Market Effects of Crop Support Measures

AGRICULTURE AND FOOD



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FOREWORD

Financial support afforded farmers through government policy intervention will be more or less trade distorting and more or less efficient in achieving targeted objectives depending on the mix of policy instruments used and their implementation. This report examines differences in the market effects and efficiency of several different ways OECD governments provide financial support to crop producers. The analysis was developed in the context of work done for the Policy Evaluation Matrix (PEM) project underway within the OECD Directorate for Food, Agricultural and Fisheries that seeks to integrate through the PEM model the measurement of support using the Producer Support Estimates (PSE's) with quantitative analysis of the economic and market effects of support.

A description of the PEM crop model and the analysis undertaken with it together with a synthesis of key findings from policy simulations constitute the main body of this report. There are three annexes. The first contains model documentation and additional detail from the policy simulations. The second and third annexes reproduce two consultant reports commissioned by the Secretariat to assist in developing the analytical framework used. Professor David Abler of Pennsylvania State University and Professor Klaus Salhofer of the University of Vienna provided specific guidance on how to model crop policy effects, on the economic parameters to use and on the procedures for doing policy simulation experiments. Each of their reports reviews past analyses of agricultural supply response and contains their recommended ranges of plausible elasticities to use.

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Executive summary

Farmers in OECD countries benefit from many different support policies. Some of these policies lead to higher-than-otherwise receipts from sales of farm production, some to lower-than-otherwise variable costs and some increase farm income more directly by, for example, giving farmers a fixed payment per hectare of land. The effects of different ways of supporting farmers on variables such as production, trade and farm income can differ depending on how the associated policy works.

This paper combines the OECD's Producer Support Estimates (PSE's) and an economic model of crop production and consumption to quantify these effects. The PSE is an estimate of the monetary value of transfers from consumers and taxpayers to producers resulting from government intervention to support agriculture. Support estimates are classified for the PSE according to a taxonomy that distinguishes first between market price support and budgetary payments and then among budgetary payments according to how they are implemented.

Support measures studied and indicators used

The analysis focused on five stylised crop support measures — market price support and four categories of budgetary payments based on, respectively: output, variable input use, area planted in the current period and area planted in an historical period. The crucial question for the analysis was: "How do the various forms of budgetary payments differ from market price support and from each other in their market and economic effects?"

Production, trade and world market prices were the indicators singled out to study differences in the *market effects* of the support measures. Comparisons were based on estimated 'impact ratios' using market price support as the reference category. These ratios measure the estimated effect of a given change in a support measure on each of the indicators of market effects, *relative to the estimated impact on that indicator of the same change in market price support.*

In studying differences in the *economic effects* of the support measures, five groups of economic agents were distinguished: 1) consumers 2) taxpayers 3) landowners 4) farm households and 5) suppliers of purchased inputs. Consumers and taxpayers pay the monetary costs of support. Farm households, supplying both land and non-land owned factors, and suppliers of purchased inputs typically get the benefits. The difference between what consumers and taxpayers pay and what the *intended* beneficiaries receive reflects the transfer efficiency of support. Farm households were designated as the intended beneficiaries of farm support in this study.

Qualifications

Results come from simulation analysis comparing the effects of small, equal changes in the amount of support from the different policy measures. These results are subject to the usual qualification that they may not provide the basis for conclusions about the effects of large changes in support levels. Moreover, the support measures studied are 'stylised', not representing exactly the specific mechanisms of policy implementation in any of the study countries. The analysis focused exclusively on how support measures initially affect prices and thereby quantities demanded and supplied of crops and of inputs used in crop production, ignoring some other channels through which they might differ. These latter include the possible risk, wealth and expectations effects of policies.

Comparing impacts among support measures

Bearing the above qualifications in mind, the main finding of this analysis is that, depending on the indicator used to measure policy impacts, the effects of a given amount of support differ substantially among the support measures used to provide that support. Area payments, even when implemented with a requirement to plant, were found to be both more efficient in transferring income to farm households and less production and trade distorting than all the other forms of support investigated.

(continued)

For a given total amount of money to spend on them, and assuming equal payment rates for different crops, the greater the number of crops covered by area payments the smaller their estimated production and trade effects and the greater their efficiency in transferring income to farm households. Thus, payments requiring planting of a specific crop are generally more trade distorting and less income efficient than if the same payment applies irrespective of which crop is planted. Likewise, area payments requiring planting of at least one of a list of eligible crops were found to be somewhat more trade distorting and less efficient than if the same amount of money were spent in the form of a payment requiring only that the land remain in agricultural production. Finally, payments having the least trade distorting impact are those that impose no condition whatsoever on the use to which eligible land is put.

The estimated trade effects of market price support were always higher and the estimated income effects always lower than the corresponding effects associated with any category of payments based on area planted. The estimated market and economic effects of budgetary payments based on output were similar: sometimes lower, sometimes the same and sometimes higher, depending on the country and crop, to those of market price support. Finally, payments based on variable input use were the least efficient in transferring income to farm households and the most production distorting of any form of support studied.

Landowners were found to be the major beneficiaries of support regardless of the measure used to provide it. In fact, among the categories of support measures studied landowners captured the largest share of benefit in all cases except that of payments based on variable inputs. Even in that case, the estimated landowner share was only slightly less than that of the main beneficiary — suppliers of purchased inputs. Although the estimated transfer efficiency of area payments was found to be relatively high, almost all the associated income gains go to landowners, benefiting farm households only to the extent they own the land they farm.

Numerical estimates of policy impacts depend critically on initial support levels: the greater the initial amount of support arising from a support measure, the less the simulated impact of a given increase in support provided by that measure. Accordingly, the estimated impact of a given increase in any one of the budgetary payments studied *relative to increased market price support* is greater: 1) the lower the initial level of support provided by that measure and 2) the higher the initial level of market price support. Partly this 'diminishing marginal impact' is due to the particular, non-linear, specification of the supply and demand equations in the model. A more important and fundamental factor however is that of diminishing marginal transfer efficiency of support — the economic costs of support grow more than proportionately with the level of support provided, regardless of the support measure used.

The paper also reports findings from analysis undertaken to test for sensitivity of results to uncertainty about precise values of key economic parameters. This part of the analysis focused especially on the robustness of the implied rankings of support measures in terms of their estimated impacts on production, trade and income. The analytical question posed was whether those rankings would change for particular combinations of plausible values of elasticities of factor supply and substitution. Although quantitative estimates of policy impact ratios were found to vary depending on parameter values chosen, the qualitative rankings of support measures were highly similar for all combinations studied.

Trade and world market effects of reducing support

The effects of support given to producers in one country or region spill over to other countries or regions through trade and world market prices. The model was employed to estimate the effects on these and other variables of an across the board 10% reduction in all the various categories of support provided crop producers in the study countries using 1998 as the base year for the data. The world market impacts of reducing any one category of support by a given percentage depend on two characteristics of the associated policy measure; 1) trade distortion 'per dollar of support' provided, and 2) the initial level of support provided by that measure.

The simulation analysis was done in progressive steps, one for each different kind of support. In 1998, market price support accounted for less than half the total PSE for crops in the study countries. However, reducing market price support by 10% led to a greater simulated decrease in subsidised crop production and a greater simulated increase in world market prices than the 10% reduction in all other categories of support.

(continued)

Reducing the rates of payments based on area led to the smallest simulated decrease in crop production and trade and the least simulated gain in world market prices. The total of payments based on area planted and payments based on historical entitlements made to crop producers in the study countries in 1998 was greater than the amount of support provided through any other channel in that year. On a 'per dollar of support' basis though, area and historical entitlement payments, were found to be less trade distorting and more income efficient than the other support measures. In the simulation analysis this latter effect dominated with the result that, even when added together, the trade effects of reducing area and historical entitlement payments were less than for any other single category of support reduction accounting for less than one-tenth the total simulated increase in world market prices due to all support reductions.

Policy implications

A key finding of this study is that those support measures causing the greatest distortion to production and trade (per dollar transferred to farmers from consumers and taxpayers) are those least efficient in providing income benefits to farm households and vice versa. These findings point to the possibility that governments could, by changing the way support is provided, significantly reduce distortions to trade while minimising the negative impacts on farm household incomes.

Market price support is often singled out for special consideration in international policy discussions because the associated trade interventions increase both domestic producer and consumer prices, reduce imports or increase subsidised exports and depress world market prices. In comparison to area payments, market price support is indeed a relatively inefficient and trade distorting way of supporting farm incomes. However, budgetary payments based on output or on variable input use were also found to be highly inefficient and trade distorting when compared to area payments.

Distinctions between programmes of area payments that require planting of eligible crops and those that require only that land remain in agricultural uses also feature prominently in international debate about agricultural policy. Results from this analysis confirm that the trade effects are greater and the income effects less for programmes that require planting. However, if area payment rates are identical for all crops competing for the same land these differences in trade and welfare effects are lessened. The similarities in trade and welfare effects of programmes requiring planting and those that do not would be especially acute in circumstances of identical payment rates and where approved uses include idling land from production or where area payments are accompanied by planting restrictions and/or set-aside requirements.

MARKET EFFECTS OF CROP SUPPORT MEASURES

I. Introduction

Governments in OECD countries use a diverse combination of policy measures to support farmers: a combination that changes over time with changes in domestic policy priorities and because of other factors such as the evolution of trade commitments. Individual support measures comprising the mix may differ in their effects on production, consumption and trade as well as in the efficiency with which they achieve their goals. This document contains results of analysis aimed at identifying and quantifying such differences.

The particular support measures compared in this analysis were chosen from a list of categories of the Producer Support Estimates (PSE's). The PSE indicates the monetary value of transfers from taxpayers and consumers to farmers resulting from agricultural policy. The system for classifying data for the PSE categorises support measures according to implementation criteria — the general conditions under which producers are eligible to receive support. (OECD 2001*b*).

The analysis focused on differences in policy effects among five main categories of support provided crop producers in OECD countries: 1) market price support, 2) payments based on output, 3) area payments, 4) payments based on variable input use and 5) payments based on historical entitlements. Differences in the production, trade and farm income effects between these support measures were estimated using an economic model representing producer and consumer price response and the incidence of support measures on prices.

The main body of this report is divided into three sections. The first section explains the basic analytical model and illustrates the analysis undertaken with it using conventional supply-demand diagrams. Although highly stylised, this graphical exposition spells out the main features of the analysis. The second section is concerned with quantifying differences in support measures and an empirical version of the model is presented. This model represents production and consumption of four crops: wheat, coarse grains, oilseeds and rice in six OECD Member countries: Canada, the European Union[1], Japan, Mexico, Switzerland and the United States. In addition to documenting key features of the model and its parameters, it also contains main policy simulation results. The final section contains a summary of findings as well as conclusions of the analysis.

II. Qualitative analysis of differences in policy effects among support measures

General characteristics and limitations of the model used

The starting point in developing an analytical framework for this analysis was the model of the farm sector elaborated in Gardner. First developed by Hicks to study issues in labour economics, it has been widely applied in general economic policy analysis. An important precedent to its application in studying agricultural policy was in an analysis of housing and urban land economics by Muth. The

development of the model for analysis of agricultural price supports is generally credited to Floyd. Its application here follows most closely applications found in Atwood and Helmers, Gunter *et al.*, and in Hertel.

The type of analysis undertaken using this modelling framework has become known more generally as 'equilibrium displacement modelling' (Salhofer and Sinabell, Piggott, Cahill). In this framework, commodity supply is usually represented in terms of an aggregate production function and the associated factor demand and factor supply functions. Commodity demand and supply equations typically relate quantities and prices at the farm level, although several of the applications in the literature involve modelling sector-wide policy and market linkages (Alston). Normally, as was done for this analysis, the functional relationships in the model are approximated with equations linear in elasticities and percentage changes in quantities and prices.

In doing policy analysis, supply and demand behavioural relationships are combined with the equilibrium requirements that supply must equal demand to simultaneously clear all output and factor markets. This system of equations is calibrated to replicate a given market situation — actual prices and quantities observed in a particular 'base year', for example. A small change in the value of some exogenous policy parameter, *e.g.* an administered price, an area payment, or an input subsidy is then introduced and the model used to calculate a new set of equilibrium values for all endogenous prices and quantities. This procedure is termed a 'policy experiment' or 'policy simulation experiment'. Effects of combinations of policy changes can be calculated by summing the estimated effects of changes in individual policy parameters.

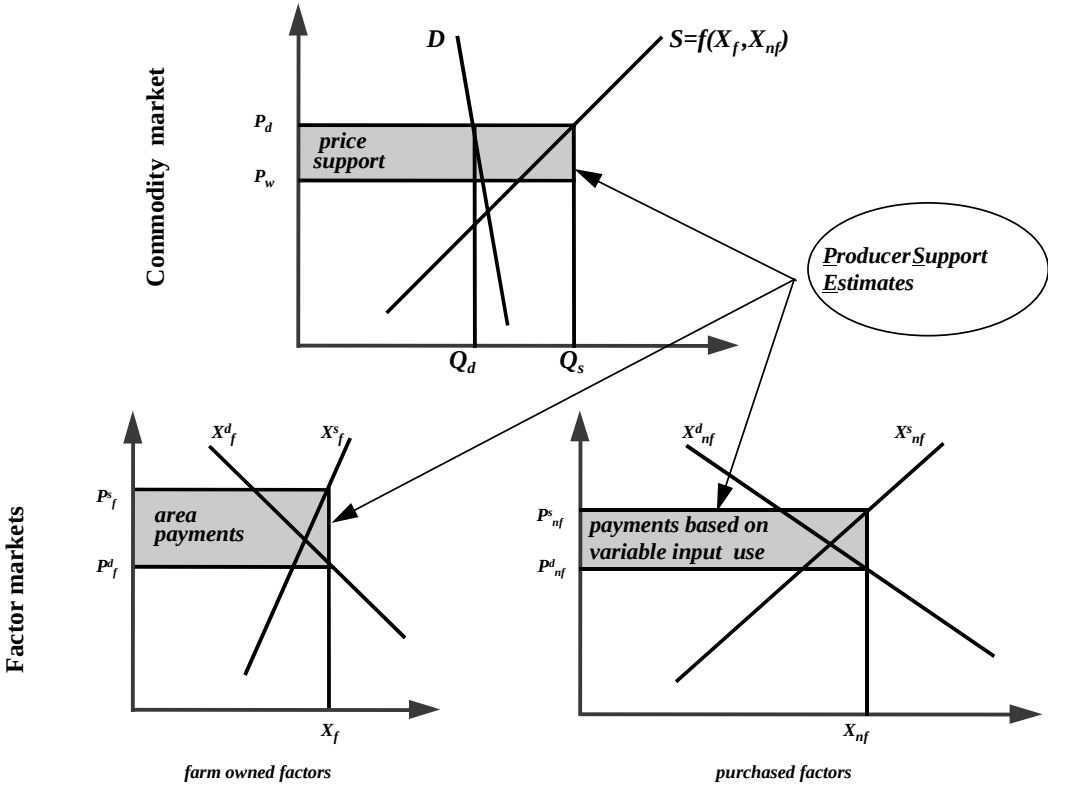
Policy simulation experiments usually involve relatively small changes in policy variables because of concern about whether model estimates of policy effects will be valid for large changes (*e.g.* complete elimination of government support programs for agriculture). The concern arises firstly because demand and supply relationships in the model are derived from theory applied to evaluation of small 'marginal' changes in variables and, secondly, because all the supply and demand relations in the model are *approximated* with constant elasticity linear equations.[2] The validity of the constant elasticity assumption can be brought into question when applying the model to evaluation of large changes in policy. Further, there is no way of knowing whether the elasticities of supply and demand appropriate for evaluating larger changes should be higher or lower than those appropriate for evaluating small changes. (We shall return to this issue in Section 3 of the paper when discussing the numerical simulation experiments undertaken to quantify differences in policy effects among support measures.)

Figure 1 contains supply and demand diagrams illustrating the main features of the model. Let the curves in the upper panel represent the farm gate demand and supply for any one of the crops (or an aggregate of them), in any one of the countries featuring in the study. The lower two panels show supply and demand curves for two aggregated factors of production: 'farm owned' and 'purchased'. Farm owned factors are those supplied by farm households, primarily land[3] and farm household labour. Purchased factors include all remaining variable inputs such as fertiliser and all remaining quasi-fixed inputs such as (the services of) machinery and equipment.

The crop supply curve in the upper panel of Figure 1 is derived from the system of factor demand and factor supply equations represented by the curves in the two lower panels of that figure. The price responsiveness of crop supply is reflected in the values assumed for the price elasticities of factor supplies and the parameters measuring the substitutability of factors in production as well as the factor shares. The slopes of the factor supply curves reflect an assumption that neither factor is completely fixed in production of crops but that farm owned factors are relatively more fixed (have lower price elasticities of supply) than the purchased factors. Likewise, no factor is assumed freely mobile, but purchased inputs are assumed relatively more mobile (a higher elasticity of supply) than

the farm-owned factors.[4] Most empirical studies have found or assumed elasticities of farm owned factor supply, such as land, that are substantially less than those found or assumed for purchased factors, such as fertiliser (Annexes 2 and 3). In addition, most studies have found or assume that, in the aggregate, factors of production may be substituted in response to relative price changes.

Figure 1. Incidence of PSEs



The incidence of support measures

In the analysis, the crucial distinction among the support measures studied is initial price incidence, or "which price is affected *first?"* Measures providing market price support have their first incidence on both the price producers receive and the price consumers pay for the crop in question. Payments based on output initially impact only the producer price of that crop. Factor subsidies have their initial incidence on prices in the associated factor markets. Regardless of initial incidence though, the price and quantity links in the model tie the factor and output markets together so that a change in a policy measure that affects any one of the crop or factor markets will end up having some effect on all of them.

Figure 1 illustrates how price wedges corresponding to unit market price support, a subsidy to farm owned factors and a subsidy to purchased factors are represented in the model. The market price support wedge separates prices paid by domestic consumers to domestic producers P_d from the corresponding price on world markets, P_w. A subsidy to a farm owned factor such as cropland creates a wedge between the price a farmer earns from using that factor P^s_f and the return P^d_f it would earn in some alternative use. A subsidy to a purchased input creates a difference between the price suppliers receive P^s_{nf} and the price farmers pay P^d_{nf} for that input.

As in any economic model of policy effects, it is difficult to represent the mechanisms of policy implementation and therefore 'incidence' in complete detail. The choices made in this analysis were heavily influenced by the way support measures are classified in the PSE itself under the new system of classification. For the latter purposes, support measures are classified according to the main or primary condition that producers must meet in order to be eligible for the support. Usually, knowledge of the conditions of eligibility of a particular support measure, as revealed by its classification in the PSE, will be enough to infer its 'initial incidence'.

As Figure 1 reveals, the principal focus of this analysis was on the way support measures affect *prices* received and paid in farm commodity and factor markets. Support measures may have effects that show up not in terms of price changes in farm commodity or factor markets, but through other channels. The costs of program administration and taxation constitute one important example [OECD (1995), Moschini and Sckokai].

In addition, the mere existence of a government-backed program of pricing or support undoubtedly increases the sense of security of farm revenues and income for both farmers and people who lend money or extend credit to farmers. Given a farmer's specialised skills and the absence of perfect capital and information markets, this could lead to 'higher than otherwise' crop production, even for seemingly 'completely decoupled' support measures, while not having any observable direct effect on factor or commodity prices. Finally, payments made to farmers that are based on historical production or plantings might create an incentive to retain land in crop production to preserve entitlement rights to future program benefits [Hennessy, OECD (2001) Roberts *et. al*.(1991), Gardner, ABARE].

Graphical analysis

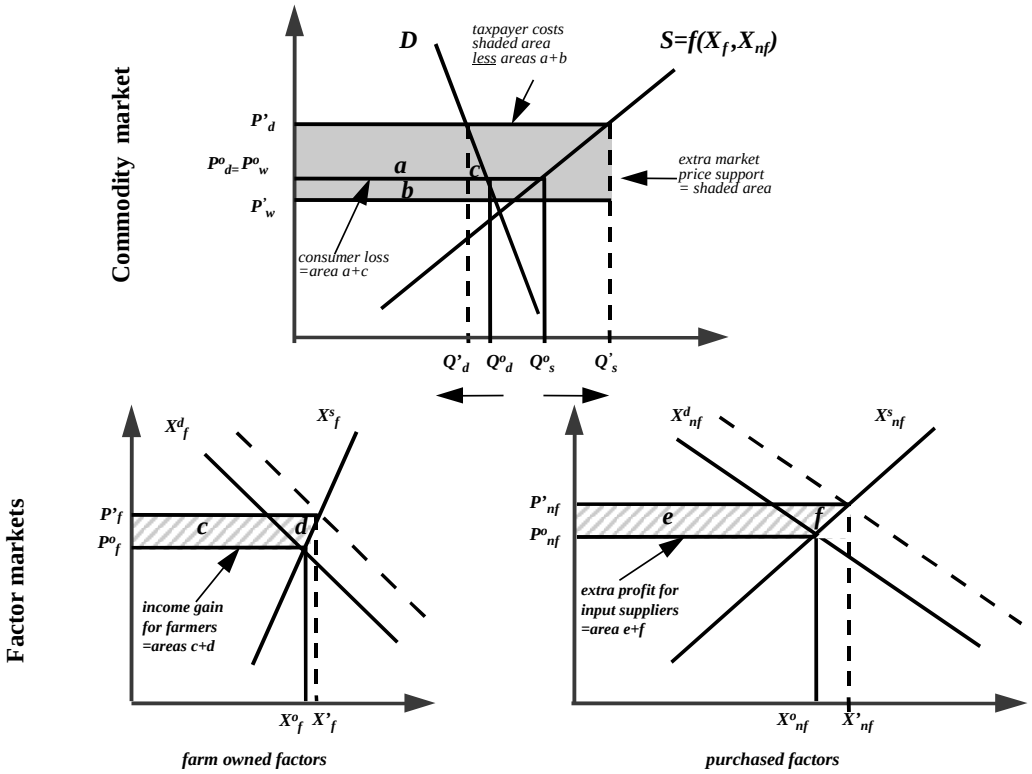
Figures 2 and 3 contain graphical representations of market equilibriums 'before and after' hypothetical changes in support. We use the same frame as in Figure 1 but, for expositional convenience, assume in each case that support is increased in a situation where there was no support of any kind before. This simplification causes no great problems in tracing through the effects of hypothetical changes in policy measures. However, existing distortions cannot safely be ignored when trying to *quantify* policy effects in numerical analysis. We will return to this important issue later in the paper.

Market price support

Figure 2 illustrates the analysis undertaken in assessing effects of market price support. Look first at the upper panel of the figure showing commodity market impacts. For this illustration, assume a situation in which initially domestic price P^0_d and world price P^0_w are equal. Then, suppose a change in some market support instrument results in a price wedge ($P'_d - P'_w$) and an accompanying level of market price support of some given amount as indicated by the shaded area in the top part of Figure 2.

The increase in crop production induced by the increased support is ($Q'_s - Q^0_s$). The associated reduction in consumption is ($Q^0_d - Q'_d$). The consequent effect on net trade is equal the difference between the implied quantity of exports after the change in support ($Q'_s - Q'_d$) less the implied quantity of exports before the policy change ($Q^0_s - Q^0_d$). This illustration assumes the country in question is an exporter both before and after the policy change.[5]

Figure 2. Trade and income effects of market price support



The increase in support is represented in the figure by the rectangle whose base is Q'_s and whose height is $(P'_d - P'_w)$. The sum of the areas marked *a* and *c* represents the induced increase in consumer costs (reduction in consumer surplus). The induced increase in taxpayer costs needed to pay for export subsidies is shown by the rectangle whose base is $(Q'_s - Q'_d)$ and whose height is $(P'_d - P'_w)$. The sum of taxpayer and consumer costs equals the whole of the shaded area measuring the change in support less the area marked *b*.

We can distinguish two components of the increased market price support: the induced *increase* in the domestic price from P^0_d to P'_d and the induced *decrease* in the world price from P^0_w to P'_w. The relative magnitudes of these two price changes will depend on the size of the country in the production and trade of the commodity in question.

Look now at the bottom part of Figure 2 showing associated factor market effects. The hypothesised increase in the producer price due to increased market price support translates into outward shifts in demand for both farm owned and purchased factors of production as shown by the dashed lines to the right of the demand curves labelled X^d_f and X^d_{nf} in the figure. This causes the quantities and prices of both factors to rise, the degree to which clearly depends on relative elasticities reflected in the slopes of the factor supply schedules.

