm income changes

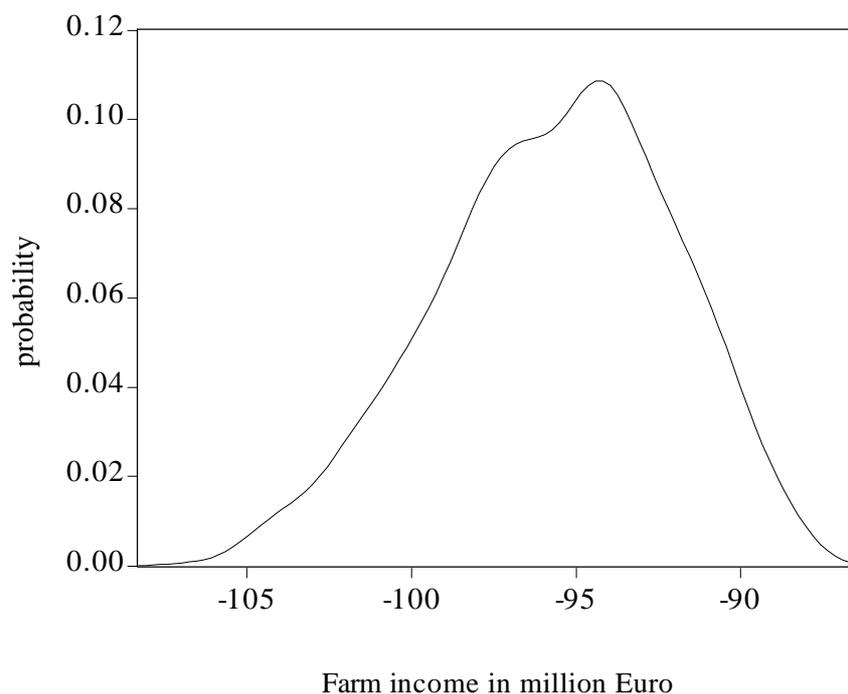


Table 13: The influence of parameter values on estimated changes in farm income

Variable	Linear model		Log-linear model	
	Coefficient	t-Statistic	Coefficient	t-Statistic
Constant	-100.099	-648.829	4.461	5273.848
<i>Farm level</i>				
Elasticity of substitution	3.652	48.971	-0.041	-37.854
Supply elasticity of land	5.663	29.187	-0.013	-22.292
Supply of capital	-1.034	-34.284	0.020	26.171
Supply of labor	11.261	170.207	-0.050	-128.485
Supply of operating inputs.	-2.580	-86.508	0.051	67.118
<i>Industry level</i>				
Elasticity of substitution	0.045	0.756	0.001	0.780
Supply of capital	-0.002	-0.072	-0.001	-0.804
Supply of labor	-0.165	-2.539	-0.000	-0.854
Adjusted R-squared	0.981		0.968	

V. Suitability of the available estimates for modeling the effects of agricultural policy changes as

Though the plausible ranges and base values given above are based on an comprehensive literature review, there is still a significant amount of uncertainty. This is especially true for the base values.

Elasticities of Substitution

As illustrated in Table 2 the main problem with the reviewed studies on AES is the wide range they cover. Though, applying some procedure to correct for outliers cuts the standard deviation by one half in most cases, it is on average still around 1.2, implying a 95% interval of 4.8 units (Table 3).

The large deviations in the values might be partly explained by the fact that these elasticities are estimated for countries with very different production structures. One of many examples is the fact that the percentage of crop output accounts for 71% of total output in Greece, but only for 12% in Ireland in 1995 (Eurostat, 1997). Other sources for the differences in estimated AES values are for example differing assumptions on which factors are variable, the level of disaggregation in inputs and outputs, the period (year) covered by the data, the period (year) for which the elasticity is calculated,⁶ the assumed functional form, and applied econometric estimation techniques.

Another circumstance to be mentioned, is the fact that the observations are by no means distributed normally around the mean. This is illustrated in Figure 4a to Figure 4c, for the AES between land (labor, capital) and variable inputs.

Moreover, given that the final goal of the study is to derive AES for the EU, it has to be mentioned that the 24 reviewed country studies are not representative for the EU.

Factor Supply Elasticities

Though all of the reviewed microeconomic (farm-level) studies on farm labor supply report elasticities of on-farm labor supply with respect to the on-farm shadow wage rate in a quite narrow and inelastic range (from 0.1 to 0.3) (and this is also confirmed by several other facts), there is some uncertainty about the aggregated farm-sector wide labor supply elasticity. As discussed above microeconomic studies cover only one aspect of labor supply, namely the effect of a change in the wage rate on the hours worked and not the effect of labor force moving into (out) of the sector. Unfortunately, only one study on aggregated labor supply was available for Europe, where this limitation does not prevail.

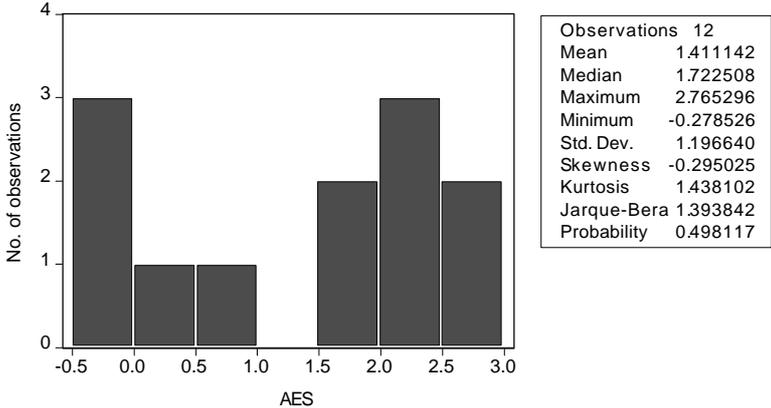
Land supply elasticities, as defined in the PEM model, are not directly available from the literature, but have to be deduced from elasticities of supply of land with respect to output

⁶ Note that the AES can change substantially over time. For example Michalek (1988, Table 14b) reports that the AES between land and labor increased from -1.1 in 1960 to 0.5 in 1983. Similar Niendieker (1992) reports that the AES between capital and operating inputs increased from -0.3 in 1977 to 2.9 in 1987.

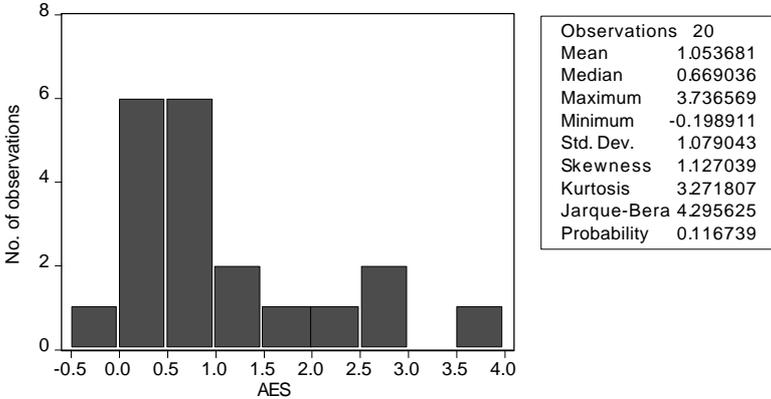
prices. In doing so, the main uncertainty is about how much of and how fast product price changes are capitalized in land prices. The capitalization ratios used here are ad hoc and only based on the assumption that in the very long run all benefits from higher agricultural product prices will be capitalized in land prices since this is the least variable factor and the fact that the PEM model is medium run oriented.

Figure 4: Histograms of different AES

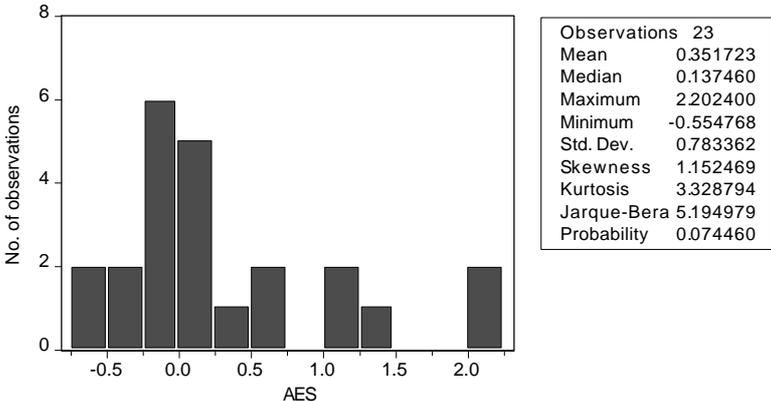
(a) AES between land and variable inputs