The sum of the areas marked *c* and *d* in the lower left hand panel of Figure 2 represent the impact of the supposed change in market price support on net incomes of farm households supplying the farm owned factors of production. Correspondingly, areas marked *e* and *f* in the lower right hand panel show increased profits for suppliers of purchased inputs. Which of these is the greater depends on the elasticities of factor supply and substitution as well as on the relative importance (as revealed by cost shares) of the factors in crop production.

The *price* increases will always be the greater for the factor exhibiting the lowest supply elasticity; in this case the farm owned factor. However, this does not guarantee that the largest share of total benefits of support goes to this factor since this depends on factor shares as well as elasticities. The essential point is that there will be some sharing of the economic benefits of increased support between these two groups of economic agents.

Although the spotlight in the above discussion was on market price support, the same diagram could easily be used to trace through the effects of another important category of the PSE, that of payments based on output. Such payments increase the producer price in the same way as market price support but have no (direct) effects on consumer prices. Thus, they would be expected to have similar effects on production and on factor markets as market price support, but with smaller effects on net trade.

Payments based on area planted

Suppose now that rather than providing the hypothetical increase in support as market price support, it is provided as a payment to land. Suppose further that the payment comes with a requirement to plant so that we can expect some induced increase in the area of land used in crop production. This payment drives a wedge between the effective rental rate received for land used in crop production and the associated rental rate charged for that land.

This is depicted in the lower left hand panel of Figure 3 in terms of the price wedge, (P^s_f - P^d_f). As compared to the initial equilibrium price P^o_f the equilibrium supply price for the farm owned factor rises to P^s_f while the equilibrium demand price falls to P^d_f. This leads to an increase in quantity of land and other farm owned factors demanded and used in crop production of (X'_f-X^o_f), which will be greater or less depending on the elasticity of supply of cropland. In turn, this increased factor use shows up as the rightward shift in the commodity supply schedule shown in the top portion of Figure 3, with associated increases in supply and net trade, equal (Q'_s- Q^0_s).

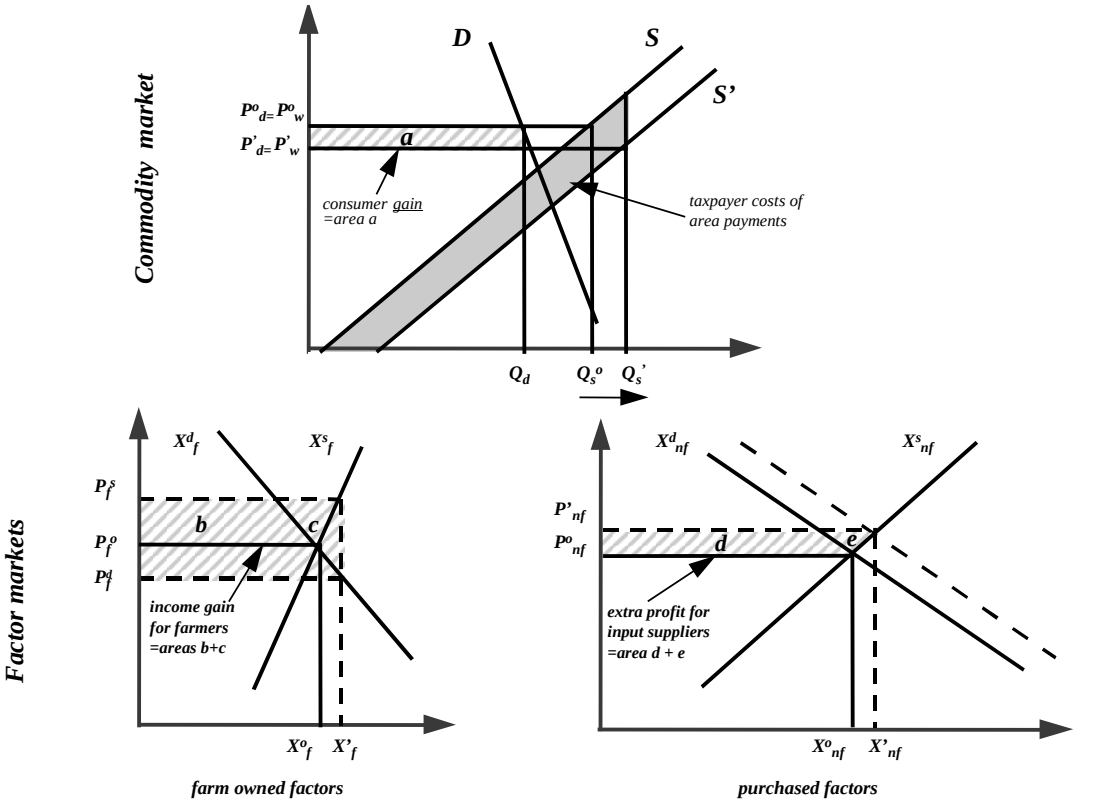
The increased supply results in some fall in world market prices. To the extent that the world market price falls, and to the extent that this price fall is transmitted to the domestic market, consumption of the commodity will increase. This is opposite the direction of change in consumption accompanying the increase in price support (Figure 2). That is, to the extent that the payment to land ends up (indirectly) affecting consumption at all, it will be to increase it. This is one reason to suspect that increased support made in the form of a payment tied to land would have less of an effect on trade than the same amount of support provided as market price support.

Another reason, as noted above, has to do with the fact that the area payment is a subsidy targeted to one factor of production — land — while market price support may be viewed as a subsidy spread more or less evenly across all inputs. All other things the same, the former will have less effect on output so long as the elasticity of supply of land is less than the elasticity of the supply of non-land factors of production.

The increased support is traced out as the shaded area between the before and after commodity supply curves labelled S and S', respectively in the top panel of Figure 3. (Or, equivalently, the crosshatched areas in the lower left hand panel.) In this case, there is no distinction between the amount of support provided and the taxpayer costs of support. They are equal. If consumers are affected at all because of extra support provided as area payments it is through the induced *reduction* in market prices. Area *a* in the top panel of Figure 3 shows the amount of such potential gain. The income gain for farm households is area *b* plus area *c* in the lower left panel of Figure 3, while area *d* plus area *e* in the lower right hand panel constitute gains to input suppliers.

Input suppliers gain, in this example, because the increase in commodity production creates additional demand for purchased inputs. This is represented as the rightward shift in the demand curve for purchased factors shown by the dashed line in the lower right hand panel of the figure.[6] There is thus once again a sharing of the benefits of support amongst farm households and input suppliers, but this time farm households might be expected to get the lion's share.

Figure 3. Trade and income effects of area payments

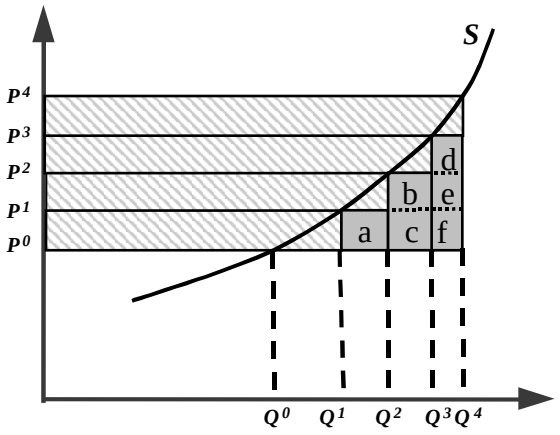


Subsidies based on (variable) input use are relatively less important than other forms of support to agriculture in OECD countries. Analysing their incidence would involve analysis using the diagrams in Figure 3 in the same way as is done above for the area payments.

The initial level of support matters

An especially important factor to consider when comparing the market effects of marginal changes in different support measures is differences in the initial level of support. In general, the market effects of a given increase in the amount of support provided by a support measure will be less the greater the amount of support already being provided by that measure. There are two factors that work together to cause this. Figure 4 will be used to illustrate each of them in turn. First, recall that the functional relationships in the model are approximated with equations linear in elasticities and *percentage* changes in quantities and prices. This is reflected in Figure 4 in the curvilinear shape given the supply curve *SS*. (For purposes of this illustration it does not matter whether the supply in question is that of a crop or of a factor used in crop production.) Consider first the situation in which there is a zero initial rate of support. This corresponds to the combination of a supply price P^0 and quantity supplied Q^0 in the figure.

Figure 4. Diminishing marginal impact of support



Imagine increasing the level of support in stages, each of which leads to exactly the same incremental increase in the supply price: from price P^0 all the way up to price P^4 in Figure 4. Note that although the monetary increment in the supply price is the same in each case, the *percent* increase will not be. Indeed, the higher the initial supply price, the lower the *percent* increase in it caused by each of those increments. For a constant elasticity supply relationship, the lower the percent increase in price the lower the induced quantity response. Compare, for example, the marginal increases in quantity supplied (Q^0 to Q^1) caused by the first increment to price (P^0 to P^1) with that (Q^3 to Q^4) caused by the last increment to price (P^3 to P^4)

The second reason that the pre-existing levels of support matters is that equal increments in the supported price do not translate into equal increases in the amount of support provided. In fact, the marginal increase in support *increases* with each additional increment in supply price. This means that the increment to the supply price needed to achieve a given expansion in the level of support provided will be lower (and the associated supply response as well) the higher the initial level of support.

This is because any additional supply induced by higher support levels will have to receive not only the marginal increment in the support rate, but the old level of per unit support as well. The shaded rectangles in Figure 4 labelled *a, b, c, d, e* and *f* mark out these extra amounts of support. Notice that there is no such additional support associated with the first increment to prices. In moving from price P^1 to P^2 the extra amount is marked off by area a, from price P^2 to P^3, it is the sum of areas b and c. For the last increment to the supply price it the sum of areas marked *d, e* and *f*.

III. Quantitative differences amongst support measures

This section presents numerical results from two kinds of policy simulation experiments undertaken with a quantitative model of the world market for crops. In the first group of policy experiments, the relative effects of the various support measures on production, trade, world market prices and farm income were examined. These comparisons were based on policy impact ratios using market price support as the reference category. A second group of policy simulation experiments was aimed at quantifying the market effects of a 10% reduction in levels of market price support and budgetary payments provided crop producers in the study countries using data from 1998 as the base.

The seven-region PEM Crop Model

The policy simulation model used in this analysis was developed as part of the Policy Evaluation Matrix or PEM project (OECD, 2000). Annex 1 describes the essential features of the model. That annex also contains tables presenting the elasticities of crop demand, factor supply and substitution and the cost shares used. The model comprises individual modules for each one of six individual Member countries: Canada, the European Union, Japan, Mexico, Switzerland and the United States as well as a 'rest of world' module. The farm sector model described in Gardner served as the common analytical foundation on which the individual country modules were built. Each of the country modules contains the equations needed to model supply and demand response, policy measures and prices for four crops: wheat, coarse grains, oilseeds and rice. Not all commodities are produced in substantial quantities in all countries. In those cases: rice in Canada, Switzerland and Mexico; oilseeds in Switzerland; wheat, coarse grains and oilseeds in Japan, supply are held fixed at base year levels.

Modelling support to crop producers

The classification of support measures for the PSE guided the modelling of incidence in the empirical version of the model in the same way as for the stylised analysis of the previous section. (Table 1 shows the specifics.) However, where the stylised analysis focused on differences in effects of the various support measures for only one crop, now there are four crops in the picture. In doing some of the simulation experiments we must choose whether the experimental changes in support are to apply to all crops or just one or two or three of them.

Moreover, to fully represent the variety of main crop support measures used in Member countries, we need to add another category of support measures not considered above, that of payments based on historical entitlements. In this analysis the distinction between area payments and payments based on historical entitlements is that eligibility for the former requires planting one or more of the four crops while eligibility for the latter requires only that a producer retain cropland in agricultural use.

Table 1. How different categories of the PSE are represented in the PEM crop model

PSE classification	First incidence of support in price wedge between:
Market price support	Domestic (producer and consumer) and the world price
Payments based on output	Domestic producer and domestic consumer prices
Payments based on area planted	Rent per hectare received (by landowners) and rent per hectare paid (by land users) - this wedge may be the same for different crops, or it may be different[a]
Payments based on historical entitlements	Rent per hectare received by land owners and rent per hectare paid by land users, not specific to any one crop[b]
Payments based on input use	Domestic supply price and demand price, not specific to any one crop

Notes: a. In the model, landowners are distinguished from land users to provide a basis for distributing the economic effects of policy changes. In reality, not all cropland is rented. The per hectare 'rent' for land not rented needs to be interpreted as sort of shadow price reflecting the opportunity costs of using land in one or another of the crops under study here as opposed to some other use. *b.* In the simulation analysis, this (same) wedge is also introduced as a difference between rental rates paid and received for an aggregate of all other arable land.

The crop coverage question arises only with respect to support provided either in the form of market price support, payments based on output, or payments based on area. Generally speaking, if any of these forms of support applies to any one of the four crops in the list, it will apply to at least one of the other three as well, but not necessarily to all of them. For example, it is frequently the case that if one of the cereal crops grown in a country benefit from border protection and the attendant market

price support, all competing cereal crops also receive some protection and support. In the past, however, it was not uncommon for producers of cereal crops to receive market price support while producers of oilseeds received no support at all. Moreover, even when the same kind of support is provided to more than one crop it is difficult to design the policy that spreads it evenly.

Here we dealt with the issue by evaluating two extreme cases with respect to coverage of those three kinds of support measures. In one case the coverage applies only to the most important crop — that one responsible for the greatest share of a country's crop production. At the other extreme, the hypothetical change in support is uniformly spread amongst all four crops. This was accomplished by applying a common percentage change to the initial price of each output or to the initial rental rate of land depending on the policy simulation experiment. While neither of these extremes corresponds exactly to the way support measures are actually implemented in any one of the study countries the range of possibilities is thought to be wide enough to provide a good indication of how policy effects differ with differences in crop coverage.

Another question touched upon in the stylised analysis above concerns the magnitude of experimental change in support measures. We know that the confidence we can attach to numerical simulation results is greater for small as opposed to large simulated changes in support measures. What in practical terms, however, is 'too large' a change? Gardner (pp. 132), cautions, "*Strictly speaking, the [experimental] changes imposed must be infinitesimal, since the equations are generated from differentials; small finite changes yield approximations. The approximations will usually be not as good for larger changes,* ***like 30%***." Piggott (pp. 133) notes, *'The procedure [equilibrium displacement modelling] is also valuable in allowing headway to be made in measuring the displacement effects of small (****say, in the order of 10% or less****) finite changes in exogenous variables."* A recent ABARE analysis, Roberts *et al.* (1999) uses the GTAP model developed by Hertel (1997) to simulate the economic gains from agricultural liberalisation based on an experimental *"…****36% reduction*** *in all forms of support in all countries…"* (p. 3).

Note that it is not the size of the change in the support measure per se that matters in this context. What matters is the size of the induced changes in prices and quantities along supply and demand curves. Recall from above that two kinds of numerical policy simulation experiments were done to obtain the results reported in this section of the paper. One involved uniform increases of five points in the percent PSE for each crop and country represented in the model: the other a 10% reduction in the *level* of support provided by the various support measures, using 1998 as the base year. In no case did the induced changes in producer and consumer prices exceed 5%. Throughout the paper then, care should be taken to interpret the reported findings, and policy inferences flowing from those findings, as based on simulated "small" changes in support measures. It is not possible, at this stage, to generalise the results to conclude that they would equally apply to 'large' changes, such as the complete elimination of government support to agriculture.

Similarities and differences in the policy effects of support measures

The goal in comparing policy effects of a given amount of support provided via different support measures is to draw some 'in general' type conclusions about their *relative* impacts on the selected indicators. Accordingly, the simulation analysis was undertaken in two steps. First, in each country we simulated the impacts on each and every policy indicator of a given change in the level of support provided alternately by each of the selected support measures. The 'given amount' of the experimental change was equal 5% of the initial value of production.[7] Then, each indicator of policy effects is expressed as the ratio of that result to the result obtained for that indicator in simulating the effect of market price support. This is, in essence, the same approach used by Cahill (1997) and Moro and Sckokai (1998) in their studies of the degree of decoupling of crop support measures used in the European Union.

Table 2. Policy simulation experiments undertaken to compare effects among support measures

Policy simulation experiment	Reference symbol
Market price support provided only to the main crop produced in each country.	MPS (main)
Market price support provided to all crops produced in each country	MPS (all)
Payments based on output provided only to the main crop	OUTS (main)
Payments based on output and provided to all crops	OUTS (all)
Payments based on area planted provided only to the main crop	AP (main)
Payments based on area planted and provided to all crops	AP (all)
Payments based on input use (no distinction among crops)	IS
Payments based on historical entitlements (no distinction among crops)	HE

Table 2 above lists the policy simulation experiments undertaken. The second column of the table contains acronyms used subsequently as a shorthand reference to the results. Full details of the simulations and tables showing country by country results can be found in Annex 1. Figures 5 to 8 summarise the highlights of comparisons of effects for, respectively: production, trade, world-market prices and farm income. The labels along the horizontal axis of each figure correspond to one or another of the policy simulation experiments defined in Table 2. The vertical axis in each figure measures the effects of the support measures along the horizontal axis relative to the effects of market price support. Thus, a value of 1.0 indicates that the support measure has an effect equal to that of market price support. Values less than 1.0 mean that the associated support measure had a simulated effect less than market price support and vice versa.

Both the indicators of production, trade and world market prices and the reference category of market price support used are different for those experiments where the support measure applies to all crops than for those experiments where the experimental change in support applied only to the main crop. In the latter, the indicator is the production, trade or world market price for that main crop. The reference category for these experiments is market price support applied to the main crop. For those experiments where the extra support applies to all crops the indicators are, for production and trade, *quantity* indexes and for world markets prices a *price* index. The reference category for these all-crop cases was market price support provided to all crops.

Each simulation experiment was repeated six times, once for each of the study countries (and without regard to whether the corresponding category of support features in each country or not). The 'spikes' in the body of the figures directly above each of the support category labels measure the range of ratios obtained from each 'sextuplet' of simulation experiments. The dot in each spike denotes the six-country (simple) average.

Figure 5. Ranges of production impact ratios

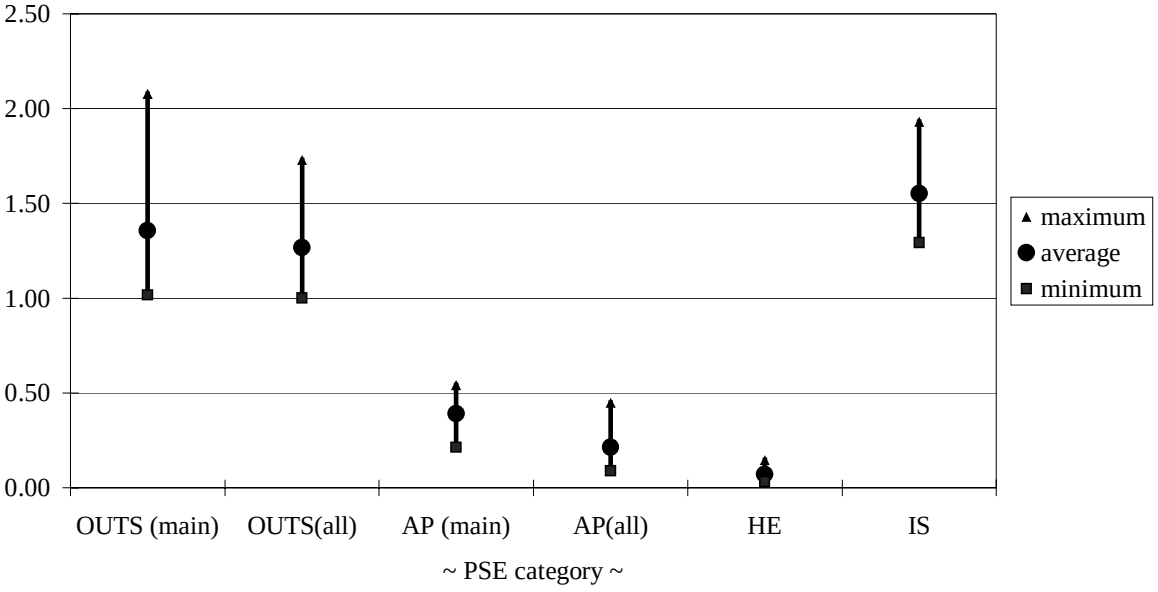


Figure 6. Ranges of trade impact ratios

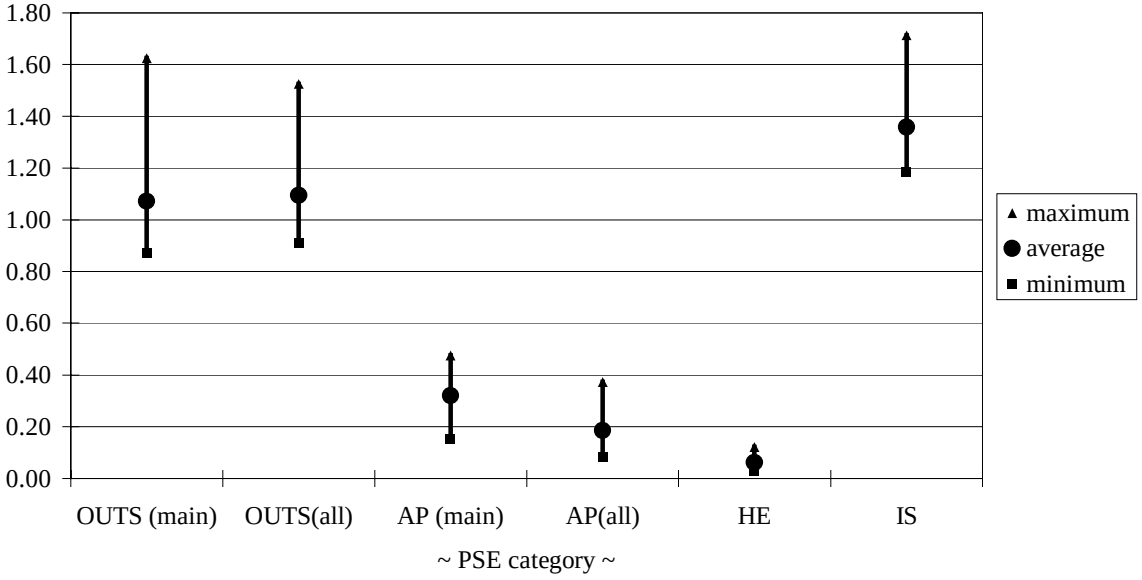


Figure 7. Ranges of world-market price impact ratios

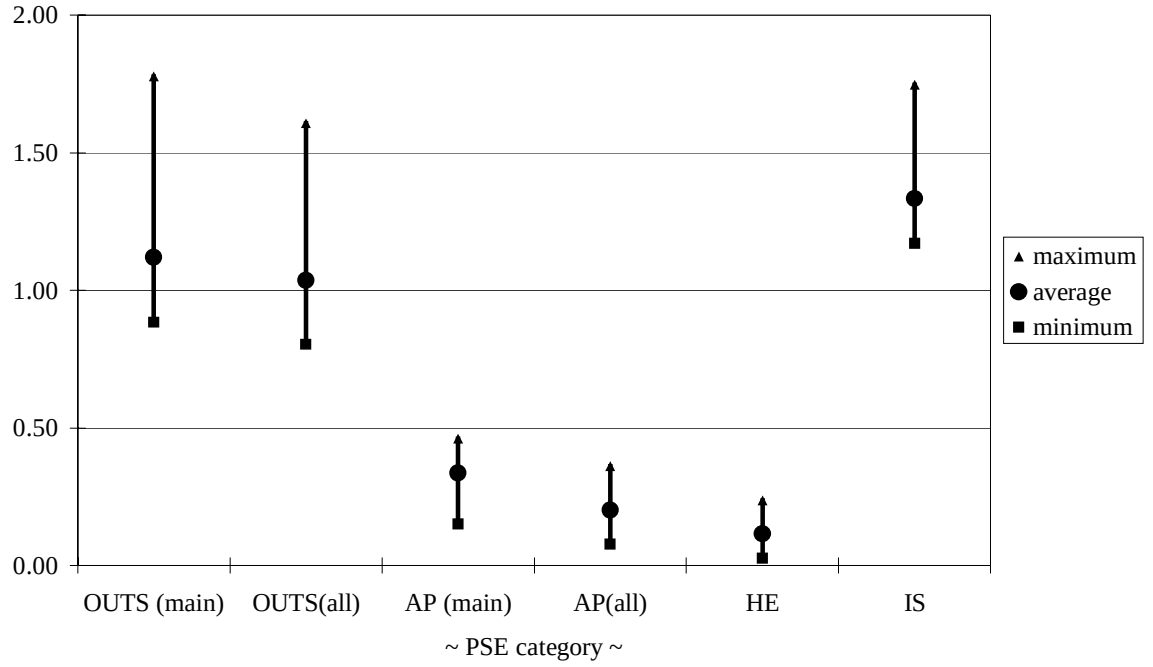
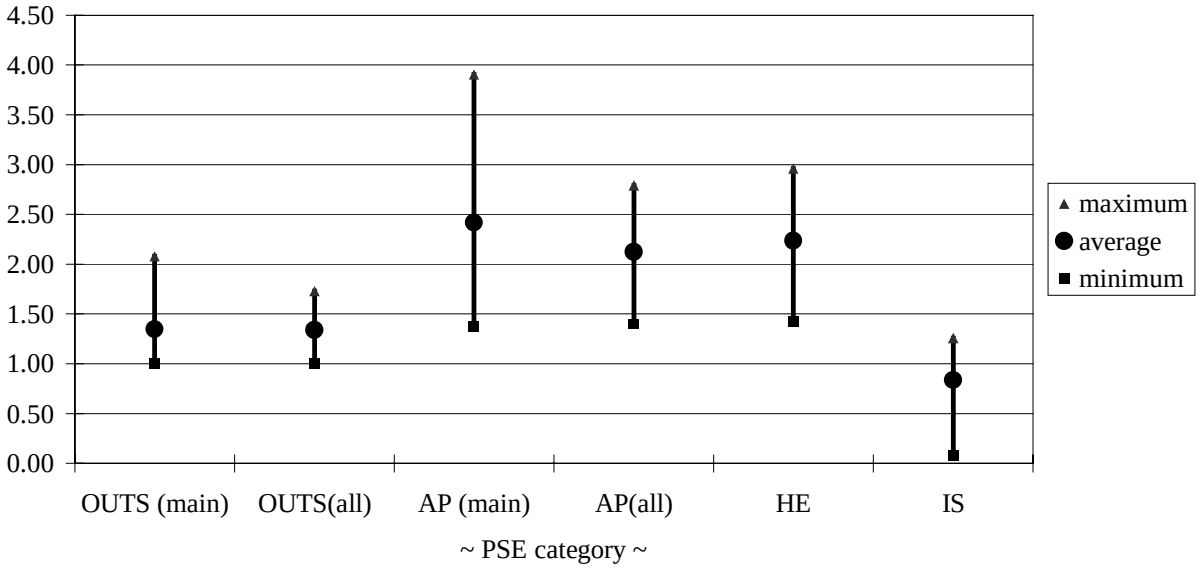


Figure 8. Ranges of income impact ratios



Payments based on the use of inputs (IS) were found to have, on average, the greatest simulated impact on production, trade and world market price and the least simulated impact on farm household income. That the world market effects of input subsidies are greater than those of market price support may come as a surprise given that the higher domestic prices associated with market price support lead both to lower consumption and higher production whereas input subsidies directly

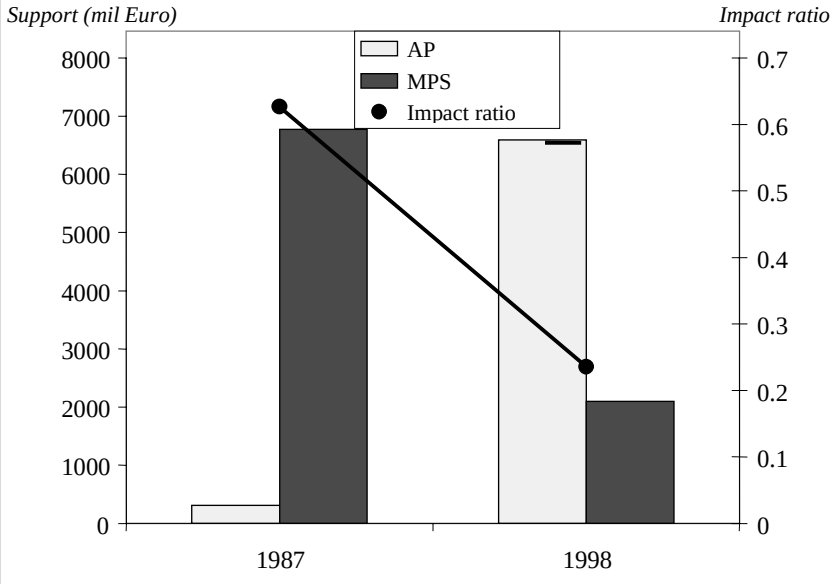
affect only the production side. One explanation is that because input subsidies go to the factors assumed to be most elastic in supply, the *production* effects of an input subsidy will always be greater than the *production* effects of market price support. The finding that the *trade* effects are also greater indicates that the margin of difference in their production effects is larger than the consumption effects of market price support.

Another factor contributing to higher production, trade and price impact ratios for a payment based on input use is the diminishing marginal impact of support. The ratio of the effects of any category of budgetary payment to those of market price support will be larger the larger the initial rate of market price support and it will be smaller, the smaller the initial rate of support provided by the category of payments in the comparison. In the study countries, payments based on input use, the simulated effects of which are in the numerator of the impact ratio were a much less important source of support provided crop producers in 1998 than was market price support, whose effects are in the denominator of the ratio (Box 1).

Box 1. The initial level of support matters — an empirical illustration

In order to further illustrate the importance of the initial levels and patterns of support in determining the impact of different support measures, we will focus on a specific example: the change in the structure of support provided wheat producers in the European Union between 1987 and 1998. Estimated market price support for wheat in 1987 was around seven billion Euros. By 1998, it had fallen to near two billion Euros. Between those same years payments based on area planted increased from almost zero to more than six billion Euros. The figure below shows how estimates of the relative effects of these two support measures differ depending on whether data from 1987 or from 1998 are used as the base for the calculations. The ratio of the simulated production impact of wheat area payments to that for wheat market price support using 1998 as the base year is just over 0.2. However, it is just over 0.60 when the 1987 data is used.

Support levels and impact ratios for wheat in the EU 1987 vs. 1998



Additional payments based on area planted in 1987 would have had a larger production effect than in 1998 because there was almost no support to land supply prices in 1987. On the other hand the 1998 rate of area payments was already quite high so that the effect the same monetary increase in area payments in that year would have been much less. Symmetrically, additional market price support in 1987 would have had smaller per cent impacts on prices and production than that same amount of market price support provided in 1998.

The production effects of payments based on output are seen in Figure 5 to be similar, but generally slightly greater than are those of market price support. Recall that producer price support whether in the form of payments based on output or market price support is equal the product of the gap between producer and world market prices and the quantity produced. Both the price gap and production change when the level of support is changed. Thus, to achieve a given increase in support, the greater the induced increase in the price gap, the less the required increase in production. The price gap increases relatively more, and thus production needs to increase relatively less, with market price support because market price support leads to increases in producer prices, with consequent increases in domestic production, *and* in consumer prices, with consequent reductions in domestic consumption.

Payments based on area and payments based on historical entitlements have the lowest estimated production, trade and world price impacts and the greatest effects on farm household income. Area payments made only to the main crop have greater simulated impacts on production, trade and world market prices than if those payments are spread across the four crops. Likewise, area payments, even with this wider eligibility, have greater effects on these indicators than the historical entitlement payments. Area payments are usually implemented in conjunction with mandatory and or voluntary set aside. These features of policy implementation, ignored in this analysis, would reduce further the production impacts of area payments as compared to market price support, payments based on output or payments based on variable input use.

Table 3 contains estimates of the change in costs or benefits for consumers, taxpayers, farm households (separately for land and other farm owned) and input suppliers *per extra dollar of total consumer and taxpayer cost* attributable to the various support measures. The numbers presented are six-country averages of results that are presented on a country-by-country basis in Annex 1. The last column of Table 3 contains estimates of the dead-weight loss per dollar of transfer. Dead-weight losses are the consequence of domestic resource allocation effects and, in the case of exporting countries, transfers to overseas consumers via lower world prices. Payments based on variable input use, payments based on output and market price support are seen to be the least efficient in transferring income to farm households and exhibit the highest dead-weight costs. Payments based on area and payments based on historical entitlements are more transfer efficient and have much lower dead-weight losses than all the other kinds of support.

The data in Table 3 also show that although payments based on historical entitlements and on area planted were found to be the most efficient in transferring income to farm households the overwhelmingly greatest share of the benefits come in the form of higher land rents. Indeed, land captures the greater share of benefits of extra support for all but one of the categories of support measures studied - that of payments based on inputs. Even in that case, the gain in land rents as a share of total gain is just under that of the main beneficiary, suppliers of purchased inputs.

Table 4 displays a rank ordering and a grouping of the support measures studied summarising the main findings from this part of the analysis. The ordering of the rows in the table indicates which support measure has the greater and which the lesser relative impacts on the various indicators. Displaying the results in this way highlights one of the chief findings from the whole analysis: the inverse relationship between the production and trade effects of support measures and their income transfer efficiency. Three groups of support measures are distinguished. Support measures having similar policy effects, as revealed in Figures 5 to 8, are placed in the same group. Group 1 contains only one category of support; payments based on variable input use, that category having the greatest production and trade effects with the least impact on farm household income. Group 2 contains market price support and output price support. Group 3 includes area payments and payments based on historical entitlements, those categories having the least production and trade effects and the greatest income effects.

Table 3. Distribution of economic effects of support measures

	Gain or loss per dollar of taxpayer and consumer costs for:					
Caused by a simulated 5% increase in:	**Taxpayers**	**Consumers**	**Farm households**		**Input suppliers**	**Deadweight loss**
			land	*other farm owned*		
Market price support:						
Main crop	-0.42	-0.58	0.28	0.19	0.19	-0.34
All crops	-0.28	-0.72	0.34	0.16	0.23	-0.27
Payments based on:						
Variable input use	-1.17	0.17	0.24	0.09	0.31	-0.36
Output of main crop	-1.22	0.22	0.40	0.17	0.18	-0.26
Output of all crops	-1.12	0.12	0.45	0.15	0.18	-0.21
Plantings of main crops	-1.04	0.04	0.84	0.03	0.02	-0.11
Plantings of all crops	-1.02	0.02	0.86	0.02	0.02	-0.09
Historical entitlements	-1.01	0.01	0.95	0.01	0.01	-0.03

Table 4. Rank ordering of policy effects by support measure

Rank order*	**Impact on Production**	**Impact on Trade**	**Impact on World prices**	**Degree of Transfer Inefficiency**
Group 1	IS	IS	IS	IS
Group 2	OUTS (all)	MPS	MPS	MPS
	OUTS (main)	OUTS (main)	OUTS (main)	OUTS (all)
	MPS	OUTS (all)	OUTS (all)	OUTS (main)
Group 3	AP (main)	AP (main)	AP (main)	AP (main)
	AP (all)	AP (all)	AP (all)	AP (all)
	HE	HE	HE	HE

* Rows are ordered from larger to smaller impact on production, trade and prices, but from smaller to larger transfer efficiency.

Differences in estimated policy effects attributable to differences in parameter values

The quality and abundance of productive factors and the way they are combined to produce crops are not the same in all countries. Such dissimilarities may be reflected in differences among countries in the numerical values of critical economic parameters such as the elasticities of factor substitution and supply characterising the aggregate crop production relationships. Of special relevance here, different parameter values also lead to different estimates of the relative impact of

support measures. The problem is, for the broad aggregates of production and factor use needed for national and international policy analysis, the exact numerical values of these parameters can never be known with a high degree of certainty.

The reviews of published studies of crop supply response comprising Annexes 2 and 3 yielded estimates of plausible ranges for key parameter values, but no precise point estimates of them. That is to say, we can know with reasonable confidence the upper and lower bounds of a range of plausible values of a critical elasticity, but have no strong basis for choosing any particular value falling within those bounds. This kind of uncertainty, common to all applied modelling, can be studied systematically following a sensitivity analysis procedure (Davis and Espinoza, Griffiths and Zhao, Schneider *et al*.). The goal of this sensitivity analysis is to obtain a probability measure of uncertainty about (or an indication of central tendency of) a particular result, given the uncertainty about the parameter values.

The sensitivity analysis comprised a three-step procedure. In the first step, we select a complete set of factor substitution and supply elasticities for every crop and every country in the model randomly drawing each one from its own (uniform) distribution.[8] Second, we perform two policy simulation experiments: one to estimate the effects of a given change in market price support provided producers of the main crop, the other to estimate the effects of an area payment of equal magnitude given to that same main crop. Third, we calculate the corresponding impact ratios. We repeat the same three-step procedure 250 times for each country in the model leading to a total number of impact ratios to compare of (6 x 250 = 1500).

Figures 9 and 10 present main findings for two indicators: trade impact ratios and farm income impact ratios, in histograms combining simulation results for all countries. In Figure 9, the average trade impact ratio is 0.34. This average is nearly the same as the corresponding six-country average reported in Figure 6.[9] The estimated standard deviation is 0.17 implying that only for a very few combinations of parameter values and initial conditions were the trade effects of area payments equal to or greater than those of market price support were.

Figure 10 contains the distribution of farm income impact ratios. The mean of the farm income ratio is 2.4 also very close to the six-country average for this indicator as shown in Figure 8. The standard deviation is 1.8. However, there were very few combinations of parameter values and initial conditions yielding a simulated farm income impact due to a change in market price support provided the main crop in a country that was as great or greater than the farm income impact of area payments provided that crop. Moreover, the distribution is characterised by a few very high impact ratios. These extremes were obtained when combinations of parameter values, initial levels of support and size of country were such that the simulated income impact of changes in market price support were very small, driving the denominator in the impact ratio toward zero.

Figure 9. Distribution of simulated trade impact ratios for area payments (main crop)

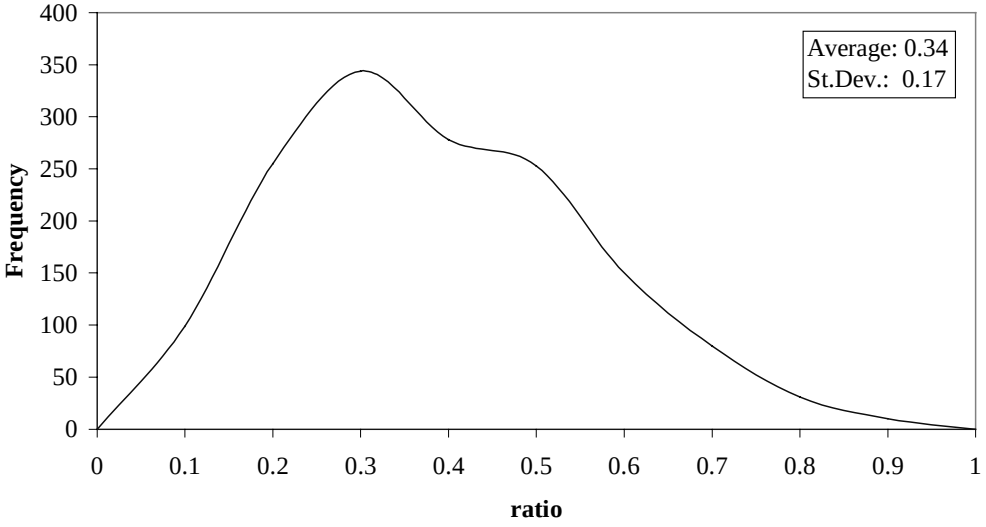
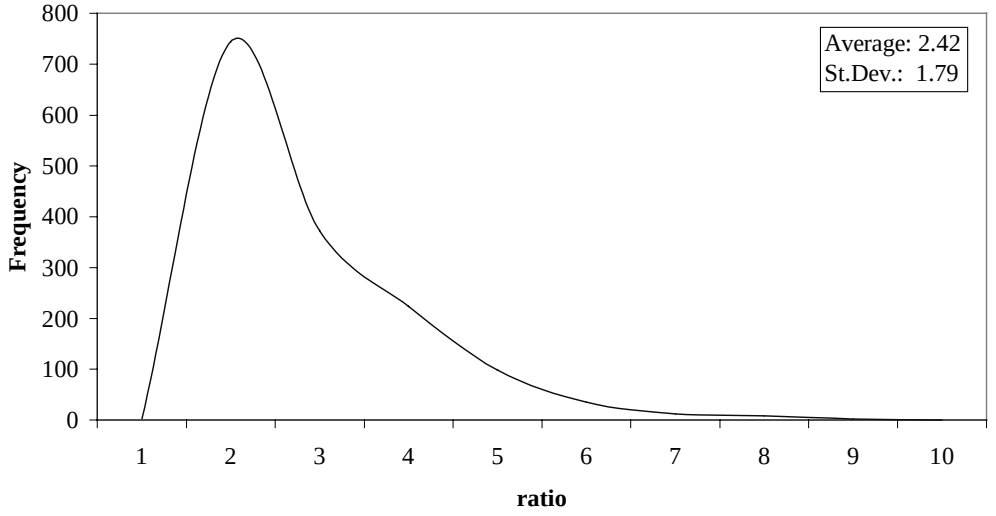


Figure 10. Distribution of simulated farm income impact ratios for area payments (main crop)



Estimated effects of a 10% reduction in crop support measures

This section reports results of the policy simulation experiments undertaken to estimate the impacts of uniform 10% reductions in the 1998 rates of market price support[10] and budgetary payments in the study countries. Table 5 reports initial levels of support provided in the respective categories in that year.

Table 5. Estimated market price support and budgetary payments in 1998: totals for study crops

	Canada	European Union	Japan	Mexico	Switzerland	United States	All countries
				~ USD million ~			
Market price support	0	5 416	15 750	432	367	13	21 977
Payments based on output	43	0	919	6	0	2 291	3 258
Payments based on area planted	149	15 562	0	9	103	1 150	16 973
Payments based on historical entitlements	0	136	0	786	52	7 595	8 570
Payments based on input use	124	7 467	689	87	14	1 223	9 604
PSE 5 categories	316	28 581	17 358	1 319	537	12 272	60 382
Other PSE categories	8	3 227	22	134	22	536	3 948
Total PSE	324	31 808	17 380	1 453	559	12 808	68 280
%PSE	5%	40%	77%	26%	59%	19%	45%

Although this percentage reduction was applied equally to all crops and all countries in the model, the largest simulated changes in support came, naturally, from reducing support in those categories that were largest in 1998. These comprised: market price support for rice in Japan, area payments for crops in the European Union, market price support for cereals in the European Union and historical entitlement payments in the United States.

Table 6 summarises the main results in terms of the simulated impacts on world market prices. The last column contains results for a constant quantity index of crop prices. The simulated increase in that index is 2.2%, half of it due just to the impact of the reductions in market price support. However reduction in the other categories of support also contribute to the price increase. The 10% reduction in the rate of payments based on input use leads to a simulated increase in crop prices of 0.6%, while the 10% reductions in the rates of payments based on area planted and those based on historical entitlements together add another 0.2% to the total simulated price gain. Among the crops, the largest simulated change in world market price is a 3.0% increase in wheat price; the smallest a 1.3% increase in world price of oilseed crops.

Table 6. Simulated world market price impacts of support reductions

	simulated percent change in world market price of:				
due to 10% reduction in the rates of	**wheat**	**coarse grains**	**oilseeds**	**rice**	**index**
Market price support	1.1%	1.0%	0.3%	1.4%	1.1%
Payments based on output	0.3%	0.4%	0.2%	0.1%	0.2%
Payments based on area planted	0.3%	0.2%	0.1%	0.1%	0.1%
Payments based on historical entitlements	0.2%	0.2%	0.1%	0.1%	0.1%
Payments based on input use	1.1%	0.8%	0.6%	0.3%	0.6%
All categories simultaneously	3.0%	2.5%	1.3%	1.9%	2.2%

Table 7 contains estimated economic gains and losses caused by reducing all crop support by 10%. The first set of rows contains the estimated impacts on farm household income, input supplier profits, consumers and taxpayers; all measured in millions of US dollars. The second set of rows express the results as percentages of the initial value of total producer receipts (value of production plus payments) to enable better cross-country comparisons. There is a simulated net welfare gain in all countries, except Mexico. In Mexico, both consumers and farmers lose: the former due to higher world and internal prices, the latter due to the reduction in payments based in historical entitlements.

Table 7. Simulated economic costs and benefits of reducing all crop support rates by 10%

	Canada	European Union	Japan	Mexico	Switzerland	United States	All countries
in USD million							
Farm household income	62	-1 726	-1 184	-64	-13	-241	-3 166
Profits of input suppliers	25	-448	-321	-4	-3	74	-675
Consumer surplus	-78	367	1 828	-31	51	-686	1 451
Taxpayer costs	37	2 615	897	83	13	1 218	4 863
Total	46	808	1 221	-16	48	366	2 473
as % of total initial farm revenues							
Farm household income	1.1%	-3.0%	-5.5%	-1.4%	-1.7%	-0.4%	-2.1%
Profits of input suppliers	0.4%	-0.8%	-1.5%	-0.1%	-0.3%	0.1%	-0.4%
Consumer surplus	-1.4%	0.6%	8.5%	-0.7%	6.6%	-1.1%	1.0%
Taxpayer costs	0.6%	4.6%	4.2%	1.8%	1.6%	2.0%	3.2%
Total	0.8%	1.4%	5.7%	-0.3%	6.2%	0.6%	1.6%
Total if support is reduced unilaterally							
in USD million	9	800	1 328	27	51	352	2 566
as % of total initial farm revenues	0.2%	1.4%	6.2%	0.6%	6.6%	0.6%	1.7%

The last two rows of Table 7 contain results obtained by simulating the impact of unilateral support reductions. These results correspond to a scenario under which each country simultaneously reduces all its categories of crop producer support by 10%. Comparing these results to those in the corresponding rows labelled 'Total' in the main body of the table gives an idea of the difference in total net welfare gain achievable when all countries reduce support at the same time versus when a country does it all by itself. For example, a unilateral 10% reduction in crop producer support in the European Union gives a total simulated net welfare gain in the European Union of USD 800 million. This compares with a USD 804 million simulated gain for the European Union for the scenario in which all countries simultaneously reduce their crop support levels by the same 10%. All countries would experience a welfare gain from a unilateral reduction in their crop support levels. Indeed, Japan, Mexico and Switzerland are shown to experience an increase in welfare even larger than in the multilateral reduction scenario. This fact highlights the political difficulties for reducing support due to reasons that do not show up from the net welfare calculations.

One of these difficulties may be connected to the negative farm income impacts of reducing support. Overall, there are gains to farm households in only one of the study countries — Canada. However, it is easy to infer from the results for world market prices (Table 6) that farm households in exporting countries producing these crops, but not subsidising their producers, would also gain (*e.g.* Australia). Farmers lose in all other study countries. Most of the gains across countries, and especially in the European Union, are not for the consumers but for taxpayers. This distribution of gains may also affect the political dimension of support reduction.

Some kinds of price intervention by governments not only create a price gap, but also eliminate the transmission of price signals from the world to the domestic market. To investigate the importance of this form of intervention, we repeated the simulation experiments by reducing all support rates again by 10%, but this time under the assumption that there is price transmission from the world markets to the European Union's wheat, coarse grains and rice markets. Selected results are found in Table 8. The European Union accounts for a significant share of world crop production and consumption. If world market prices are transmitted to EU producers and consumers, a part of the adjustment in production and consumption needed to accommodate support reductions occurs, thereby reducing the need for adjustment in the rest of the world.

The simulated increase in world wheat price under the scenario with price transmission to EU cereal producers and consumers was only 2/3 that obtained for the case when there was no price transmission. The adjustment in wheat production in Canada, the most dramatically affected country, would be reduced by nearly half, and that of the rest of the world would be a third. For some indicators in the 10% scenario, the allowance for price transmission in the EU could be almost as significant as the whole of reduction in the amount of support. For instance, the simulated impacts on farm income for Canada and for the United States are significantly different under the two alternative assumptions.