(b) AES between labor and variable inputs



(c) AES between capital and variable inputs



The least is known about the supply elasticity of purchased inputs. There are only two studies available, reporting single-equation time-series estimates. The suggested range between 1 and 5 more or less just reflects the theoretical considerations that supply of these factors should be elastic, but not perfectly elastic in the medium run. For the same reason many other policy analysis studies, mostly for the US (see Abler, 2000 Table 7 and Table 8), assume elasticities in a similar range.

Given the information collected here, it was not possible to differentiate between elasticities for specialized crop farms and animal farms, since most of the studies use data of the agricultural sector as a whole.

Given all these uncertainty concerning parameter values sampling procedures, as discussed above, are a valuable tool to build trust for the PEM method. Since we can put much more confidence on the possible ranges than on the base values one possibility would be not to report point estimates at all. Moreover, a uniform or a hierarchical distribution (see Zhao et al., 2000) might have some advantage compared to a normal distribution.

Finally, it has to be pointed out once again that the recommended ranges and base values in this study are based on a extensive literature review and hence are picked much less ad hoc than in most policy analysis studies. The remaining uncertainty is maybe of a degree scientists as well as politicians probably have to learn to live with in economic analysis.

Annex 1

Table A.1.1: Statistics of AES between land, labor, capital, and operating inputs (crop inputs, animal inputs), corrected for outliers and weighted^{a)}

	land/ labor	land/ capital	labor/ capital	land/ var. inp.	land/ crop inp.	land/ animal inp.	labor/ var. inp.	labor/ crop inp.	labor/ animal inp.	capital/ var. inp.	capital/ crop inp.	capital/ animal inp.
Observ.	10	10	20	12	4	4	21	12	10	23	13	12
Mean	0.3	0.3	0.5	1.7	2.7	3.5	0.8	1.3	1.7	0.4	0.5	0.2
St.Dev.	0.6	1.4	0.9	1.1	2.1	1.6	0.9	1.2	0.9	0.7	0.8	1.1

a) Publications in international agricultural economic journals are weighted 50% higher; the publication year is weighted such that a publication in 1980 has 50% of the weight of a publication in 1990. The year for which the AES is calculated is weighted such that an elasticity for 1970 has 50% of the weight of an elasticity for 1980.

Table A.1.2: Statistics of AES between farm-owned inputs and purchased inputs, and between land and other farm-owned inputs, corrected for outliers and weighted^{a)}