Table 8. The impact of a 10% reduction in all support rates with price transmission

	Impact of 10% reduction in all support rates	Impact of the same simulation with price transmission in the EU
World wheat price	3.0%	2.0%
Canada wheat production	3.6%	1.8%
Rest of the World wheat production	0.3%	0.1%
World price index	2.2%	1.9%
Farm income *in*		
Canada	62	44
The European Union	-1726	-1619
Japan	-1184	-1187
Mexico	-64	-66
Switzerland	-13	-13
The United States	-241	-313

IV. Conclusions and policy implications

Market price support and budgetary payments based on either: outputs, variable inputs, area planted or historical entitlements account for over 90% of the total PSE for crops in OECD countries. This paper posed the following questions about those support measures:

Do they differ in their effects on production, consumption, trade and farm income?

What are the policy implications?

In interpreting answers to these questions provided by this analysis, three caveats need to borne in mind. First, the assumptions made about the incidence of support measures are based on the way they are classified for the PSE. In that sense, the policy representation is 'stylised', not representing the specific mechanisms of policy implementation in any one of the study countries. Second, the empirical model developed required assumptions of plausible ranges for key supply and demand parameters. Policy simulation results are sensitive to the particular choices of parameter values from their respective ranges. Model estimates of policy effects are approximations. Such approximations are likely to be better when the analysis involves small changes. Evaluating large changes (such as the complete elimination of government support programs) introduces some uncertainty about the validity of both the parameter estimates and the underlying behavioural assumptions of the model. Third, the model represents support measures only in terms of their incidence on prices of commodities and factors while, in reality, policies may produce effects through

less direct channels: by reducing perceived risks, by increasing a farmer's credit worthiness, by creating expectations and so on.

Do support measures differ in their effects on crop production, consumption, trade and farm income?

Results of theoretical and numerical simulation analysis reported in the paper leads to an unequivocal yes to this question. Support measures differ in their effects because they differ in their incidence on prices in crop and factor markets, because the land intensity of variable factor use can vary with relative prices and because some productive factors, cropland especially, are relatively more fixed in crop production than other factors.

One part of the policy simulation analysis aimed at estimating policy *impact ratios*. An impact ratio was defined as the ratio of the simulated impact of a particular support measure on a selected indicator, to the simulated impact on that same indicator of an equal amount of market price support. The differences in these impact ratios were found to be sensitive to initial support levels and to the settings of key parameters whose precise numerical values are uncertain. However, comparisons of averages and variances of results provides strong support for the following general conclusions:

- The estimated effects on farm household income of a given amount of support provided either in the form of payments based on historical entitlements or based on area planted are substantially higher than for the other support measures. The greater the coverage of payments based on area the greater this income transfer efficiency.
- The estimated effects on farm household income of a given amount of support provided in the form of payments based on the use of purchased inputs are always lower than when that same amount of support is provided through the other measures.
- The estimated effects on production and on net trade of a given amount of support provided as a payment based on area, even when accompanied by a requirement to plant, are systematically lower than when that same amount of support is provided through any of the other support measures. Again, the greater the coverage of area payments the lower their production and trade effects.
- World market price impacts of support measures are frequently used to indicate international spillover effects of support policy. In the simulations, world market prices decline regardless of the form in which support is provided, but the decline is significantly less for payments based on historical entitlements and area planted than for any of the other measures studied.

Another part of the policy simulation analysis aimed at quantifying the implications of an across the board 10% reduction, relative to the 1998 base levels, in the amount support provided by the support measures studied. That analysis takes into account both the differences in the relative effects of different support measures and the differences in the amounts of support provided by those support measures in the base period. That part of the analysis led to the following general insights:

- Reducing market price support by 10% leads to a greater simulated increase in world market prices, with the least impact on farm household income than the 10% reduction in any other single category of support measure studied.
- However, adding together the effects of 10% reductions in budgetary payments based on output and on variable input gives simulated increases in world market prices that are, for some crops, comparable to the gains associated with 10% reductions in market price support. Moreover, on a dollar-for-dollar basis, the loss in farm income is about the same.

- Together, payments based on area planted and on historical entitlements accounted for the greatest share of support provided crop producers in the study countries in 1998. However, the *combined* impacts on world market prices of a 10% reduction in these categories of support were generally smaller than for any one of the other categories of support. Conversely, the simulated reduction in farm household income was greater than for any one of the other categories of support.
- Although there are potential net welfare gains from support reduction, estimated effects on farm household incomes differ for different countries. They are positive for Canada (and, by inference, non-subsidising countries such as Australia), but negative for the other individual Member countries in the model.

What are the policy implications?

In classifying support measures for the PSE on the basis of implementation criteria no consideration is given to the underlying policy target or their purpose. Rather, the aim is to classify them in such a way that facilitates the analysis of their effects on a range of outcomes, including those featuring in this analysis. However, it is difficult to derive explicit policy implications from the findings without reference to explicit policy objectives. The policy objective assumed in deriving the policy implications discussed in this section is, *to transfer income to farm households with the least impact on trade and world market prices.*

In recent years, there has been a shift in mix of policies used to support crop farmers in OECD countries, away from other forms of support and towards area payments and payments based on historical entitlements. (OECD, 2001*b*) The finding of a relatively higher income efficiency of these categories of support measures implies that the switch in policy mix may have increased net income of farm households, even when the overall level of support to crop producers was declining. This is possible, both because of the differing degrees of income impacts of the support measures and because of the relative magnitude of the changes.

Policy simulation results suggest that payments based on variable input use can be an especially inefficient way of transferring income to farmers. Simulated small increases in such payments were also found to have the greatest estimated effects on production and, in most simulations, the greatest estimated effects on net trade of the support measures studied. Perhaps these characteristics help to explain why payments based on variable input use no longer feature significantly in the programs of agricultural support in the study countries.

Support for farmers in one country or region may significantly affect net trade and the economic well being of the farm sector in another country or region. But, policy measures leading to identical changes in measured support may differ greatly in these international spillover impacts. Estimated results obtained from the simulation analysis suggest that, as compared to market support, area payments or payments based on historical entitlements in one country or region lead to smaller production, trade and welfare impacts on other countries or regions. These results suggest that the observed change in policy mix in OECD countries away from market support towards area payments, could well have enhanced incomes of farm households in countries where such changes were implemented while reducing the damage caused to farm household incomes in other countries.

The generally inverse relationship between the trade effects of the support measures studied and their efficiency in transferring income to farm households has implications for future reform of farm policy. First, it is probably safe to assume that the greater the efficiency with which a support measure transfers income into the pockets of farmers, the more politically difficult it will be to reduce the amount of support provided by that measure. Conversely, the less efficient a support measure in

transferring income the easier it is likely to be to reduce that support measure and to find ways to compensate for the associated income losses.

Notice now that the potential gains to trading partners from support reductions are exactly the other way around. Those support measures, whose reduction would likely bring the greatest benefit (dollar-for-dollar) to trading partners, are exactly those providing the least improvement in farm income in the country where they are implemented, those for which reduction or elimination might be politically easier to achieve. On the other hand, those support measures whose reduction would likely provide (dollar-for-dollar) the least benefit to trading partners are those providing the greatest improvement in farm household income in the country where they are implemented, those which undoubtedly would prove the most politically difficult to reduce.

Although area payments and payments based on historical entitlements were found to be a more efficient means of increasing farm household income, results show that the benefits are almost exclusively in terms of higher returns to land. With due consideration to uncertainty about the life expectancy of the programs, the value of increased land rents will show up in higher valuations and selling prices of land. That is, landowners will ultimately extract such benefits and farm operators can capture them only to the extent that they happen to own the land they farm. The greater is the transfer efficiency of the payments, the greater is the degree to which they may be capitalised into land values.

Furthermore, although estimated results suggest that area payments and payments based on historical entitlements are *relatively* less production distorting than other forms of support they result in *higher-than-otherwise* crop production. Enhancing the packaging of such payments by linking them to a fixed historical period, eliminating requirements to plant or introducing other refinements that ensure current production intentions are not directly affected, would help to neutralize such effects. And, of course, limiting the time period during which such payments would be made would facilitate reasonable adjustments by affected farms, while mitigating concerns with capitalization and any 'second level' distortions (associated with farmer perceptions of future payments/payment conditions, new investments in increased production capacity, etc.).

Such enhancements should be pursued. Perhaps more importantly, they would remove further impediments to increased producer responsiveness to changing market signals and hence improved market income opportunities. Finally, such further actions would reduce the spillover effects that give rise to accusations of unfair trading practices and increased trade tensions, and ultimately counter-measures that introduce further distortions. Moreover, the support measures examined in this analysis do not constitute the entire universe of possibilities for providing income support to farmers. There are others, pure lump sum transfers for example, that theory suggests would be even less distorting.

NOTES

1. The European Union was treated as a single entity in the analysis. Accordingly, the occasional reference to 'study countries' includes the European Union.

2. These types of equations provide log-linear approximations to the 'true' functional forms of the underlying production function, the associated factor demand equations and the equations of factor supply and commodity demand. The approximations would be better, especially for evaluating relatively large changes, if the underlying true production functions were of the constant elasticity of substitution, and the factor supply and commodity demand equations were truly log linear (Gardner).

3. Throughout the paper we assume that farm households own all the land they farm. In reality, farm households rent some cropland from people who do not farm. Later, in the empirical part of the paper, we distinguish between the benefits of support accruing to land versus non-land factors owned by farm households.

4. In the simulation model wheat coarse grains, oilseeds and rice are treated as tradable commodities with prices determined through market clearing in world markets. On the other hand, all inputs whether farm owned or purchased are treated as non-tradable, an assumption of questionable validity for some purchased inputs.

5. Illustrating the effects of market support for an importing country involves a straightforward adaptation of Figure 2. Except, in the case of an importing country, the consumer costs of a given increase in market price support are relatively much greater. Depending on the policy regime, such higher costs for consumers may be partially offset by an increase in tariff revenues.

6. Notice the extra production constitutes only one of two channels through which suppliers of purchased inputs may be impacted by the area payments. Recall that we assume farm owned factors and purchased inputs are substitutes in production. (This must be the case when there are only two input categories.) In so far as production decisions are concerned, an area payment reduces the cost of land (rental rate) relative to non-land factors of production. If this were the only effect, the demand for purchased inputs would decline. The increased demand shown reflects a 'net' effect wherein this substitution effect is more than offset by the scale effect associated with increased production.

7. Five per cent was an arbitrary choice. During the preliminary phases of the analysis we tested a number of alternatives in the range one to ten per cent of the initial value of production. We found that results, when expressed in relative terms as described, did not change appreciably with differences in the magnitude of the shock over that range.

8. Annex 1 explains that the supply of cropland in the model is represented via a system of crop-specific land supply equations. Consequently, the own and cross elasticities in these equations are not independent of each other. Any combination of values chosen for them must satisfy two restrictions derived from theory: the symmetry of cross price derivatives, and homogeneity (adding up). Accordingly, at each turn of step one in the procedure a check was performed to verify whether these two restrictions were satisfied. If not, that step was repeated as many times as necessary until a set of land supply elasticities satisfying the two restrictions was obtained.

9. As noted, the sensitivity analysis done for inclusion in the paper concerned only the two categories of support measures: market price support provided just to the main crop and area payments provided just to the main crop. However, in related work we repeated the same analysis comparing market price support provided all crops with area payments provided all crops. The mean of the distribution of

impact ratios obtained in that analysis was nearly identical to the corresponding six-country averages for AP (all) reported in Figures 6 and 8. Furthermore, the distribution of the AP (all) versus MPS (all) impact ratios is narrower than for the 'main crop only' comparisons reported above.

10. The reductions in market price support applied equally to producers and consumers. In some study countries these rates are different for producers than for consumers: wheat, coarse grains and oilseeds in Japan are examples.

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Annex 1.

MODEL DOCUMENTATION AND ADDITIONAL RESULTS

I. Crop model structure, parameters and elasticities

Table A1.1 contains equations constituting a representative country module of the PEM crop model. This basic structure is the same for each one of the six individual OECD Member country modules in the model. The presentation in Table A1.1 follows very closely that found in Gunter *et al*. Note that the world market price and trade are endogenous only in the context of the 7-region model as a whole.

Consumption of wheat, coarse grains, oilseeds and rice is relatively important in all study countries. However, not all four crops are produced in significant quantities in all countries. This is the case for rice in Canada, Mexico and Switzerland; oilseeds in Switzerland; and all crops but rice in Japan. In all these cases, production is fixed at base period levels and held there in all the policy simulation experiments. In all country modules, there are two farm owned factors: land and a residual of "other farm owned" factors. The list of purchased factors is different for each country. Fertiliser is distinguished in all, and hired labour in all except Mexico and Japan where the cost share for hired labour is relatively quite small (Table A1.2 presents complete detail on input coverage by country).

Factor supply

An important consideration in modelling the demand and supply of inputs used in crop production is the degree to which they are specific to any one or the other of the crops produced. In principle, some factors of production may be specific to the crop in which they are used; for example, certain individual items of fixed capital may be necessary for each one of the crops produced. Moreover, there is regional specialisation in production with associated costs to factor mobility among regions [Abler and Shortle (1997), p. 48]. At the other extreme, there are inputs that can be used just as easily in one crop as in another. In principle, given quantities of these inputs would be re-allocated easily amongst crops in response to changes in relative returns.

In the PEM crop model, the aggregate factor — 'other farm owned', comprising (mostly) farm household labour and management — is assumed to be completely crop-specific. That is to say, we defined a unique category of this factor for each crop and allow no substitution in its use among crops. Moreover, the supply of this factor depends only on its own price. Conversely, we did not distinguish any one of the purchased factors on a crop basis, assuming thereby a perfect substitutability in their use amongst crops in response to changes in relative prices. Likewise, the supply of each and every purchased factor depends only on its own price.

Table A1.1 Representative country module of PEM crop model

Endogenous variable symbol	***Stands for***
q_i^d, q_i^s, q_i^t	percentage change in crop demand, supply and trade quantities
p_i^d, p_i^s, p_i^w	percentage change in domestic demand and supply prices and in world price of crops
x_j^d, x_j^s	percentage change in input demand and supply quantities
r_j^d, r_j^s	percentage change in input demand and supply prices
k_i^d, k_i^t	ratios of domestic demand and trade to domestic supply
Policy variable symbol	***Stands for percentage change in rate of***
m_i	market price support
o_i	output price support
a_i	area payment
h	historical entitlement payment
s_j	subsidy to variable inputs
Parameter symbol	***Stands for***
n_{ij}	elasticity of demand for crop i with respect to price of crop j
c_{ji}	cost share of input j used in producing crop i
σ_{ij}	elasticity of substitution between factor i and j
Equations	
$q_i^d = \sum_{j=1}^{4} n_{ij} p_i^d$	domestic consumption demands for i=1 to 4 crops
$q_i^s = q_i^d * k_i^d + q_i^t * k_i^t$	domestic crop production for i=1 to 4 crops
$x_{j,i}^d = \sum_{j=1}^{m} c_{ji} \sigma_{ji} r_j^d + q_i^s$	input demands for j=1 to m inputs, i=1 to 4 crops
$p_i^s = \sum_{j=1}^{4} c_{ji} r_j^d$	zero profit conditions for i=1 to 4 crop supply prices (crop supply price equals unit average cost of production)
$x_j^s = \sum_{j=1}^{4} e_j r_j^s$	cropland supplies for j=1 to 5 categories of cropland (wheat, coarse grain, oilseed, rice and 'other arable').
$x_j^s = e_j r_j^s$	non-land input supplies for j=6 to m non-land inputs
$x_j^s = x_j^d$	input market clearing for j=1 to m inputs
$r_j^s = r_j^d + a_j + h$	cropland supply prices for j=1 to 5 categories of cropland
$r_j^s = r_j^d + s_j$	non-land supply prices for j=6 to m non-land inputs
$p_i^s = p_i^d + o_i$	crop supply prices for i=1 to 4 crops
$p_i^d = p_i^w + m_i$	crop demand prices for i=1 to 4 crops

The special case of land supply in the PEM crop model

In modelling demand and supply of cropland, we defined a unique category of land for each crop in the same way as for the 'other farm owned' aggregate. However, except for rice, we assume that the supply of land to each crop depends not only on the rental rate for that category of cropland but on the rental rates for all other categories of cropland as well. This approach recognises that while some land may be better suited for one crop than for another, there can be some substitution amongst uses in response to changes in land rental rates.

Table A1.2. Factor coverage

	~ Country ~					
Farm owned factors:	**Canada**	**European Union**	**Japan**	**Mexico**	**Switzerland**	**United States**
Land	Yes	Yes	Yes	Yes	Yes	Yes
Other farm-owned factors	Yes	Yes	Yes	Yes	Yes	Yes
Purchased factors:						
Fertilisers	Yes	Yes	Yes	Yes	Yes	Yes
Hired labour	Yes	Yes			Yes	Yes
Chemicals					Yes	Yes
Energy					Yes	Yes
Interest					Yes	Yes
Insurance					Yes	Yes
Machinery and equipment					Yes	
Rented land					Yes	
Irrigation						Yes
Other purchased factors	Yes	Yes	Yes	Yes	Yes	Yes

Following Abler and Shortle, we model this imperfect substitutability amongst the various categories of land use using land supply equations containing both own and cross-price elasticities. These elasticities measure the proportional change in area planted to a particular crop in relation to the proportional change in land rents earned from use of land in that and other crops. Thus, for those countries where all four crops are grown there are four land supply equations, one for each crop. However, in the wheat, coarse grain and oilseed equations all cross elasticities defined with respect to the rental rate of rice land are set equal to zero. Likewise, in all the rice land supply equations the cross-elasticities measuring response of rice land to changes in rents for other crops are also set equal to zero.

The list of cross-price elasticities in all these land supply equations includes one for a residual category of land use, 'other arable land'. This category was included to enable full coverage of the potential impacts of the various categories of payments based on area. In the analysis, and following their classification for the PSE, we assumed area payments require planting of the specific crop or crops for which they are made. Correspondingly, we assumed payments based on historical entitlements require that the land remain in production but do not specify what particular use is to be made of the land. In both cases, the total amount of land planted to wheat, coarse grains, oilseeds or rice may be changed by moving land to or from 'other arable land' in response to induced changes in land rents.

As noted in the main text, the impact of a given change in support provided in the form of payments based on area planted depends on how many categories of land use are covered by the payments; the larger the number of eligible crops, the smaller the *average* impact. To understand why this is so notice the structure of the land supply equations in Table A1.1. The own-price elasticity of land supply is always positive; the cross-elasticities always negative (all categories of land use are

assumed to be substitutes). The net effect of an increase in payment made only to one category of land use, even after allowing for induced market increases in rental rates for all other categories, will always be greater than if that payment is spread amongst several categories of land use. Accordingly, the smallest net effect, *on average*, will always be associated with a program that provides uniform payments regardless of the use to which the land is put.

The area supply elasticities in the PEM crop model were calibrated to ensure, to the maximum degree practical, consistency with available empirical estimates of land supply elasticities and theoretical restrictions applying to systems of equations derived from cost functions. Specifically, we calibrated those elasticities to guarantee that the average net effect of any hypothetical increase (decrease) in area payments is always positive (negative). The particular calibration we made yields an elasticity linking a proportional change in land rental rates due to an increase in area payments spread uniformly across all categories of arable land use (study crops as well as 'other arable') that is the same, 0.033, in all countries. Under the assumptions made for this analysis this is the elasticity that applies in the case of payments based on historical entitlements.

Moreover, we imposed a cross-elasticity defined with respect to a proportional change in the rental rate for 'other arable' land that is the same, 0.067, for all categories of cropland and for all countries. The upshot is that the net elasticity measuring the proportional change in plantings to study crops in response to a uniform proportional increase in area payments made just to those crops is 0.10 (0.033+0.067). Finally we calibrated the cross-elasticities in the land supply equations for wheat, coarse grains and oilseed crops to ensure symmetry in all cross derivatives. This restriction means that the effect of a change in area planted to crop i in response to a change in the rental rate for crop j is the same as the change in area planted to crop j in response to a change in rental rate for crop i.

Elasticities of factor supply

Estimates of factor supply used in PEM crop modules are presented in Table A1.3. The estimates for North American countries: Canada, Mexico and the United States and for the European Union are based directly on the commissioned reviews of agricultural supply response in those regions, presented as Annexes 2 and 3 of this report. The two consultants, David Abler for the North American countries and Klaus Salhofer for Europe, were asked to review past studies in their respective regions and recommend base values and plausible ranges of values of both elasticities of factor supply and substitution for use in the PEM models. Japanese and Swiss colleagues participating in the PEM pilot study work group reviewed and provided similar information from studies of supply response done in their respective countries.

The numbers shown in Table A1.3 are based largely on the recommendations of the two consultants. There are just two important exceptions. First, there were too few independent estimates of the elasticities of supply of purchased factors to be able to justify differences in assumptions among countries. Accordingly, the same base values and ranges were used for all. Second, we adjusted the cross elasticities among wheat, coarse grain and oilseed land for the European Union to impose a net elasticity of supply of total cropland of 0.10, the same as for the North American countries. The net elasticity of EU cropland supply implied in the consultant's recommendations was 0.05.

To simplify the presentation only the averages of cross elasticities of land supply for wheat, coarse grains and oilseeds are presented in Table A1.3. Specific values of cross-elasticities for the various crop and cross-price combinations were calculated using these averages, the base period area shares and imposing the adding up and symmetry restrictions as described above.

Table A1.3. Factor supply elasticities

		Non-land factors:		*Land:*		
		Purchased	Farm owned	Wheat, coarse grains and oilseeds land		Rice land
		w.r.t. own price		*w.r.t. own*	*average cross*	*w.r.t. own*
Canada	**base**	**2.50**	**0.40**	**0.40**	**-0.15**	**N/A**
	minimum	0.50	0.10	0.20	-0.10	N/A
	maximum	4.50	0.70	0.60	-0.20	N/A
European Union	**base**	**2.50**	**0.50**	**0.25**	**-0.08**	**0.05**
	minimum	0.50	0.10	0.10	-0.04	0.00
	maximum	4.50	0.90	0.40	-0.15	0.10
Japan	**base**	**2.50**	**0.50**	**0.25**	**-0.08**	**0.05**
	minimum	0.50	0.10	0.10	-0.04	0.00
	maximum	4.50	0.90	0.40	-0.15	0.10
Mexico	**base**	**2.50**	**0.50**	**0.40**	**-0.15**	**N/A**
	minimum	0.50	0.30	0.20	-0.10	N/A
	maximum	4.50	0.70	0.60	-0.20	N/A
Switzerland	**base**	**2.50**	**0.50**	**0.25**	**-0.08**	**N/A**
	minimum	0.50	0.10	0.10	-0.04	N/A
	maximum	4.50	0.90	0.40	-0.15	N/A
United States	**base**	**2.50**	**0.40**	**0.40**	**-0.15**	**0.10**
	minimum	0.50	0.10	0.20	-0.10	0.00
	maximum	4.50	0.70	0.60	-0.20	0.20

Factor demand

The factor demand equations shown in Table A1.1 are derived from an implicit production function with constant elasticity of substitution (Gardner, pp. 87-93, and Gunter *et al.*, pp. 314-316). There are two key sets of parameters determining the factor demands: elasticities of substitution and the factor cost shares.

The main source of estimates for the elasticities of substitution, shown in Table A1.4, was the two consultant reports discussed above. In fact, the numbers tabled in Table A1.4 for the three North American countries and for the European Union are, with only one exception, exactly those proposed by the two consultants. The exception is the elasticity of substitution between land and purchased inputs for the European Union. In that case the base value proposed by the consultant 0.90 led to implausibly high elasticities of EU crop supply. (There is a discussion and presentation below of these derived elasticities.) We chose instead a base value of 0.50 for this parameter, a number from the lower end of the range of plausible values recommended by the consultant.