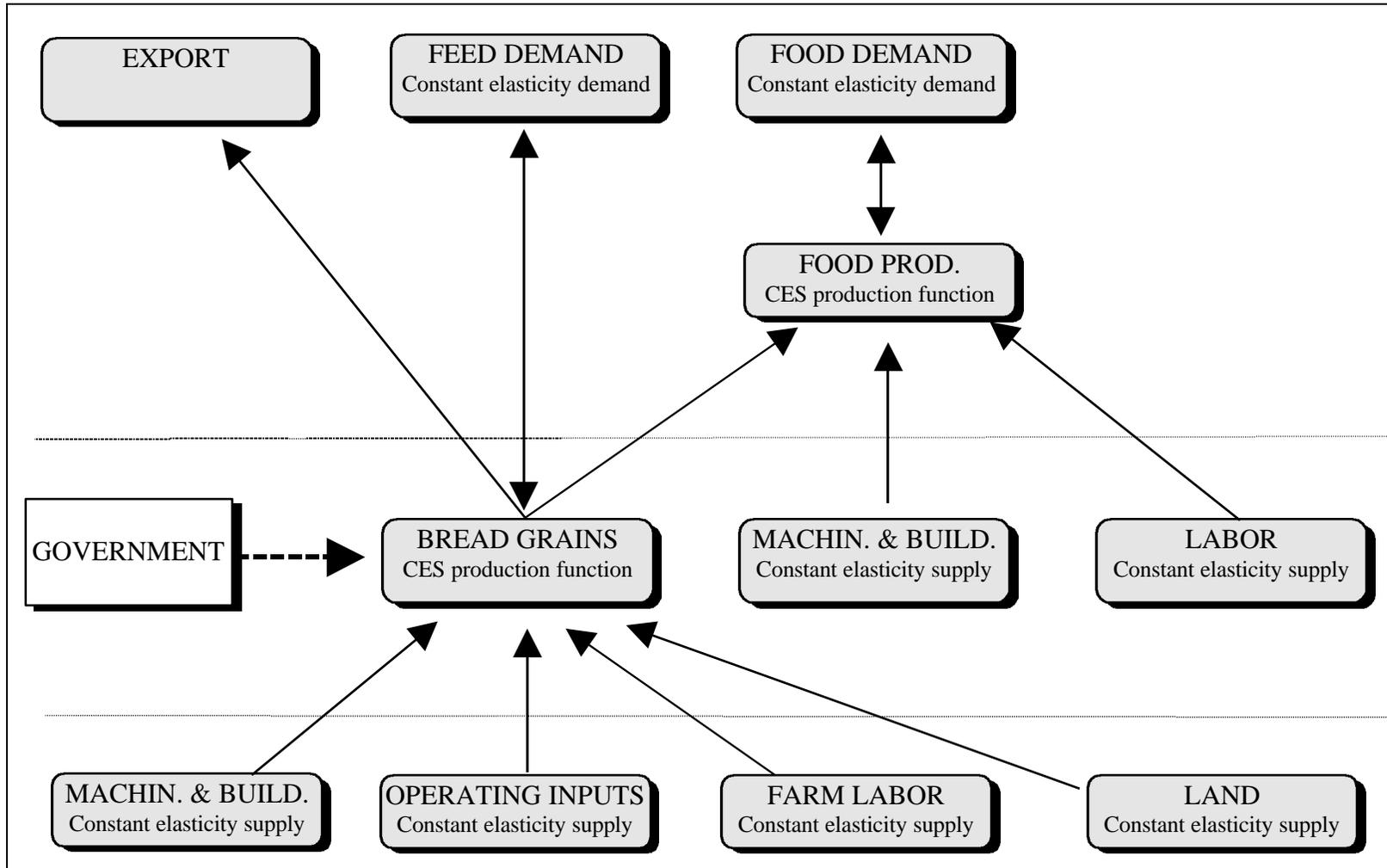
	farm-owned/ variabel inp.	farm-owned/ crop inp.	farm-owned/ animal inp.	land/other farm-owned
Observ.	56	29	26	20
Mean	0.9	1.4	1.7	0.3
St.Dev.	0.9	1.3	1.1	0.8

b) Publications in international agricultural economic journals are weighted 50% higher; the publication year is weighted such that a publication in 1980 has 50% of the weight of a publication in 1990. The year for which the AES is calculated is weighted such that an elasticity for 1970 has 50% of the weight of an elasticity for 1980.

Table A.2.1: Parameter values used in the Austrian bread grains model

Parameter	Value	Parameter	Value
Factor Share of Farm Labour	0.30	Supply Elasticity of Agricultural Labour	0.1 – 1
Factor Share of Land	0.10	Supply Elasticity of Land	0.1 – 0.4
Factor Share of Capital Goods in Agriculture	0.15	Supply Elasticity of Capital Goods in Agriculture	1 – 3
Factor Share of Operating Inputs	0.45	Supply Elasticity of Operating Inputs	1 – 3
Factor Share of Food Industry Capital Goods	0.50	Supply Elasticity of Food Industry Capital Goods	1 – 3
Factor Share of Food Industry Labour	0.15	Supply Elasticity of Food Industry Labour	0.1 – 1
Factor Share of Bread Grains	0.35	Supply Elasticity of Bread Grains	Implicitly given
Elasticity of Substitution at the Farm Level	0.5 – 1.5	Elasticity of Substitution at the Food Industry Level	0.5 – 1.5
Demand Elasticity of Food	– 0.40	Demand Elasticity of Feed	– 1.1

Figure A.2.1: Austrian bread grains model



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