Table A1.4. Factor substitution elasticities

		elasticity of substitution among:			
		Purchased factors	**Land & farm owned**	**Land & purchased**	**Purchased & farm owned**
Canada	**base**	**0.10**	**0.10**	**0.50**	**0.90**
	minimum	0.00	0.00	0.00	0.00
	maximum	0.20	0.20	1.00	1.80
European Union	**base**	**0.50**	**0.40**	**0.50**	**0.90**
	minimum	0.00	0.00	0.00	0.30
	maximum	1.00	0.80	1.00	1.50
Japan	**base**	**0.30**	**0.30**	**0.60**	**0.40**
	minimum	0.00	0.00	0.00	0.00
	maximum	0.60	0.60	1.20	0.80
Mexico	**base**	**0.15**	**0.50**	**0.50**	**0.50**
	minimum	0.00	0.00	0.00	0.00
	maximum	0.30	1.00	1.00	1.00
Switzerland	**base**	**0.50**	**0.40**	**0.50**	**0.90**
	minimum	0.00	0.00	0.00	0.30
	maximum	1.00	0.80	1.00	1.50
United States	**base**	**0.15**	**0.30**	**0.50**	**0.80**
	minimum	0.00	0.00	0.00	0.00
	maximum	0.30	0.60	1.00	1.60

The various Member country experts participating in the pilot study provided estimates of factor cost shares used in the PEM crop model. The estimates are based on results from surveys of costs of production done in study countries. For the United States and Mexico, published data are available to estimate crop specific cost shares. For the European Union and Canada the publicly available data refer to 'whole farm' costs. In these cases, special analyses were done to produce the crop specific estimates shown in Table A1.5. In each case, the category 'other farm owned', comprising returns to farm household labour, management and non-land permanent capital, was calculated residually.

Table A1.5. Factor cost shares

		~ Wheat ~						
		Canada	European Union	Japan		Mexico	Switzerland	United States
				up-land	*paddy land*			
Farm owned factors:	Land	0.21	0.14	0.22	0.17	0.24	0.07	0.21
	Other farm owned factors	0.22	0.14	0.08	0.19	0.13	0.25	0.23
Purchased factors:	Fertilizers	0.10	0.14	0.13	0.10	0.09	0.05	0.11
	Hired labour	0.00	0.05				0.04	0.04
	Chemicals						0.02	0.06
	Energy						0.02	0.08
	Interests						0.04	0.05
	Insurance						0.03	0.05
	Machinery and equipment						0.19	
	Rented land						0.06	
	Irrigation							0.01
	Other purchased factors	0.47	0.53	0.56	0.54	0.55	0.23	0.17

		~ Coarse grain ~						
		Canada	European Union	Japan		Mexico	Switzerland	United States
				up-land	*paddy land*			
Farm owned factors:	Land	0.19	0.18	0.20	0.20	0.27	0.07	0.21
	Other farm owned factors	0.23	0.02	0.22	0.22	0.17	0.20	0.21
Purchased factors:	Fertilizers	0.12	0.14	0.12	0.12	0.16	0.04	0.15
	Hired labour	0.00	0.06				0.04	0.02
	Chemicals						0.04	0.07
	Energy						0.03	0.06
	Interests						0.05	0.06
	Insurance						0.04	0.07
	Machinery and equipment						0.20	
	Rented land						0.06	
	Irrigation							0.00
	Other purchased factors	0.46	0.60	0.46	0.46	0.40	0.24	0.14

Table A1.5. Factor cost shares *(continued)*

		~ Coarse grain ~						
		Canada	European Union	Japan		Mexico	Switzerland	United States
				upland	*paddy land*			
Farm owned factors:	Land	0.22	0.18	0.17	0.17	0.30	0.05	0.27
	Other farm owned factors	0.13	0.17	0.37	0.37	0.09	0.44	0.23
Purchased factors:	Fertilizers	0.11	0.16	0.08	0.08	0.02	0.04	0.05
	Hired labour	0.00	0.06				0.03	0.03
	Chemicals						0.02	0.11
	Energy						0.03	0.04
	Interests						0.03	0.07
	Insurance						0.03	0.09
	Machinery and equipment						0.14	
	Rented land						0.04	
	Irrigation							0.00
	Other purchased factors	0.54	0.43	0.38	0.38	0.60	0.15	0.12

		~ Rice ~						
		Canada	European Union	Japan		Mexico	Switzer-land	United States
				upland	*paddy land*			
Farm owned factors:	Land	N/A	0.05	0.20	0.20	0.20	N/A	0.19
	Other farm owned factors	N/A	0.43	0.30	0.30	0.28	N/A	0.14
Purchased factors:	Fertilizers	N/A	0.07	0.05	0.05	0.08	N/A	0.08
	Hired labour	N/A	0.02				N/A	0.05
	Chemicals	N/A					N/A	0.10
	Energy	N/A					N/A	0.10
	Interests	N/A					N/A	0.04
	Insurance	N/A					N/A	0.05
	Machinery and equipment	N/A					N/A	
	Rented land	N/A					N/A	
	Irrigation	N/A					N/A	0.02
	Other purchased factors	N/A	0.43	0.45	0.45	0.45	N/A	0.24

Crop supply

Although crop supply elasticities are not explicit parameters in the PEM crop model, they can be calculated for given values of all the parameters of the factor supply and demand equations and for given base period values of the variables. In the present case, these calculations were accomplished by creating a model of crop supply for each country in the PEM. We created these models by isolating systems of equations comprising just the factor demand and factor supply equations for each country plus the 'zero profit' equilibrium conditions. The endogenous variables in these models are the factor prices and quantities and crop production. Importantly though, crop *prices* are exogenous. This means we can simulate the model under alternative settings of these prices to generate equilibrium supply elasticities. Findings from these simulations are presented in Table A1.6.

Table A1.6. Crop supply elasticities

	~ *Country* ~					
	Canada	**European Union**	**Japan**	**Mexico**	**Switzerland**	**United States**
elasticity w.r.t. price of:			***Wheat***			
wheat	**1.58**	**1.75**	**N/A**	**1.25**	**1.81**	**1.33**
coarse grains	-0.21	-0.57	N/A	-0.41	-0.59	-0.36
oilseeds	-0.65	-0.11	N/A	-0.01	0.00	-0.16
rice	0.00	-0.09	N/A	0.00	0.00	-0.17
			Coarse grains			
wheat	-0.36	-0.68	N/A	-0.07	-1.03	-0.12
coarse grains	**1.71**	**1.99**	**N/A**	**0.72**	**2.37**	**1.31**
oilseeds	-0.57	-0.12	N/A	-0.01	0.00	-0.26
rice	0.00	-0.12	N/A	0.00	0.00	-0.17
			Oilseeds			
wheat	-0.60	-0.41	N/A	-0.10	N/A	-0.08
coarse grains	-0.30	-0.38	N/A	-0.44	N/A	-0.36
oilseeds	**1.82**	**1.61**	**N/A**	**1.47**	**N/A**	**1.11**
rice	0.00	-0.06	N/A	0.00	N/A	-0.11
			Rice			
wheat	N/A	-0.39	0.00	N/A	N/A	-0.08
coarse grains	N/A	-0.37	0.00	N/A	N/A	-0.24
oilseeds	N/A	-0.07	0.00	N/A	N/A	-0.11
rice	**N/A**	**1.87**	**0.81**	**N/A**	**N/A**	**1.46**

Domestic crop demand

Estimates of own-price and cross-price elasticities used in PEM models were derived principally from special analysis done with the OECD's Aglink model. They are presented in Table A1.7. In Aglink, farm-gate demand for the various crops for food use is distinguished from that for livestock feed use. Moreover, the demand for feed use contains variables measuring livestock output, which also changes endogenously with changes in crop prices. The elasticities in the PEM demand equations refer to the relationship between total demand for each crop, reflecting adjustment in all related markets (or at the least, as many related markets as there are represented in Aglink). These were obtained from price-impact simulation experiments done with Aglink.

Table A1.7. Crop demand elasticities

	~ Country ~					
	Canada	**European Union**	**Japan**	**Mexico**	**Switzerland**	**United States**
elasticity w.r.t. price of:			***Wheat***			
wheat	**-0.56**	**-0.33**	**-0.13**	**-1.13**	**-0.40**	**-0.46**
coarse grains	0.30	0.26	0.00	0.93	0.50	0.32
oilseeds	0.18	-0.10	0.02	-0.01	0.10	0.10
rice	0.00	0.00	0.00	0.10	-0.26	0.00
elasticity w.r.t. price of:			***Coarse grains***			
wheat	0.12	0.20	-0.01	0.07	0.58	0.07
coarse grains	**-0.14**	**-0.33**	**-0.10**	**-0.15**	**-1.00**	**-0.16**
oilseeds	-0.09	0.03	0.05	0.01	0.10	0.00
rice	0.00	0.00	0.00	0.00	0.00	0.00
elasticity w.r.t. price of:			***Oilseeds***			
wheat	0.25	-0.19	0.03	0.00	0.01	0.09
coarse grains	-0.18	0.06	0.19	0.11	0.10	0.04
oilseeds	**-0.18**	**-0.08**	**-0.26**	**-0.17**	**-1.00**	**-0.20**
rice	0.00	0.00	0.00	0.00	0.00	0.00
elasticity w.r.t. price of:			***Rice***			
wheat	0.00	0.00	0.00	0.03	0.00	0.00
coarse grains	0.00	0.00	0.00	0.00	0.00	0.00
oilseeds	0.00	0.00	0.00	0.00	0.00	0.00
rice	**-0.05**	**-0.24**	**-0.26**	**-0.04**	**-0.24**	**0.00**

Demand and supply in the rest of world

The crop demand equations in the rest of world module are of the same simple form as those in all of the individual country modules. Rest of world crop supply however is modelled with aggregate supply equations, one for each crop. The own and cross price elasticities in both the demand and supply equations were obtained from the Aglink model using the same procedure as used to get the crop demand elasticities discussed in the previous section. These estimates are in Table A1.8.

Table A1.8. Elasticities of crop demand and supply for rest of world

	w.r.t. price of			
elasticity of demand for	*Wheat*	*Coarse grains*	*Oilseeds*	*Rice*
Wheat	**-0.10**	0.04	0.04	0.03
Coarse grains	0.06	**-0.08**	0.01	0.00
Oilseeds	0.02	0.00	**-0.15**	0.00
Rice	0.01	0.00	0.00	**-0.10**
	w.r.t. price of			
elasticity of supply of	*Wheat*	*Coarse grains*	*Oilseeds*	*Rice*
Wheat	**0.13**	-0.03	-0.04	0.00
Coarse grains	-0.05	**0.20**	-0.11	-0.01
Oilseeds	-0.02	-0.07	**0.37**	-0.01
Rice	0.00	-0.02	-0.02	**0.05**

II. Country results from simulation experiments comparing policy effects among support measures

Country-by-country results from those simulation experiments undertaken to compare the effects of uniform increases in support provided by the various support measures are presented in this section. For each combination of country, crop and support measure the simulated increase in support was 5% of the value of wheat, coarse grains, oilseeds and rice production in the 1998 base year. We chose to simulate the impact of *increases* rather than *decreases* in support measures because for many of the combinations of country, crop and support measures no support was provided in the base period. During the model validation phase of the work, we estimated some impact ratios based on simulated *decreases* in support. The results were not identical to, but were not significantly different, from those found when simulating the effects of increases in support.

There are two tables of simulation results presented for each country. The first contains simulated impact ratios for production, trade, world market prices and farm household income. As explained in the text these ratios show the simulated effect on these indicators of the given increase in one or the other categories of budgetary payments *relative to the simulated effect of that change in an associated category of market price support.* The second table of country results compares the distribution of economic costs and benefits of additional support provided via the various support measures. The unit of measure is monetary in both tables. Specifically, the results show the cost or benefit of increased support for taxpayers, consumers, farm households and input suppliers *per dollar of additional support provided.* Economic effects of changes in support on consumers, farm households and input suppliers were estimated using standard formulas for calculating changes in economic surplus.

Canada

Table A1.9. Estimated impact ratios for Canada

Simulated impact of a 5% increase in payments based on	*Effect relative to that of a 5% increase in market price support on these indicators*			
	Production	**Trade**	**World Price**	**Farm income**
Variable inputs	1.29	1.18	1.17	0.66
Output of wheat	1.02	0.89	0.91	1.00
Output of all crops	1.00	0.93	0.93	1.00
Plantings of wheat	0.54	0.48	0.46	1.46
Plantings of all crops	0.23	0.22	0.23	1.47
Historical entitlements	0.08	0.08	0.24	1.56

Table A1.10. Distribution of economic impacts by support measure for Canada

	Gain or loss per dollar of taxpayer and consumer costs for:					
Caused by a simulated 5% increase in:	**Taxpayers**	**Consumers**	**Farm households**		**Input suppliers**	**Deadweight loss**
			land	*other farm owned*		
Market price support:						
Wheat	-0.76	-0.24	0.37	0.23	0.20	-0.20
All crops	-0.48	-0.52	0.44	0.18	0.26	-0.11
Payments based on:						
Variable input use	-1.07	0.07	0.35	0.08	0.40	-0.16
Output of wheat	-1.06	0.06	0.38	0.24	0.20	-0.19
Output of all crops	-1.05	0.05	0.45	0.19	0.26	-0.11
Plantings of wheat	-1.02	0.02	0.83	0.07	0.01	-0.09
Plantings of all crops	-1.01	0.01	0.89	0.04	0.04	-0.04
Historical entitlements	-1.00	0.00	0.96	0.01	0.01	-0.01

The European Union

Table A1.11. Estimated impact ratios for the European Union

Simulated impact of a 5% increase in payments based on	*Effect relative to that of a 5% increase in market price support on these indicators*			
	Production	**Trade**	**World Price**	**Farm income**
Variable inputs	1.58	1.37	1.33	0.97
Output of wheat	1.29	1.06	1.06	1.24
Output of all crops	1.44	1.18	0.80	1.61
Plantings of wheat	0.24	0.21	0.19	2.69
Plantings of all crops	0.08	0.09	0.08	2.44
Historical entitlements	0.03	0.03	0.03	2.65

Table A1.12. Distribution of economic impacts by support measure for the European Union

	Gain or loss per dollar of taxpayer and consumer costs for					
Caused by a simulated 5% increase in	**Taxpayers**	**Consumers**	**Farm households**		**Input suppliers**	**Deadweight loss**
			land	*other farm owned*		
Market price support:						
Wheat	-0.56	-0.44	0.26	0.14	0.26	-0.34
All crops	-0.35	-0.65	0.31	0.09	0.29	-0.30
Payments based on:						
Variable input use	-1.04	0.04	0.25	0.05	0.37	-0.34
Output of wheat	-1.31	0.31	0.27	0.15	0.27	-0.31
Output of all crops	-1.10	0.10	0.38	0.13	0.21	-0.28
Plantings of wheat	-1.00	0.00	0.87	0.02	0.01	-0.10
Plantings of all crops	-1.00	0.00	0.89	0.00	0.02	-0.09
Historical entitlements	-1.00	0.00	0.96	0.00	0.01	-0.03

Japan

Table A1.13. Estimated impact ratios for Japan

Simulated impact of a 5% increase in payments based on:	*Effect relative to that of a 5% increase in market price support on these indicators:*			
	Production	**Trade**	**World Price**	**Farm income**
Variable inputs	1.76	1.24	1.24	1.26
Output of rice	1.52	1.07	1.07	1.52
Plantings of rice	0.21	0.15	0.15	2.00
Historical entitlements	0.07	0.05	0.06	2.03

Table A1.14. Distribution of economic impacts by support measure for Japan

Caused by a simulated 5% increase in:	*Gain or loss per dollar of taxpayer and consumer costs for:*					
	Taxpayers	**Consumers**	**Farm households**		**Input suppliers**	**Deadweight loss**
			land	*other farm owned*		
Market price support:						
Rice	-0.39	-0.61	0.23	0.19	0.11	-0.47
Payments based on:						
Variable input use	-1.01	0.01	0.20	0.17	0.18	-0.45
Output of Rice	-1.01	0.01	0.26	0.22	0.13	-0.39
Plantings of Rice	-1.00	0.00	0.88	0.03	0.01	-0.08
Historical entitlements	-1.00	0.00	0.95	0.01	0.00	-0.03

Mexico

Table A1.15. Estimated impact ratios for Mexico

Simulated impact of a 5% increase in payments based on	*Effect relative to that of a 5% increase in market price support on these indicators*			
	Production	**Trade**	**World Price**	**Farm income**
Variable inputs	1.43	1.21	1.23	0.86
Output of coarse grains	1.10	0.91	1.01	1.09
Output of all crops	1.10	0.93	0.94	1.10
Plantings of coarse grains	0.51	0.42	0.46	1.37
Plantings of all crops	0.36	0.37	0.36	1.39
Historical entitlements	0.15	0.12	0.12	1.42

Table A1.16. Distribution of economic impacts by support measure for Mexico

Caused by a simulated 5% increase in:	*Gain or loss per dollar of taxpayer and consumer costs for:*					
	Taxpayers	**Consumers**	**Farm households**		**Input suppliers**	**Deadweight loss**
Market price support:			*land*	*other farm owned*		
Coarse grains	0.09	-1.09	0.45	0.21	0.21	-0.13
All crops	0.25	-1.25	0.44	0.19	0.21	-0.16
Payments based on:						
Variable input use	-1.04	0.04	0.35	0.15	0.32	-0.18
Output of coarse grains	-1.03	0.03	0.44	0.21	0.20	-0.15
Output of all crops	-1.03	0.03	0.44	0.19	0.21	-0.15
Plantings of coarse grains	-1.01	0.01	0.74	0.05	0.05	-0.16
Plantings of all crops	-1.01	0.01	0.75	0.05	0.05	-0.15
Historical entitlements	-1.01	0.01	0.91	0.02	0.02	-0.05

Switzerland

Table A1.17. Estimated impact ratios for Switzerland

Simulated impact of a 5% increase in payments based on	*Effect relative to that of a 5% increase in market price support on these indicators*			
	Production	**Trade**	**World Price**	**Farm income**
Variable inputs	1.93	1.71	1.75	1.20
Output of wheat	2.08	1.62	1.78	2.08
Output of all crops	1.73	1.53	1.61	1.73
Plantings of wheat	0.34	0.26	0.42	3.06
Plantings of all crops	0.18	0.08	0.18	2.79
Historical entitlements	0.04	0.03	0.19	2.96

Table A1.18. Distribution of economic impacts by support measure for Switzerland

	Gain or loss per dollar of taxpayer and consumer costs for:					
Caused by a simulated 5% increase in:	**Taxpayers**	**Consumers**	**Farm households**		**Input suppliers**	**Deadweight loss**
			land	*other farm owned*		
Market price support:						
Wheat	-0.35	-0.65	0.12	0.20	0.22	-0.46
All crops	-0.28	-0.72	0.13	0.18	0.24	-0.45
Payments based on:						
Variable input use	-1.00	0.00	0.10	0.11	0.28	-0.50
Output of wheat	-1.00	0.00	0.12	0.21	0.22	-0.45
Output of all crops	-1.00	0.00	0.13	0.19	0.24	-0.43
Plantings of wheat	-1.00	0.00	0.80	0.03	0.03	-0.14
Plantings of all crops	-1.00	0.00	0.86	0.01	0.02	-0.11
Historical entitlements	-1.00	0.00	0.94	0.00	0.01	-0.05

The United States

Table A1.19. Estimated impact ratios for United States

Simulated impact of a 5% increase in payments based on	*Effect relative to that of a 5% increase in market price support on these indicators*			
	Production	**Trade**	**World Price**	**Farm income**
Variable inputs	1.52	1.31	1.28	0.08
Output of coarse grains	1.13	0.87	0.88	1.14
Output of all crops	1.07	0.91	0.90	1.08
Plantings of coarse grains	0.52	0.40	0.35	3.90
Plantings of all crops	0.15	0.16	0.15	2.64
Historical entitlements	0.06	0.05	0.05	2.80

Table A1.20. Distribution of economic impacts by support measure for United States

Caused by a simulated 5% increase in	*Gain or loss per dollar of taxpayer and consumer costs for*					
	Taxpayers	**Consumers**	**Farm households**		**Input suppliers**	**Deadweight loss**
Market price support:			*land*	*other farm owned*		
Coarse grains	-0.53	-0.47	0.27	0.15	0.16	-0.42
All crops	-0.53	-0.47	0.35	0.17	0.16	-0.31
Payments based on						
Variable input use	-1.87	0.87	0.10	-0.05	0.39	-0.56
Output of coarse grains	-1.92	0.92	0.29	0.16	0.18	-0.37
Output of all crops	-1.50	0.50	0.37	0.18	0.17	-0.29
Plantings of coarse grains	-1.16	0.16	0.94	-0.01	-0.01	-0.08
Plantings of all crops	-1.06	0.06	0.92	0.01	0.00	-0.07
Historical entitlements	-1.02	0.02	0.97	0.00	0.00	-0.02

Averages across countries

Table A1.21 summarises all the country-by-country impact ratios for the various indicators in terms of their simple averages, the minimum and the maximum. This table is the source of data for Figures 5 to 8 in the main text.

Table A1.21. Average, minimum and maximum impact ratios across countries

Simulated impact of a 5% increase in payments based on		*Effect relative to that of a 5% increase in market price support on these indicators*			
		Production	**Trade**	**World Price**	**Farm income**
Variable inputs					
	average	1.59	1.34	1.33	0.84
	minimum	1.29	1.18	1.17	0.08
	maximum	1.93	1.71	1.75	1.26
Output of main crop					
	average	1.36	1.07	1.12	1.35
	minimum	1.02	0.87	0.88	1.00
	maximum	2.08	1.62	1.78	2.08
Output of all crops					
	average	1.31	1.09	1.04	1.34
	minimum	1.00	0.91	0.80	1.00
	maximum	1.73	1.53	1.61	1.73
Plantings of main crop					
	average	0.39	0.32	0.34	2.42
	minimum	0.21	0.15	0.15	1.37
	maximum	0.54	0.48	0.46	3.90
Plantings of all crops					
	average	0.20	0.18	0.19	2.12
	minimum	0.08	0.08	0.08	1.39
	maximum	0.36	0.37	0.36	2.79
Historical entitlements					
	average	0.07	0.06	0.11	2.24
	minimum	0.03	0.03	0.03	1.42
	maximum	0.15	0.12	0.24	2.96

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Annex 2.

ELASTICITIES OF SUBSTITUTION AND FACTOR SUPPLY IN CANADIAN, MEXICAN AND UNITED STATES AGRICULTURE

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I. Introduction

The Policy Evaluation Matrix (PEM) project is designed to test the feasibility of using a "matrix of policy effects" approach to quantifying the impacts of agricultural policy change in OECD countries. Impacts of interest include production, consumption, trade, commodity prices, and benefits and costs to various groups such as farm households, agricultural input suppliers, taxpayers, and consumers. Three of the countries currently included in the PEM project are Canada, Mexico and the United States.

Elasticities of substitution among factors of production and elasticities of factor supply are important parameters in the PEM model. Sensitivity analyses reported in OECD (1999) indicate that estimates of policy effects can vary depending on the values assigned to these parameters.

This annex has four objectives:

- Tabulate and compare estimates of elasticities of substitution and factor supply reported in past studies of agricultural adjustment in the United States, Mexico, and Canada — separately for crops and livestock commodities.
- Comment on the suitability of the available estimates for modelling the effects of agricultural policy changes as the PEM model is designed to do.
- Recommend plausible ranges of these parameters to use in policy simulations with the PEM crop and livestock models.
- Advise OECD on appropriate statistical procedures for sensitivity testing to deal with parameter uncertainty.

II. Estimates of elasticities of substitution

A bibliography of past studies of agricultural adjustment in Canada, Mexico, and the US was compiled based on searches of several online databases, including AGRICOLA, ArticleFirst, Cambridge Scientific Abstracts, EconLIT, LIAS (Penn State University), Ovid, Social Sciences Abstracts, and UnCover. Recent issues of the *American Journal of Agricultural Economics*, *Canadian*

Journal of Agricultural Economics, and *Estudios Económicos* (Mexico) were also searched. Contact was also made with researchers at the Centro de Investigación y Docencia Económica (CIDE) in Mexico.

Estimates of elasticities of substitution for US agriculture reported in 57 past studies of agricultural adjustment are presented in Table A1.1. Forty-two of these 57 studies examined aggregate agricultural production (crops and livestock), so that the estimates reported in these studies reflect substitution possibilities in both crop and livestock production. Ten studies were directed specifically at crop production, while five were directed specifically at livestock production.

Estimates of elasticities of substitution for Canadian agriculture reported in nine past studies of agricultural adjustment are presented in Table A1.2. Estimates of elasticities of substitution for Mexican agriculture from three previous studies are also reported in Table A1.2. All of the studies for Canada and Mexico examined aggregate agricultural production (crops and livestock), so that once again the estimates reported in these studies reflect substitution possibilities in both crop and livestock production.

In the PEM model, factors of production are divided into three broad categories: land, other farmer-owned inputs (capital, family labour), and purchased inputs (hired labour, fertilisers, pesticides, seeds, feed, irrigation, energy, etc.). With these categories in mind, the results of the studies listed in Tables A1 and A2 were used to calculate elasticities of substitution appropriate to the PEM input categories: between land and other farmer-owned inputs; between land and purchased inputs; between other farmer-owned inputs and purchased inputs; among farmer-owned inputs (*i.e.* between capital and labour); and among purchased inputs (*e.g.* between fertilisers and energy). In most cases, it was not possible using a single study's results to calculate all five elasticities of substitution. For example, many studies treated land as a fixed input rather than a variable input, so that no elasticities of substitution involving land could be calculated.

The estimates in Tables A1.1 and A1.2 are Allen elasticities of substitution. There are other economic measures of input substitutability in addition to Allen elasticities, and some advocate use of Morishima elasticities of substitution instead (Blackorby and Russell 1989, Chambers 1988). However, the substitution elasticities as typically estimated in the literature are Allen elasticities. The substitution elasticities in the PEM model are also Allen elasticities. Furthermore, Morishima elasticities have their own theoretical and practical shortcomings (Davis and Shumway, 1996).

Thirty-one of the 57 studies for the US in Table A1.1 estimated a cost function, while 25 estimated a profit function (the remaining study, Chavas and Cox (1995), estimated production relationships using nonparametric techniques). Seven of the studies for Canadian agriculture in Table A1.2 estimated a cost function, while the remaining two estimated a profit function. One of the studies for Mexican agriculture, Lim and Shumway (1999), estimated a profit function, while the remaining two used programming techniques to estimate production relationships.

A cost function yields estimates of parameters that, with a small amount of manipulation, can be converted into estimates of Allen elasticities of substitution. A profit function yields estimates of parameters that require additional manipulation, using the economic concept of duality, in order to arrive at estimates of Allen elasticities of substitution (Chambers, 1988). These manipulations were necessary in order to obtain the substitution elasticities in Tables A1.1 and A1.2. The manipulations were done in the following manner. Let M_{ww} be the matrix of own- and cross-price elasticities of factor demand with respect to input prices as estimated from a profit function study, let M_{pp} be the matrix of own- and cross-price elasticities of output supply with respect to output prices, let M_{wp} be

the matrix of elasticities of factor demand with respect to output prices, and let M_{pw} be the matrix of elasticities of output supply with respect to factor prices. Then it can be shown that the matrix of Hicksian (output held constant) factor demand elasticities is:

$$H = M_{ww} - M_{wp} M_{pp}^{-1} M_{pw}.$$

Let H_{ij} be the element in row i and column j of the matrix H, and let s_j be the factor share for input j. Then it can also be shown that the Allen elasticity of substitution between factors i and j is $\sigma_{ij} = H_{ij} / s_j$. Estimates of factor shares were either available directly from each profit function study or were calculated using the study results.

Duality is a concept that, strictly speaking, applies only at the level of an individual producer and may or may not hold with the aggregate data typically used in profit and cost function studies (Shumway, 1995). However, in the case of the US, there were no statistically significant differences between cost and profit function studies in mean values of four out of the five substitution elasticities in Table A1.1 (at a 5% significance level). The single exception was the substitution elasticity between land and other farmer-owned inputs, which turned out to be lower on average in the profit function studies than in the cost function studies. There were not enough studies in the Canadian or Mexican cases to statistically test for differences in substitution elasticities according to the type of function estimated.

Means and standard deviations across studies for the substitution elasticities in the US are shown in Table A1.3, while statistics for Canada are shown in Table A1.4. The averages for Canada exclude Horbulyk (1990), for which the estimates are not plausible. In the case of the US, averages are reported for all studies, for aggregate agriculture studies (both crops and livestock), for studies specifically directed at crops, and for studies specifically directed at livestock. In the Canadian case, all the studies examined aggregate agricultural production.

In the US, using the means under column labelled “All Studies” in Table A1.3, all of the substitution elasticities turn out to be less than one. The highest elasticity of substitution is among farmer-owned inputs (where the mean is 0.9) while the lowest is among purchased inputs (mean of -0.2). For Canada, the mean values of four out of the five substitution elasticities in Table A1.4 are less than one. The highest elasticity of substitution is once again among farmer-owned inputs (mean of 1.8) while the lowest is again among purchased inputs (mean of -0.1).

In both the Canadian and US cases, none of the substitution elasticities is statistically different from zero (at a 5% significance level). Thus we cannot reject the hypothesis that agricultural production functions are Leontief—all factors are used in fixed proportion to each other. However, none of the substitution elasticities is statistically different from one, either (at a 5% level). Thus we also cannot reject the hypothesis that agricultural production functions in Canada and the US are Cobb-Douglas—all factor shares are constant.

With only three studies, it is difficult to say anything about elasticities of substitution in Mexican agriculture. None of the three studies provides an estimate of the elasticity of substitution between land and other farmer-owned inputs or the elasticity of substitution between land and purchased inputs. There is one estimate of the elasticity of substitution between other farmer-owned inputs and purchased inputs (0.1), while there is also one estimate of the elasticity of substitution among purchased inputs (2.3). There are two estimates of the substitution elasticity among other farmer-owned inputs (0.5 and 2.2).

The mean values of substitution elasticities in Canada and the US tend to be close to each other. There are no statistically significant differences in mean values of substitution elasticities between Canada and the US (at a 5% level). This is true whether we use all the US studies or just the aggregate agriculture studies. This finding appears reasonable because Canadian and US farmers produce similar crop and livestock products using similar technologies.

In the case of the US, using all the studies, statistically significant differences among some of the substitution elasticities do emerge (at a 5% level). The following three differences turn out to be statistically significant: between the elasticity of substitution among purchased inputs and the elasticity of substitution between land and purchased inputs; between the elasticity of substitution among purchased inputs and the elasticity of substitution between other farmer-owned inputs and purchased inputs; and between the elasticity of substitution among purchased inputs and the elasticity of substitution among farmer-owned inputs. In all three cases, the elasticity of substitution among purchased inputs is less than the other substitution elasticities. None of the other differences among substitution elasticities is statistically significant.

In the case of Canada, using all studies except Horbulyk (1990), there are no statistically significant differences among any of the substitution elasticities (at a 5% level). However, it should be noted that there are only eight studies for Canada excluding Horbulyk (1990). There are not enough studies in the case of Mexico to test for differences among substitution elasticities.

The mean values of substitution elasticities from the US crop studies and from the US livestock studies tend to be different from each other. However, none of these differences is statistically significant (at a 5% level). (No statistical test for differences in means could be conducted for the elasticity of substitution between land and other farmer-owned inputs, or for the elasticity of substitution between land and purchased inputs, because there was only one crop study and/or one livestock study that estimated these substitution elasticities.)

III. Estimates of factor supply elasticities

Estimates of land supply elasticities from eleven past studies of agricultural adjustment for the US are reported in Table A1.5. Estimates of land supply elasticities from six studies for Canada and Mexico are reported in Table A1.6. Estimates of supply elasticities for other farmer-owned inputs (capital and labour) from fifteen studies for the three countries are shown in Table A1.7. Estimates from ten studies of supply elasticities for purchased agricultural inputs for the three countries are shown in Table A1.8.

The estimates in Tables A1.5-8 are divided into two categories: econometric estimates and "expert assessments." In contrast to the substitution elasticities discussed in Section II above, only a small number of studies have econometrically estimated factor supply elasticities for agriculture. To rely on these studies alone would leave too thin a knowledge base upon which to recommend plausible values for these parameters in the PEM model. I therefore attempted to expand the knowledge base by drawing on expert assessments that researchers have used in their own modelling efforts. All the expert assessments are from studies that have been published and subject to peer review.

With the exception of Chavas and Holt (1990), the elasticities of land supply reported in the econometric studies are with respect to agricultural output prices rather than with respect to rental rates of land. However, the PEM model requires elasticities with respect to rental rates on land. The results of these studies were therefore converted into elasticities with respect to rental rates on land, and it is these converted elasticities that are shown in Tables A1.5 and A1.6. The conversions were

made in the following manner. 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 is:

$$\phi_{ij} = s_{jL}\eta_{ij}/\theta_{jL},$$

where s_{jL} is the factor share for land for commodity j, η_{ij} is the elasticity of supply of land to commodity i with respect to the output price of commodity j (as reported by the econometric studies), and θ_{jL} is the fraction of benefits from an increase in the price of commodity j that accrue as benefits to landowners. In the long run, nearly all benefits from higher agricultural product prices accrue as benefits to landowners (Johnson 1991). In the medium run, which is the length of run relevant for the PEM model, a reasonable estimate is that $\theta_{jL} =$ □. Using this estimate and factor shares for land from the PEM model (OECD 1999), I computed the elasticities in Tables 5 and 6.

In the case of the US, the econometric studies included in Table 5 were limited to those appropriate to the current agricultural policy environment. These studies either used recent data, controlled for the impacts of government programs in estimating supply elasticities, or reported separate supply elasticities for "free market" and "farm program" regimes (in which case the free market elasticities were used). Many other econometric studies have been done for the US, but these studies are not included here because they generally failed to take proper account of the influence of set-asides and other government programs on acreage supply response.

Both the econometric estimates and expert assessments of own- and cross-price elasticities of land supply tend to be low. There are not enough studies for either the US, Canada, or Mexico to compute meaningful averages or statistically test any hypotheses. However, all of the own-price supply elasticities for the three countries are between zero and one, and most are between zero and 0.5. All of the cross-price supply elasticities are less than one in absolute value, and most are less than 0.5 in absolute value. Most of the estimates suggest that coarse grains, wheat, and oilseeds are modest substitutes for each other in land supply or are unrelated in land supply.

There are no recent, published econometric estimates for any of the three countries of the supply elasticity of livestock pasture. Hertel (1997, 1999) uses an elasticity of land supply of one for every agricultural product (crop or livestock) in the base version of Global Trade Analysis Project (GTAP) model. Expert assessments by Hertel (1989) for the US and Duloy and Norton (1983) for Mexico are that the elasticity of land supply to agriculture as a whole (all crops and livestock) is zero.

Estimates of the elasticity of supply of other farmer-owned inputs (capital and farm family labour) tend to vary more than estimates of the elasticity of supply of land. Econometric estimates of the elasticity of supply of labour to agriculture in the US and Canada vary from 0.1 to 2.6. Expert assessments about the supply elasticity of labour for the US and Canada vary from 0.5 to infinite, while expert assessments about the supply elasticity of capital for these two countries vary from zero to infinite. The "labour" in some of the econometric studies and in most of the expert assessments is all labour (both farm family labour and hired labour) rather than just family labour. However, most labour used in crop production in Canada, Mexico, and the US is family labour (OECD, 1999).

The supply elasticities for capital and labour may vary in part because of differences from one study to another in the length of run being considered. Abler and Shortle (1992, 1995), for example, considered medium- and long-run policy scenarios, and arrived at fairly high elasticities. The low labour supply elasticity in Weersink and Tauer (1990), on the other hand, is a short-run estimate.

The studies by Barkley (1988, 1990) are useful contributions because they make explicit the effects of length of run on the supply elasticity of labour. Barkley (1988, 1990) estimated the determinants of labour *migration* out of agriculture, and found an elasticity of outmigration with respect to relative earnings in nonagriculture vs. agriculture of 4.5 for total labour, 3.3 for farm operators, and 6.3 for hired workers. In the long run, everyone in agriculture is a potential migrant and the elasticity of labour supply is the same as the elasticity of migration. In any one year, however, the number of migrants is only a small fraction of the total agricultural labour force, so that the elasticity of labour supply is just a fraction of the elasticity of migration. The figures reported for Barkley (1988, 1990) in Tables A1.7 and A1.8 reflect labour supply elasticities for a medium-run (3-5 year) period.

In the case of farm labour in Mexico, some of the expert assessments place the supply elasticity at infinity, while another places it at zero. This divergence of opinions does not appear to be due to length of run considerations, since all the authors were examining short- to medium-run scenarios. It might instead be due to differences in the importance attached to two competing factors. On the one hand, the cost of labour mobility in and out of Mexican agriculture is probably low, as witnessed by significant rural-urban migration in Mexico in recent years. On the other hand, most farm labour in Mexico is unskilled and employment alternatives outside of agriculture may be limited.

Econometric estimates of supply elasticities for purchased inputs tend to be rare. Table A1.8 reports the results of two studies of the supply elasticity of hired agricultural labour in the US, one of which (Barkley 1988) is 0.5 and the other of which (Perloff 1991) is 1.6.

Expert assessments of supply elasticities for purchased inputs suggest, by and large, that supply elasticities are large. With the exception of a supply elasticity of 0.5 for energy and materials used by Shumway *et al.* (1988), expert assessments range from two to infinity. The choice of infinity in some studies appears to be based on a desire to reduce model complexity by making purchased input prices exogenous. In some cases, it was also based on recognition of the fact that, beyond a certain value (for example, 10), the results do not change significantly by simply setting the supply elasticity equal to infinity.

IV. Suitability of available estimates for the PEM project

On the whole, the estimates of factor substitution elasticities reviewed in Section II above appear suitable for modelling the effects of agricultural policy change in the PEM project. The estimates are based on empirical studies of Canadian, Mexican, and US agriculture, and as such reflect substitution possibilities among inputs observed in practice. As discussed above, the results in the studies themselves were used to calculate elasticities of substitution appropriate to the PEM input categories: between land and other farmer-owned inputs; between land and purchased inputs; between other farmer-owned inputs and purchased inputs; among farmer-owned inputs (*i.e.* between capital and labour); and among purchased inputs (*e.g.* between fertilisers and energy).

In the case of the US where there a sufficient number of studies of substitution elasticities to conduct meaningful statistical tests, the results discussed above indicate that the elasticity of substitution among purchased inputs is less than three of the other four substitution elasticities (between land and purchased inputs, between other farmer-owned inputs and purchased inputs, and among farmer-owned inputs). This suggests that it may not be appropriate to combine all of the factors of production in a single constant-elasticity-of-substitution (CES) production function where the elasticity of substitution between every pair of inputs is identical.

One alternative to a CES production function that would be consistent with the findings in section II above would be to model the production process for each crop and livestock product as a

two-level process, with separate CES production functions at each level. At the lower levels, capital and family labour would combine in one CES production function to form an other-farmer-owned input "aggregate," while purchased inputs would combine in another CES production function to form a purchased input "aggregate." At the upper level, land would combine with the other farmer-owned input aggregate and the purchased input aggregate in a third CES production function to produce the output of the commodity in question. Another alternative that would be consistent with the findings in Section II would be the same as the first except that there would be no other-farmer-owned input aggregate. Instead, the purchased input aggregate would be combined with land, capital, and family labour in the upper-level production function.

The estimates of factor supply elasticities reviewed above are not as directly suitable for modelling the effects of agricultural policy change in the PEM project. With the exception of land, studies of the supply of agricultural inputs have generally not taken into account the fact that there may be substitutability of inputs among commodities, and that this substitutability may be imperfect. In the case of land, substitutability exists because a given hectare of land can in principle be used for any crop or livestock product. However, the substitutability is imperfect because of commodity-specific soil capital that makes each hectare of land better suited for the production of some commodities than others (Orazem and Miranowski, 1994). As a result, rental rates on land can vary according to the commodity produced on that land.

Similar reasoning could be applied to other farmer-owned inputs and to hired labour. For example, although labour can and does move from one commodity to another, substitutability may be imperfect because farmers and hired workers may have human capital specific to the production of a particular commodity. In the same way, machinery and other capital goods may be partially or completely specific to a particular commodity.

In the case of land, Abler and Shortle (1992) modelled imperfect substitutability using commodity-specific land supply equations containing own- and cross-price elasticities. This same approach is used for land in the PEM model (OECD, 1999). It could also be used for other farmer-owned inputs and possibly for purchased inputs.

One drawback of this approach is that the number of parameters in the model can increase significantly if cross-price elasticities of supply have to be specified for several inputs in addition to own-price elasticities, particularly in light of the fact that the literature reviewed above does not offer direct guidance on values for cross-price elasticities. However, the values of cross-price elasticities of supply for land that are available in the literature may offer some guidance in setting cross-price elasticities of supply for other farmer-owned inputs. If land can move easily from one commodity to another, so that cross-price elasticities of supply are high, other farmer-owned inputs (which accompany the land as it moves between commodities) may also move easily. Conversely, if land cannot move easily from one commodity to another, so that cross-price elasticities of supply are low or zero, cross-price elasticities for other farmer-owned inputs may also be low or zero.

Additional guidance on cross-price elasticities of factor supply can come from the symmetry property of supply functions in a multiple product setting, which imposes restrictions on cross-price elasticities (Chambers 1988). Let x_i be the quantity of some input used in the production of commodity i and let w_i be its price in that use. Let x_j be the quantity of that same input used in the production of commodity j and let w_j be its price in that use. Symmetry requires that

$$\partial x_i / \partial w_j = \partial x_j / \partial w_i \ .$$

Let $E_i = w_i x_i$ denote total expenditures on the input in question in the production of commodity i and let E_j be defined similarly. The symmetry requirement can then be rewritten in terms of the cross-price elasticities of factor supply ϕ_{ij} and ϕ_{ji}:

$$\phi_{ji} = \left(\frac{E_i}{E_j} \right) \phi_{ij} .$$

Given an estimate of ϕ_{ij} and data on input expenditures, this equation can be used to arrive at an estimate of ϕ_{ji}. Symmetry does not solve all problems, but it does cut in half the number of cross-price elasticities to be estimated.

Another concern about the suitability of the factor supply elasticity estimates for the PEM project is the lack of estimates for livestock. There are no recent, published econometric estimates for any of the three countries of the supply elasticity of livestock pasture, and expert assessments also tend to be scarce. However, available estimates of the own- and cross-price elasticities of output supply for livestock products could be used as a guide in setting input price elasticities. If all factor supply elasticities are identical (which of course they are not), it can be shown that the own-price elasticity of output supply is equal to the common own-price elasticity of factor supply. More generally, the price elasticity of output supply depends on factor supply elasticities in a manner detailed by Gardner (1990) in the two-factor case and by Mundlak (1996) in the *n*-factor case. Abler and Shortle (1992) used this technique in setting land supply elasticities for crops in their model.

V. Plausible ranges of parameter values

For the US (and for the US, Canada, and Mexico combined), there are a sufficient number of studies of substitution elasticities to statistically derive plausible ranges of values for these elasticities. One option with a solid statistical footing would be to use a 95% confidence interval based on the empirical distribution of estimates from the studies listed in Tables 1 and 2. However, a 95% confidence interval turns out to be too wide from the perspective of plausibility. There are too many studies that yielded estimates that are simply not reasonable. Only when the range is narrowed to about a 50% confidence interval do we arrive at minimum and maximum values that appear plausible.

One approach to modelling agricultural production processes discussed in Section IV above would be a two-level process for each commodity, with separate CES production functions at each level. At the lower levels, capital and family labour would combine in one CES production function to form an other-farmer-owned input "aggregate," while purchased inputs would combine in another CES production function to form a purchased input "aggregate." At the upper level, land would combine with the other farmer-owned input aggregate and the purchased input aggregate in a third CES production function to produce the output of the commodity in question.

With this approach in mind, plausible ranges for the substitution elasticities for all three countries and all commodities are listed in Table A1.9. The base value of the upper level substitution elasticity (between land, the other-farmer-owned input aggregate, and the purchased input aggregate) is 0.5, with a range between zero and one. The base value of the substitution elasticity among other farmer-owned inputs is 0.75, with a range between zero and 1.5. The base value of the substitution elasticity among purchased inputs is 0.15, with a range between zero and 0.3.

Although the ranges of the three substitution elasticities in Table 9 are for all three countries and all commodities, this does not mean that there would be only three substitution elasticity parameters in the PEM model. For the sensitivity testing as described in Section VI below, the substitution elasticities for each commodity/country would be distinct parameters, and could be varied independently of the substitution elasticities for other commodities and countries. A similar comment applies with respect to factor supply elasticities.

One approach to modelling factor supply discussed in Section IV above involves the existence of imperfect substitutability between commodities, so that factor prices can differ according to the commodity in which they are used. With this approach, it is necessary to specify own- and cross-price elasticities of supply of a factor to each commodity. This approach is currently used in the PEM model for land and could be used for other farmer-owned inputs and possibly purchased inputs as well.

With this approach in mind, plausible ranges for own-price elasticities of factor supply for all commodities are listed in Table 10. The ranges are the same for all three countries except for family labour, where a somewhat higher elasticity may be appropriate for Mexico. Most farm labour in Mexico is unskilled, so that farmers may have less agriculture-specific human capital than their counterparts in Canada or the US. The base value of the own-wage supply elasticity of family labour to each commodity in Canada and US is set at 0.7 (range of 0.4 to 1), while the base value for Mexico is set at 1 (range of 0.5 to 1.5). The base value of the own-price supply elasticity of land to each commodity in all three countries is set at 0.4 (range of 0.2 to 0.6). The base value of the own-price supply elasticity of capital to each commodity is set at 1 (range of 0.5 to 1.5), while the base value of the own-price elasticity of supply of purchased inputs is set at 3 (range of 1 to 5).

Plausible ranges for "net" factor supply elasticities are also shown in Table A1.10. The net factor supply elasticity is simply the sum of the own and all cross-price elasticities. For instance, the base value of the net supply elasticity of land is set at 0.1. This means that if rental rates on land for all agricultural commodities were simultaneously increased by 1%, the supply of land to each commodity would increase by 0.1%.

Values for cross-price elasticities of factor supplies could be derived based in part on the own-price supply elasticities and net supply elasticities listed in Table A1.10. By definition, the sum of the cross-price elasticities must be equal to the own-price elasticity minus the net elasticity. Cross-price elasticities could also be based on the estimated cross-price elasticities of land supply listed in Tables A1.5 and A1.6. As discussed in section IV, the values of cross-price elasticities of land supply and the symmetry property of supply functions may offer some guidance in setting cross-price elasticities of supply for other farmer-owned inputs.

VI. Procedures for dealing with parameter uncertainty

It is clear from the preceding discussion that there is significant uncertainty about the values of elasticities of substitution and factor supply in Canadian, Mexican and US agriculture. Picking a single set of values could yield misleading conclusions or, at the very least, conclusions that are not robust to alternative values of these parameters.

Any procedure for dealing with parameter uncertainty should be systematic rather than *ad hoc*. Due to the large number of parameters in the PEM model (the version of the PEM model outlined in OECD (1999) contained more than 300 parameters), any procedure for dealing with parameter uncertainty should also be efficient. That version of the PEM model excluded livestock and

covered four countries (Canada, EU, Mexico, US). An enlarged version of the PEM model with livestock and additional countries could easily have more than 1 000 parameters.

Five methods have been proposed in the literature for dealing with parameter uncertainty in economic models. The first method, which Harrison *et al*. (1993) refers to as conditional systematic sensitivity analysis (CSSA), involves specifying a certain number of "plausible" alternative values for each parameter in the model. One set of parameter values is chosen as the base (or reference) set. On a parameter-by-parameter basis, CSSA entails solving the model for every each alternative value while keeping all the other parameters fixed at their base values. If there are k parameters in the model, and if each the number of alternative values for each parameter is m (including the base value), the model must be solved $1+k(m-1)$ times. For example, if there are 500 parameters and three alternative values for each parameter (a base value, a "high" value, and a "low" value), the model must be solved 1001 times. CSSA has the advantage of computational feasibility because the number of times the model must be solved is usually the smallest of the five methods. Perhaps in part for this reason, CSSA or the same procedure by some other name has proven quite popular. However, only one parameter is permitted to vary from the base set at a time. This approach ignores the possibility that two or more parameters may act in combination to yield unusual or unexpected results.

A natural extension of CSSA is to examine all possible parameter combinations, and this is referred to by Harrison *et al.* (1993) as unconditional systematic sensitivity analysis (USSA). USSA requires that the model be solved m^k times. This can be a very large number if the number of parameters in the model is large. For example, if $k=500$ and $m=2$, the model must be solved $2^{500} \approx 3\times10^{150}$ times. If $m=3$, the model must be solved $3^{500} \approx 4\times10^{238}$ times. Clearly, USSA is computationally feasible only if the model is very small.

Harrison and Vinod (1992) propose a variation on USSA in which a random sample of all the possible parameter combinations is analysed instead of all possible combinations. They also propose that an *a priori* distribution be specified for each parameter (*e.g.* a uniform distribution or normal distribution), and that the alternative values for each parameter be chosen based on its distribution. Specifically, if one would like m_i alternative values for parameter i, divide the distribution into m_i intervals, with each interval having the same area under the probability density function. Then compute the mean value of the parameter within each interval, and use those means as the alternative values.

While the Harrison-Vinod (1992) procedure has the advantage of computational feasibility provided the sample size is not too large, it has two major shortcomings. First, for reasons explained in Miller and Rice (1983), all of the even moments (variance, kurtosis, etc.) of each parameter's distribution will on average be underestimated. Furthermore, as the sample size increases, the probability of underestimation approaches one. As Miller and Rice (1983) demonstrate for several commonly used distributions, the magnitude of the underestimation can be substantial. The odd moments apart from the mean could be underestimated or overestimated, but the results in Miller and Rice (1983) indicate a clear tendency toward underestimation here as well. Second, no procedure is offered for choosing the proper sample size. A sample size that is sufficient for one model and one set of parameter distributions may be too small to obtain reliable results for another model or another set of parameter distributions.

Drawing on results in Miller and Rice (1983), Preckel and DeVuyst (1992) recommend a procedure based on Gaussian quadrature. The procedure entails specifying an *a priori* distribution for each parameter and then choosing points along that distribution at which to solve the model. Unlike the Harrison and Vinod (1992) procedure, Gaussian quadrature can preserve the second and higher-order moments of each parameter's distribution. Letting m be the number of points to be chosen for

each parameter, Gaussian quadrature can under relatively general conditions reproduce the first $2m-1$ moments of the endogenous variables in the model. However, this precision comes at a high price in terms of computational cost unless the model is very small. Letting k again be the number of parameters in the model, the model must be solved m^k times. For example, if we wish to reproduce the mean and variance of the endogenous variables in the model ($m=2$), and if $k=500$, the model must be solved $3^{500} \approx 4\times10^{238}$ times.

A fifth alternative is a Monte Carlo experiment in which *a priori* distributions are specified for the parameters and sets of parameter values are drawn at random from these distributions. The specific distribution used can be tailored to the parameter at hand or, if the modeller lacks information on which to choose a distribution, one or more commonly used distributions (uniform, normal, etc.) can be tried. The distributions employed can be univariate or multivariate. Multivariate distributions require estimates of covariances between parameters, which in general are unlikely to be available. In the case of the PEM model, the population parameters for these distributions can be based on prior studies for the country/commodity in question or for similar countries and commodities. For example, if the uniform distribution is used, minimums and maximums for substitution elasticities and factor supply elasticities in the cases of Canada, Mexico, and the US can be based on the plausible ranges of values identified in Section V above.

Monte Carlo methods have been used successfully in economic models by Abler and Shortle (1995) and Abler *et al.* (1999*a*, 1999*b*). They were able to obtain relatively precise estimates of changes in the endogenous variables in their models with sample sizes in the range of 1 000 to 100 000. Even with a sample size of 100 000, results can be obtained in minutes using a Pentium-III (or equivalent) personal computer.

The Monte Carlo procedure sheds light on the sensitivity of a model's results to different parameter values because it yields not just a single "point" estimate of a change in each endogenous variable but instead an entire distribution of changes. Summary statistics can be presented such as sample means, standard deviations, and the sample probability that a change in a variable is positive or negative (in cases where a variable decreases for some sets of parameter values and increases for others). Abler and Shortle (1995) also illustrated their Monte Carlo results for fertiliser and pesticide usage in the form of histograms showing the distribution of changes in these variables. Such histograms make it possible for the reader to visually identify whether a distribution is centred "tightly" around its mean — so that one can have confidence about the magnitude of the change in a variable — or whether the distribution is "flat."

A procedure for choosing the sample size of the Monte Carlo experiment can be outlined following the usual method for choosing the sample size in experimental settings (Kendall and Stuart, 1973). The procedure is designed to limit the margin of error in estimating the change in each endogenous variable of interest that emerges as an output from the PEM model. For example, endogenous variables of interest in the PEM model might include production, consumption, trade, commodity prices, and benefits and costs to various groups such as farm households, agricultural input suppliers, taxpayers, and consumers.

Let Δy be the true but unknown change in some endogenous variable y due to some change in agricultural policy or some other type of change. Running the PEM model with any given set of parameter values will yield an estimate of Δy, which can be called Δy^e. Because Δy^e is an estimate, it is subject to error, which can be represented by the equation

$$\Delta y^e = \Delta y + e,$$

where e is an error term. Let σ^2 be the variance of e. Running the PEM model n times with n different sets of parameter values will yield a series of estimates Δy_1^e, Δy_2^e, …, Δy_n^e. Let $\overline{\Delta y^e}$ be the average value of Δy^e across the n sets of parameter values.

We would like a large enough sample size for $\overline{\Delta y^e}$ to be a reasonably precise estimator of Δy. Let ε be the margin of error we are willing to tolerate in our estimate, so that we would like $\overline{\Delta y^e}$ to fall within the range $\Delta y \pm \varepsilon$. We can attain our tolerable margin of error ε with a probability of $1-\alpha$ if we set the sample size equal to:

$$n = \left(\frac{z_{\alpha/2}}{\varepsilon} \right)^2 \sigma^2,$$

where $z_{\alpha/2}$ is the critical value of the standard univariate normal distribution.

For example, suppose we are estimating the change in the world price of some commodity in the PEM model. If we would like to have a 95% probability ($\alpha = 0.05$) of limiting the margin of error in the estimated price change to USD 0.10 ($\varepsilon = 0.1$), and if the variance of the change in the price as estimated by the PEM model is USD 10 ($\sigma^2 = 10$), then the necessary sample size is

$$n = \left(\frac{1.96}{0.1} \right)^2 10 \approx 3842.$$

In the case of the PEM model, there is not just one endogenous variable of interest but instead many variables. If there are k variables of interest, the procedure described above can be repeated for each variable, yielding a series of required sample sizes n_1, n_2, …, n_k. Setting the sample size of the Monte Carlo experiment equal to $n^* = \max\{n_1, n_2, ..., n_k\}$ will ensure that the tolerable margins of error for all the variables are attained simultaneously.

Implementing this procedure requires some initial estimate of the variance (σ^2) for each variable of interest, which can be found using Stein's double sampling method (Kendall and Stuart, 1973). This method involves taking an initial random sample of size n_0 to estimate σ^2 for each variable and then using those estimates to compute n^*. If it turns out that $n_0 \geq n^*$, there is no need to take a second random sample. The final random sample can consist solely of the original sample. If n_0 does not meet this criterion, there are two options. One is to retain the initial random sample and augment it with $n^* - n_0$ additional observations. The other option is to discard the initial random sample and take an entirely new random sample of the required size. The literature does not seem to favour one option over the other.

Depending on the how the PEM model is formulated, it is possible that a set of parameter values chosen at random may violate restrictions imposed by economic theory. In such a case, following Abler and Shortle (1995), any set of parameter values violating restrictions imposed by economic theory should be discarded and replaced by another set drawn at random. Sets that are discarded do not count toward the necessary sample size n^*.

In sum, of the five procedures described here, only Gaussian quadrature and the Monte Carlo procedure can be recommended — Gaussian quadrature when it is computationally feasible and the Monte Carlo procedure when Gaussian quadrature is not computationally feasible. Given that the Gaussian quadrature is not likely to be feasible for the PEM model, the Monte Carlo procedure is the recommended choice.

Table A2.1. Estimates of Elasticities of Substitution for US Agriculture

Study	Between Land and Other Farmer-Owned Inputs	Between Land and Purchased Inputs	Between Other Farmer-Owned Inputs and Purchased Inputs	Among Other Farmer-Owned Inputs (Capital & Labor)	Among Purchased Inputs
Aggregate Agricultural Production (Crops and Livestock)					
Adelaja (1984)	—	—	0.8	3.8	-1.5
Adusei (1987)	—	—	0.4	—	1.0
Antle (1984)	0.0	-5.4	0.1	0.2	—
Antoine (1992)	—	—	0.9	—	0.3
Baffes and Vasavada (1989)	—	—	0.6	0.0	—
Ball (1988)	-0.6	1.0	0.4	0.5	0.0
Binswanger (1974)	0.5	0.2	1.8	0.9	0.5
Brown and Christensen (1981)	—	—	0.4	0.1	—
Chalfant (1984)	0.4	0.1	0.7	2.7	—
Chambers and Lee (1986)	1.0	1.0	1.0	1.0	—
Chambers and Vasavada (1983)	—	—	0.6	1.1	—
Chavas and Cox (1995)	-0.2	0.6	0.6	0.7	-1.4
Debertin *et al.* (1990)	0.9	1.0	-0.8	4.8	0.3
Deininger (1993)	0.5	1.1	1.3	0.1	—
Featherstone *et al.* (1997)	2.8	1.4	0.1	—	-0.2

Study	Between Land and Other Farmer-Owned Inputs	Between Land and Purchased Inputs	Between Other Farmer-Owned Inputs and Purchased Inputs	Among Other Farmer-Owned Inputs (Capital & Labor)	Among Purchased Inputs
Fernandez-Cornejo (1993)	—	—	0.0	5.5	0.2
Gempesaw and Dunn (1986)	—	—	0.1	-2.7	0.3
Gopalakrishnan *et al.* (1989)	0.6	0.4	1.4	-2.8	—
Hayami and Ruttan (1985)	0.2	0.7	0.2	0.2	—
Hertel (1989)	-0.2	0.6	0.8	-0.4	0.2
Howard and Shumway (1989)	—	—	0.1	-0.4	—
Hsu (1984)	—	—	1.1	0.8	-0.9
Kawagoe *et al.* (1986)	0.0	1.3	0.0	0.2	—
Khalifa (1986)	—	—	0.7	—	1.3
Kislev and Peterson (1982)	—	—	—	1.7	—
Lambert and Shonkwiler (1995)	—	—	0.4	-0.1	—
Lass (1985)	—	—	-2.6	5.5	3.0
Lee and Chambers (1986)	—	—	1.1	1.7	—
Lim *et al.* (1993)	—	—	0.4	2.5	0.3
Litterman (1980)	—	—	0.7	0.7	0.3
Luh and Stefanou (1991)	—	—	0.4	0.0	—

Study	Between Land and Other Farmer-Owned Inputs	Between Land and Purchased Inputs	Between Other Farmer-Owned Inputs and Purchased Inputs	Among Other Farmer-Owned Inputs (Capital & Labor)	Among Purchased Inputs
McIntosh and Williams (1992)	—	—	0.0	0.0	0.0
O'Donnell *et al.* (1999)	—	—	0.2	0.0	—
Ojemakinde (1989)	—	—	16.4	—	—
Polson and Shumway (1992)	—	—	0.0	0.2	0.1
Ray (1982)	—	—	1.0	0.8	-1.2
Rostamizadeh (1981)	0.9	1.0	0.9	1.1	—
Saez (1983)	—	—	-0.3	0.4	0.0
Shumway and Lim (1993)	-0.4	0.7	0.5	-0.6	0.1
Shumway *et al.* (1988)	—	—	0.1	0.4	0.0
Taylor and Monson (1985)	0.2	0.3	0.4	0.5	—
Villezca-Becerra and Shumway (1992)	—	—	0.0	2.0	0.0
Crop Production					
Garcia and Randall (1994)	—	—	0.3	—	0.1
Hertel et al. (1996)	—	1.1	—		
Huffman and Evenson (1989)	—	—	1.2	1.2	1.4
Mao and Woo (1997)	—	—	0.4		

Study	Between Land and Other Farmer-Owned Inputs	Between Land and Purchased Inputs	Between Other Farmer-Owned Inputs and Purchased Inputs	Among Other Farmer-Owned Inputs (Capital & Labor)	Among Purchased Inputs
McLean-Meyinsse (1987)	—	—	0.6	-0.7	0.5
Nieswiadomy (1988)	—	—	0.3	1.8	—
Shumway (1983)	—	—	5.8	1.7	—
Shumway *et al.* (1990)	—	—	-2.0	-0.3	—
Thirtle (1985)	0.3	1.6	0.3	1.9	—
Weaver (1983)	—	—	1.6	-4.4	0.3
Livestock Production					
Eswaramoorthy (1991)	—	—	1.7	1.2	-10.5
Grisley and Gitu (1984)	-0.7	0.3	0.2	—	0.0
Hoque and Adelaja (1984)	—	—	0.6	4.5	-0.4
Stefanou and Saxena (1988)	—	—	-0.5	—	0.0
Weaver and Lass (1989)	—	—	0.6	0.3	0.0

Note: Rounded to the nearest 0.1.

Table A2.2. Estimates of Elasticities of Substitution for Canadian and Mexican Agriculture

Study	Between land and other farmer-owned inputs	Between land and purchased inputs	Between other farmer-owned inputs and purchased inputs	Among other farmer-owned inputs (Capital & Labor)	Among purchased inputs
Canada					
Adamowicz (1986)	0.1	-0.1	0.3	0.6	0.1
Andrikopoulos and Brox (1992)	1.2	0.5	0.9	0.6	—
Horbulyk (1990)	—	—	33.7	—	-9.1
Islam and Veeman (1980)	0.3	-0.7	1.5	0.3	-0.8
Karagiannis and Furtan (1990)	0.3	0.7	0.3	0.6	—
Lopez (1980)	0.2	1.0	1.2	1.8	—
Lopez and Tung (1982)	-1.8	1.5	1.4	6.8	0.0
Moschini (1988)	—	—	0.6	—	0.2
Toichoa-Buaha and Apland (1996)	—	—	—	—	0.1
Mexico					
Bassoco and Norton (1983)	—	—	—	2.2	
Howell (1983)	—	—	—	0.5	—
Lim and Shumway (1999)	—	—	0.1	—	2.3

Note: Rounded to the nearest 0.1.

Table A2.3. Elasticities of substitution for US agriculture
(Averages across studies)

Elasticity of substitution	All studies		Aggregate agriculture studies		Crop studies		Livestock studies	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Between land and other farmer-owned inputs	0.3	0.8	0.4	0.8	0.3	—	-0.7	—
Between land and purchased inputs	0.5	1.5	0.4	1.6	1.4	0.4	0.3	—
Between Other Farmer-Owned Inputs and Purchased Inputs	0.8	2.4	0.8	2.6	0.9	2.1	0.5	0.8
Among Farmer-Owned Inputs (Capital & Labor)	0.9	1.9	0.9	1.8	0.2	2.3	2.0	2.2
Among purchased inputs	-0.2	2.1	0.1	0.9	0.6	0.6	-2.2	4.7

Note: Rounded to the nearest 0.1. Figures that are underlined are based on fewer than five studies and should be treated with caution. A — in the standard deviation column indicates there is only one study for that particular case, so that no standard deviation can be calculated.

Table A2.4. Elasticities of Substitution for Canadian Agriculture (Averages across Studies)

Elasticity of substitution	Aggregate agriculture studies*	
	Mean	Standard deviation
Between land and other farmer-owned inputs	0.1	1.0
Between land and purchased inputs	0.5	0.8
Between other farmer-owned inputs and purchased inputs	0.9	0.5
Among farmer-owned inputs (capital & labour)	1.8	2.5
Among purchased inputs	-0.1	0.4

Note: Rounded to the nearest 0.1. This table excludes Horbulyk (1990), for which the estimates are not plausible.

Table A2.5. Estimates of Land Supply Elasticities for US Agriculture

Study	Commodity grown on land	Own-price elasticity	Cross-price elasticity
Expert assessments			
Abler and Shortle (1995)	Maize	0.20	—
Abler and Shortle (1992)	Coarse Grains	0.15	-0.05 (Wheat) -0.1 (Soybeans)
	Wheat	0.20	-0.15 (Coarse G) -0.05 (Soybeans)
	Soybeans	0.20	-0.15 (Coarse G) -0.05 (Wheat)
Gardner (1990)	Crops	0.20	—
Hertel (1997, 1999)	Any Agricultural Product	1.00	-1.00 (Any Other Product)
Hertel (1989)	Agriculture as a Whole	0	—
Econometric estimates			
Chavas and Holt (1990)	Maize Soybeans	0.15 0.45	-0.15 (Soybeans) -0.30 (Maize)
Chembezi and Womack (1992)	Maize	0.10	-0.05 (Wheat) -0.05 (Soybeans)
	Wheat	0.05	-0.05 (Maize) -0.10 (Soybeans)
Lee and Helmberger (1985)	Maize Soybeans	0.05 0.25	-0.15 (Soybeans) -0.15 (Maize)
Miller and Plantinga (1999)	Maize Soybeans	0.95 0.95	-0.45 (Soybeans) -0.40 (Maize)
Morzuch *et al.* (1980)	Wheat	0.35	—
Orazem and Miranowski (1994)	Maize Soybeans	0.05 0.25	0.00 (Soybeans) 0.00 (Maize)

Note: Rounded to the nearest 0.05.

Table A2.6. Estimates of Land Supply Elasticities for Canadian and Mexican Agriculture

Study	Country	Commodity grown on land	Own-price elasticity	Cross-price elasticity
Expert Assessments				
Duloy and Norton (1983)	Mexico	Agriculture as a Whole	0	—
Hertel (1997, 1999)	Canada & Mexico	Any Agricultural Product	1.00	-1.00 (any other product)
Levy and van Wijnbergen (1995)	Mexico	Crops Livestock	0 0	— —
Sarwar and Fox (1992)	Canada	Coarse Grains	0.10	—
Econometric Estimates				
Clark and Klein (1992)	Canada	Coarse Grains	0.30	-0.10 (Wheat) -0.95 (Oilseeds)
	Canada	Wheat	0.10	-0.25 (Coarse G) 0.00 (Oilseeds)
	Canada	Oilseeds	1.00	0.05 (Coarse G) -0.10 (Wheat)
Meilke and Weersink (1990)	Canada	Coarse Grains	0.10	-0.05 (Wheat) 0.0 (Oilseeds)
	Canada	Wheat	0.10	0.0 (Coarse G) -0.10 (Oilseeds)
	Canada	Oilseeds	0.25	-0.10 (Coarse G) -0.10 (Wheat)

Note: Rounded to the nearest 0.05.

Table A2.7. Estimates of supply elasticities for other farmer-owned inputs

Study	*Country*	*Type of Input*	*Supply Elasticity*
Expert assessments			
Abler and Shortle (1995)	US	Capital Labor	7.5 5.0
Abler and Shortle (1992)	US	Capital Labor	∞ ∞
Beghin *et al.* (1997)	Mexico	Capital Labor	1.0 ∞
Burniaux *et al.* (1990)	Canada and US	Capital Labor	2.8 2.7
Duloy and Norton (1983)	Mexico	Family Labor	0
Gardner (1990)	US	Labor	1.0
Hertel (1997, 1999)	Canada, Mexico,and US	Capital Labor	∞ ∞
Hertel (1989)	US	Capital Labor	0 0.5
Levy and van Wijnbergen (1995)	Mexico	Labor	∞
Sarwar and Fox (1992)	Canada	Capital Labor	2.0 1.5
Shumway *et al.* (1988)	US	Machinery	2.0
Econometric estimates			
Barkley (1990)	US	Farm Operator Labor All Labor	0.3 0.3
Rosine and Helmberger (1974)	US	All Labor	2.6
Smit (1978)	Canada	Family Labor	1.5
Weersink and Tauer (1990)	US	All Labor (Dairy)	0.1

Note: Rounded to the nearest 0.1.

Table A2.8. Estimates of Supply Elasticities for Purchased Inputs

Study	Country	Type of Input	Supply Elasticity
Expert Assessments			
Abler and Shortle (1995)	US	Fertiliser Pesticides	7.5 7.5
Abler and Shortle (1992)	US	Fertiliser	∞
Duloy and Norton (1983)	Mexico	All Purchased Inputs	∞
Gardner (1990)	US	Fertiliser	2.0
Hertel (1997, 1999)	Canada, Mexico and US	All Purchased Inputs	∞
Hertel (1989)	US	All Purchased Inputs	∞
Sarwar and Fox (1992)	Canada	All Purchased Inputs	2.0
Shumway *et al.* (1988)	US	Energy Hired Labor Materials	0.5 5.0 0.5
Econometric Estimates			
Barkley (1988)	US	Hired Labor	0.5
Perloff (1991)	US	Hired Labor	1.6

Note: Rounded to the nearest 0.1.

Table A2.9. Plausible ranges for substitution elasticities (all three countries, all commodities)

Substitution Elasticity	Base Value	Minimum	Maximum
Upper Level (Between Land, Other Farmer-Owned Input Aggregate, and Purchased Input Aggregate	0.5	0	1.0
Among Other Farmer-Owned Inputs	0.75	0	1.5
Among Purchased Inputs	0.15	0	0.3

Table A2.10. Plausible ranges of factor supply elasticities (all commodities)

Factor	Own-Price Supply Elasticities to Each Commodity			"Net" Supply Elasticities (Sum of Own and Cross-Price Elasticities)		
	Base Value	Minimum	Maximum	Base Value	Minimum	Maximum
Canada and United States						
Land	0.4	0.2	0.6	0.1	0	0.2
Capital	1	0.5	1.5	0.5	0.3	0.7
Family Labor	0.7	0.4	1	0.3	0.1	0.5
Purchased Inputs	3	1	5	1.5	0.5	2.5
Mexico						
Land	0.4	0.2	0.6	0.1	0	0.2
Capital	1	0.5	1.5	0.5	0.3	0.7
Family Labor	1	0.5	1.5	0.5	0.3	0.7
Purchased Inputs	3	1	5	1.5	0.5	2.5

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Annex 3.

ELASTICITIES OF SUBSTITUTION AND FACTOR SUPPLY ELASTICITIES IN EUROPEAN AGRICULTURE: A REVIEW OF PAST STUDIES

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

This section of annex 3 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 modelling 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 utilised, to compile a bibliography of past studies which attempted to empirically estimate elasticities of

1. The author would like to thank Benjamin Horn for outstanding research assistance, Franz Sinabell for comments throughout the text, Jesús Antón for comments, Christoph Weib for discussions about labour supply and David Abler for the challenge.

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

The study is organised 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 summarises the results and comments on their suitability for modelling 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 A3.1, a production functions is estimated, in nine a profit function and in 21 studies a cost function. All studies report estimates for EU countries, with the exception of 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.

In the case of a translog cost function, the AES between factor *i* and *j* (σ_{ij}) can be derived from estimation results and/or from factor demand elasticities (η_{ij}) utilising the following relations (Binswanger, 1974):

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

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

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

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

and in some cases

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

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 A3.1. Studies on factor substitution

Author(s)	Country	Farm type	Method	Data	No. Inp.	No. 0utp.
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 Karagiannnis (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
Zezza (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). Afterwards, η_{ij} can be converted to σ_{ij} by equation (1).

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. Twenty-five 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 (labour 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 (labour 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, labour, 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 fertiliser, pesticides, and seeds) or operating inputs in studies of specialised 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 labour is treated as an operating input. Hence, the category labour either includes only family labour (if a study distinguishes between family labour and hired labour) or total farm labour which is strongly dominated by family labour as reported in the next section.

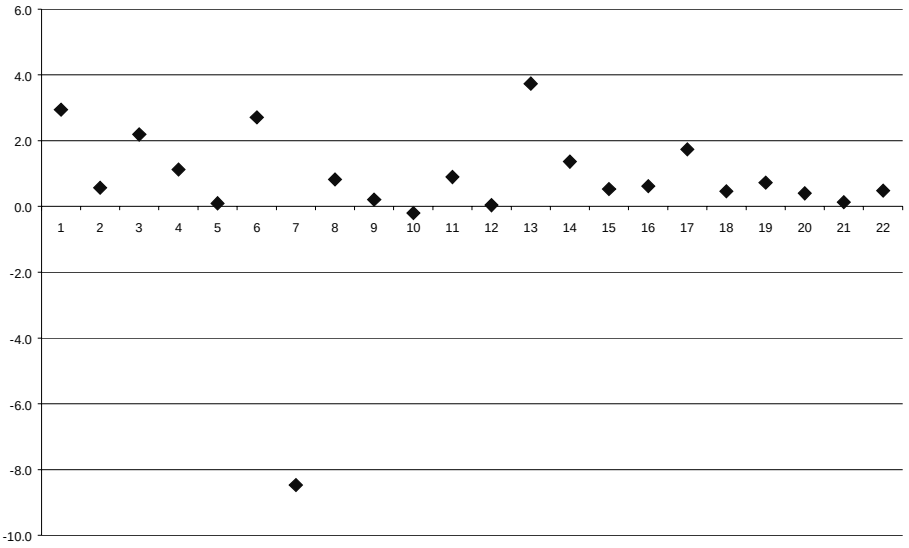
If studies report results for several years (or periods) (*e.g.* Glass and McKillop, 1989, 1990; Lang, 1993) those with the most recent base year (period) are taken. If studies report results for specific regions as well as an aggregate of those regions, the more aggregated numbers are preferred (*e.g.* 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 A3.2 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 labour 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 A3.1 for the case of the AES between labour and variable inputs. Twenty-one 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* does not lie within a range of two standard deviations from the calculated mean, it is cancelled from the data set.

Figure A3.1. AES between labour 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 A3.1. Obviously, without loosing many of the observations (about 9%) the standard deviations become considerable smaller and are cut in half in many cases.

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:

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

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

Table A3.2. Statistics of AES between land, labour, 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 A3.3. Statistics of AES between land, labour, 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 A3.4. Statistics of AES between land, labour, 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.

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 A3.15. 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 A3.5. 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

Similarly, 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 Tables A3.4 and A3.6. The results are only slightly different compared to the unweighted results in Tables A3.3 and A3.5. Different weights were tested without observing significant changes in the results (except for AES with very few observations).

Table A3.6. Statistics of AES between farm-owned inputs and purchased inputs, and between land and other farm-owned inputs, corrected for outliers and weighted[1]

	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

1. 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 fertiliser, hired labour, other purchased inputs (including seed, pesticides, fuel, energy), and feed. If a study has only the category crop inputs it is treated like fertiliser. Results of these calculations are reported in Table A3.7. The same procedure as discussed above is utilised to eliminate outliers. The AES corrected for outliers are reported in Table A3.8. 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 Tables A3.6 and Table A3.7.

Table A3.7. Statistics of AES between purchased inputs

	Fertiliser/ hired labour	Fertiliser/ other purchased	Fertiliser/ feed	Hired labour/ other purchased	Hired labour/ 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 A3.8. Statistics of AES between purchased inputs, corrected for outliers

	Fertiliser/ hired labour	Fertiliser/ other purchased	Fertiliser/ feed	Hired labour/ other purchased	Hired labour/ 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 Tables A3.5, A3.6 and A3.8 are utilised. The following observations are important: The AES between farm-owned inputs and the more specialised 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.

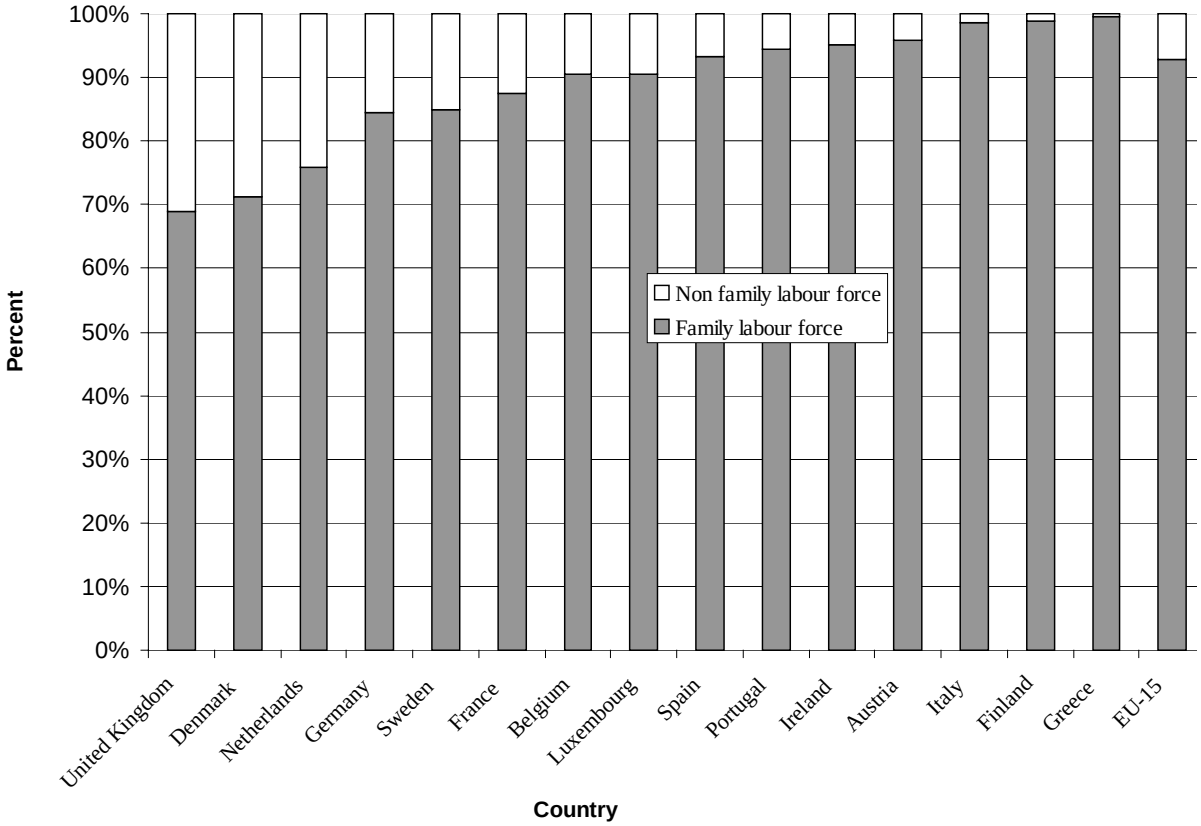
III. Factor supply elasticities

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

i) Supply of labour

Though total farm labour comprises family labour and hired labour, the first one is with 93% of paramount importance in the EU (Figure A3.2). Moreover, all except one of the studies on on-farm labour supply in Europe discussed in this review are based on agricultural household models considering farm family labour only. Hence, the plausible range of values given at the end of this section is one for the own-wage elasticity of on-farm labour 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 labour.

Figure A3.2. 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 labour allocation decisions of farm families based on household models and cross-section data especially for the United States (Hallberg *et al.* (1991) offers a good overview) and developing countries (*e.g.* Singh *et al*., 1986*a*), but also for Europe (Weiss, 1998*a*, 1998*b*). However, estimates of on-farm labour supply elasticities are scarce. Most of the empirical studies on farm household labour decisions for Europe analyze the

influence of specific characteristics of farm holders, their families, and their enterprises on off-farm labour participation in a bivariate way (*e.g.* Corsi, 1993, 1994; Benjamin, 1994, 1995; Benjamin and Guyomard, 1994*a*, 1994*b*; 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 labour 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 labour, one can derive own-wage elasticities of on-farm labour 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 A3.9).

Table A3.9. Studies on on-farm labour supply

Study	Country	Farm Type	Elasticity	Comment
Cross-section studies				
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
Time-series				
Cowling *et al.* (1970)	UK	Agriculture	0.50	

Note: Only a few studies actually derive own-wage elasticities of on-farm labour 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.

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 labour of the household's head decreases the on-farm labour supply of other family members by 0.63% and a one percentage change in the shadow wage rate of farm labour of other family members decreases the on-farm labour supply of the household's head by 0.23%. Hence, a one percentage change of the shadow wage rate of farm labour of the household's head would decrease the on-farm labour supply of the whole family by 0.41% (0.22 – 0.63) implying a backward sloping labour supply curve (see Gasson and Errington, 1993, p. 124 for a discussion). According to Woldehanna (1996) even if the farm labour shadow wage rate of both groups would increase by one percent the net effect on on-farm labour would be negative.

The range of elasticities given in Table A3.9 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.* (1986*b*) report own-wage elasticities of on-farm labour 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 labour for Canadian farmers of 0.12.

A low range of the own-wage elasticity of on-farm labour supply is to some degree also confirmed by estimates of the cross-wage elasticity of off-farm labour 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 labour supply to be in a similar though negative range as own-wage elasticities of on-farm labour 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 labour supply are also in line with numerous microeconomic household studies of labour supply for other sectors and social groups. For example Hansson and Stuart (1985) surveyed 28 studies on labour supply and calculated a median uncompensated wage elasticity of labour 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 labour 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 labour force moving into (out) of the sector. Hence, the aggregated (sector wide) labour 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 labour supply between 0.2 and 1.4 and compensated wage elasticities between 0.96 and 2.

More aggregated farm labour supply elasticities might be found in studies using time series data on labour supply and wage rates. However, as reviewed in Salhofer (1999) most of these studies on aggregated farm labour 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 labour as well as hired labour 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 labour, Cowling, Metcalf and Rayner (1970) report an aggregated own-wage elasticity of labour supply of 0.5 for the UK.

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

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 capitalised 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

$$\phi_{ij} = \frac{\alpha_{jB}\beta_{ij}}{\theta_{jB}}, \tag{9}$$

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 A3.10 summarises 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). Utilising formula (9) 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 A3.11 and Table A3.12 for θ_{jB} is 1/3 and 2/3, respectively. For example, based on the assumption that ϕ_{ij} = 0.333, a 1 percentage increase in the price for wheat land would imply 0.25% increase in the supply of wheat land, a 0.12 decrease of coarse grain land and a 0.05 decrease of oilseed land. 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.

Table A3.10. Studies on the elasticity of land supply with respect to output prices

Study	Country	Commodity	Own-price	Cross-Price	With
Boyle and McQuinn (2000)	Ireland	Barley	0.02	-0.02	Wheat
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
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
Ibanez Puerta and	Spain	Wheat	0.57	-0.57	Coarse grains
Perez Hugalde (1994),		Coarse grains	0.69	-0.69	Wheat
Jensen and Lind (1993)	Denmark	Cereals	0.36	-0.18	Rapeseed
		Rapeseed	1.28	-2.38	Cereals
O. Lansink a. Peerlings (1996)	Netherlands	Cereals a. Oilseeds	1.01		
Oude Lansink (1999*a*)	Netherlands	Cereals a. Oilseeds	0.26		
Oude Lansink (1999*b*)	Netherlands	Cereals a. Oilseeds	1.86		

Table A3.11. 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 A3.12. 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

iii) Supply of purchased inputs

Supply of purchased inputs includes operating inputs like fertiliser, 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 fertiliser 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 of 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.

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 $\mathbf{y} = (y_1, \ldots, y_n)$ be a vector of policy measures (*e.g.* y_1 is production, y_2 is farm income, etc.), let $\mathbf{x} = (x_1, \ldots, x_m)$ be a vector of policy instruments (*e.g.* x_1 is market price support,

x_2 is direct payments, etc.), let $\mathbf{b} = (b_1, \ldots b_z)$ be a vector of parameters (*e.g.* b_1 is the AES between farm-owned inputs and purchased inputs, b_2 the farm labour supply elasticity, etc.), and Let $\mathbf{f}(\cdot) = (f_1(\cdot), \ldots, f_y(\cdot))$ 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 **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, for example, 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, $\boldsymbol{\phi}(\mathbf{b}) = (\phi_1(b_1), \ldots, \phi_z(b_z))$ be a vector of distributions of parameters and let $\boldsymbol{\theta}(\mathbf{y}) = (\theta_1(y_1), \ldots, \theta(y_n))$ 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 **b**, one would create a large number *T* of new data sets $A^1, A^2, \ldots, A^T$ 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 linearisation 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 linearisation 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. The appropriateness of such a procedure depends 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 $(\mathbf{b}^1, \ldots, \mathbf{b}^T)$ is drawn randomly from the multivariate normal distribution of the parameters. Second, by substituting the *T* parameter sets into Equation (11) one can derive $\boldsymbol{\theta}(\mathbf{y})$.

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.

Recently, Davis and Espinoza (1998), Griffiths and Zhao (1999), Davis and Espinoza (1999), Salhofer and Scmid (2000), 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 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 andtheir ranges are reported in Table A.3.13. 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 A3.3 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 A1.23. 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, 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 on average reduce the estimated cost of farmers by € 3.7 million. In the case of a log-linear regression, a one percentage increase in the elasticity of substitution will reduce the estimated cost of farmers by 4.1%.

The regression results in Table A1.23 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 A3.3. Kernel Density function of a decrease in farm income

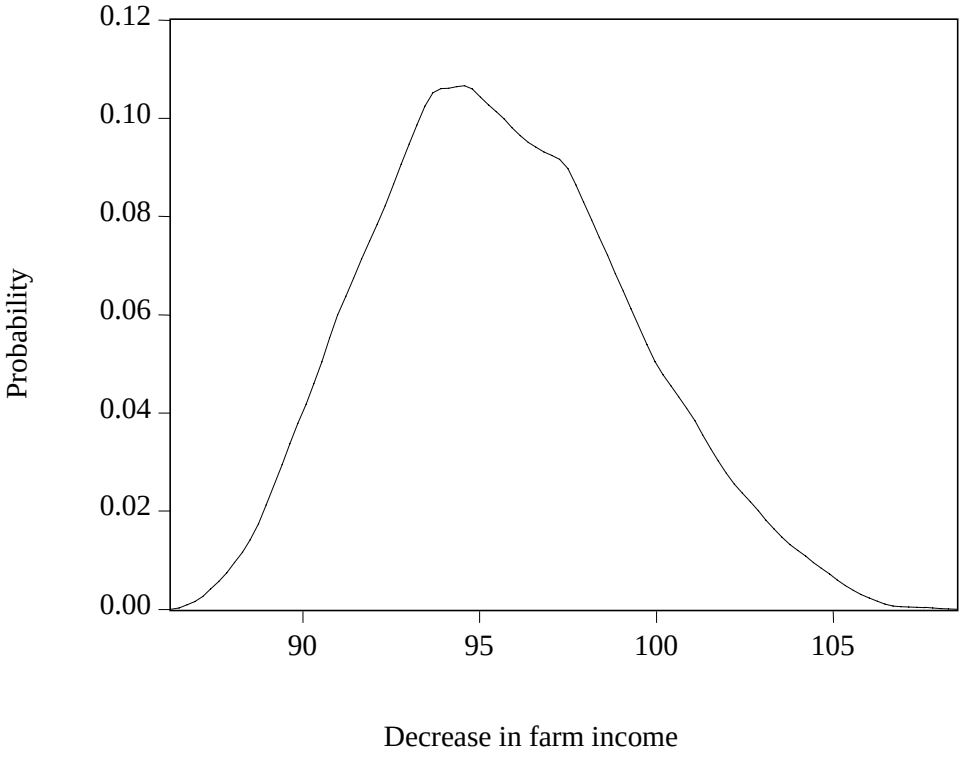


Table A3.13. The influence of parameter values on estimated decrease in farm income

	Linear model		Log-linear model	
Variable	**Coefficient**	**t-Statistic**	**Coefficient**	**t-Statistic**
Constant	100.099	648.829	4.461	5273.848
Farm level				
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
Industry level				
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 modelling the effects of agricultural policy changes

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

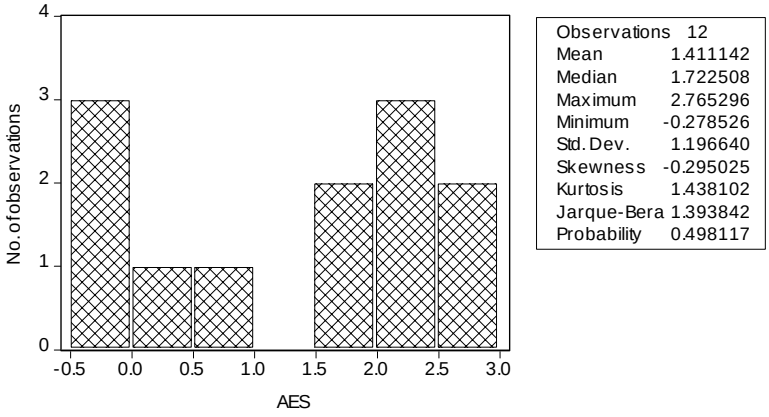
As illustrated in Table 2 the main problem with the reviewed studies on AES is the wide range they cover. Though, applying some procedure to correct for outliers cuts the standard deviation by one half in most cases, it is on average still around 1.2, implying a 95% interval of 4.8 units (Table A1.23).

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.

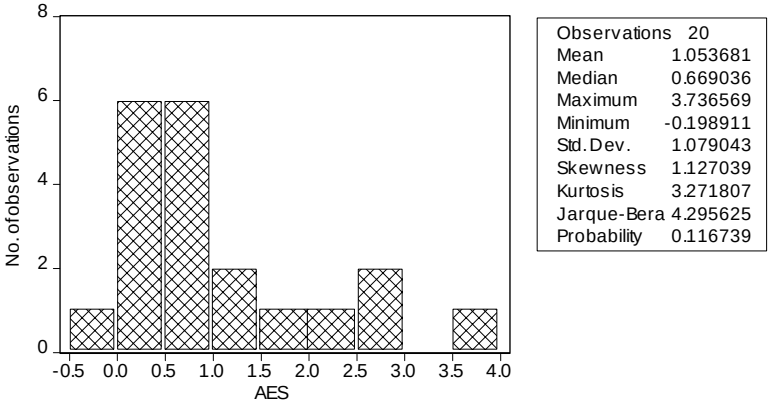
Another circumstance to be mentioned, is the fact that the observations are by no means distributed normally around the mean. This is illustrated in Figure A1.4a to Figure A1.4c, for the AES between land (labour, capital) and variable inputs. Moreover, given that the final goal of the study is to derive AES for the EU, it has to be mentioned that the 24 reviewed country studies are not representative for the EU.

Figure A3.4. Histograms of different AES

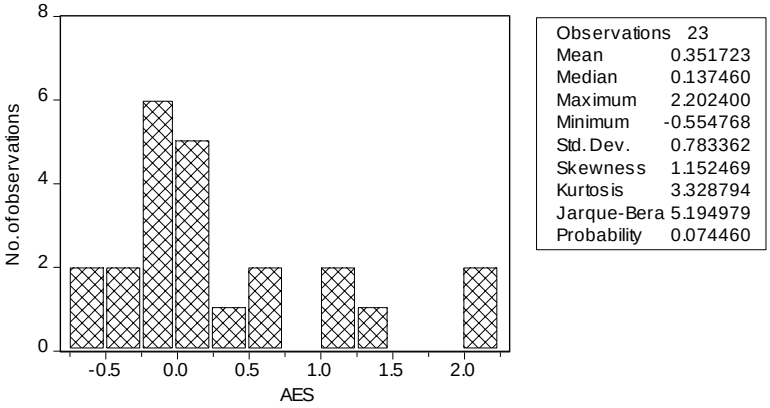
(a) AES between land and variable inputs



(b) AES between labour and variable inputs



(c) AES between capital and variable inputs



Factor Supply Elasticities

Though all of the reviewed microeconomic (farm-level) studies on farm labour supply report elasticities of on-farm labour 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 labour supply elasticity. As discussed above microeconomic studies cover only one aspect of labour supply, namely the effect of a change in the wage rate on the hours worked and not the effect of labour force moving into (out) of the sector. Unfortunately, only one study on aggregated labour 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 prices. In doing so, the main uncertainty is about how much of and how fast product price changes are capitalised in land prices. The capitalisation 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 capitalised in land prices since this is the least variable factor and the fact that the PEM model is medium run oriented.

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 United States (Abler, 2000, Tables A1.17 and A1.18), assume elasticities in a similar range. Given the information collected here, it was not possible to differentiate between elasticities for specialised 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 (Zhao *et al.*, 2000) might have some advantage compared to a normal distribution.

Finally, it should be noted once again that the recommended ranges and base values in this study are based on an extensive literature review and hence are much less *ad hoc* than in most policy analysis studies. The remaining uncertainty is perhaps of a degree that scientists and politicians will probably have to learn to live with in economic analysis.

Table A3.14. Statistics of AES between land, labour, 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 A3.15. Statistics of AES between farm-owned inputs and purchased inputs, and between land and other farm-owned inputs, corrected for outliers and weighted[a)]

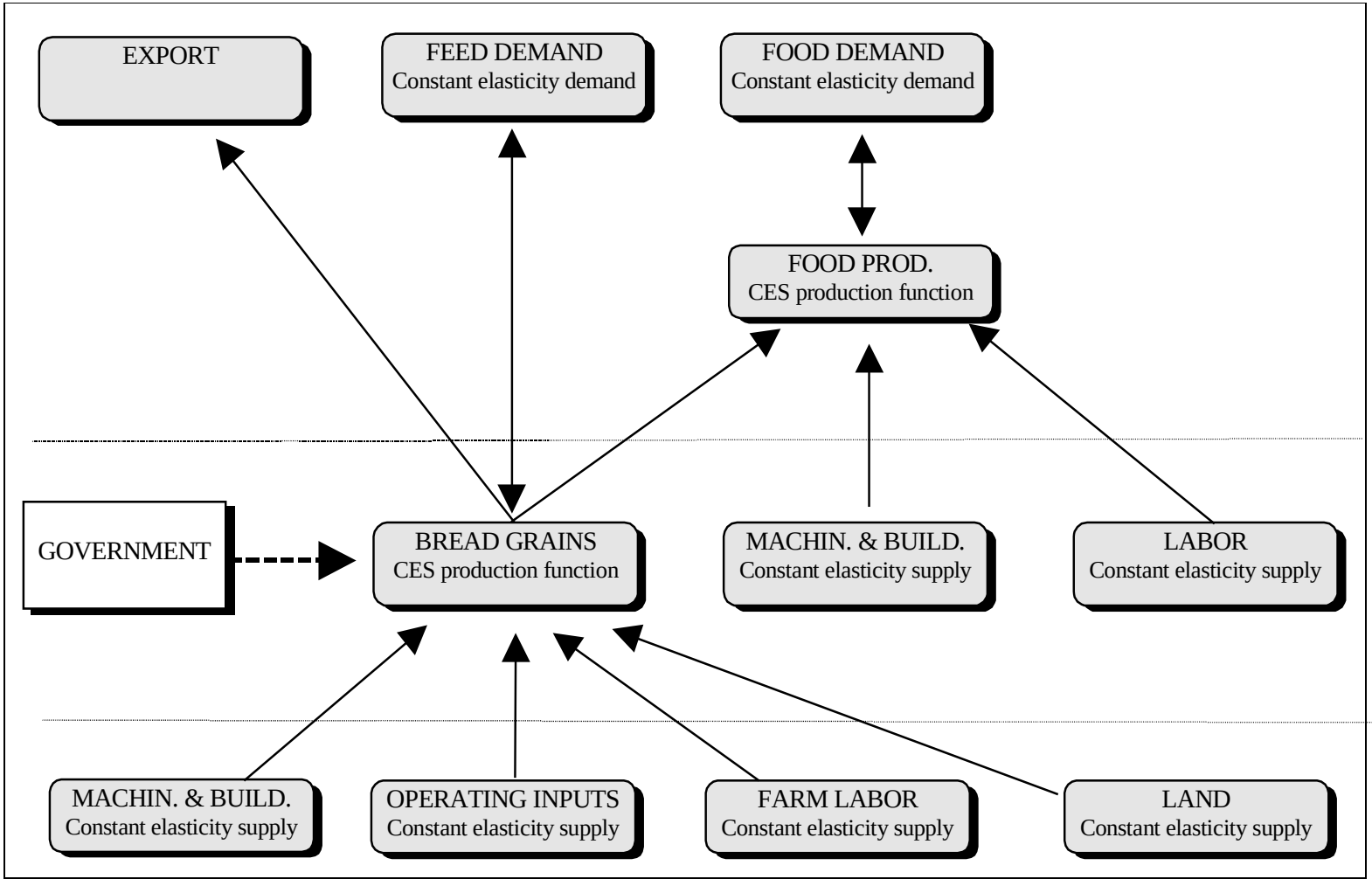
	farm-owned/ variabel inp.	farm-owned/ crop inp.	farm-owned/ animal inp.	land/other farm-owned
Observ.	56	29	26	20
Mean	0.9	1.4	1.7	0.3
St.Dev.	0.9	1.3	1.1	0.8

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 A3.16. 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 A3.5. Austrian bread grains model



NOTES

1. From this kind of study, 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.

2. Note that own-wage elasticities of off-farm labour supply are commonly estimated to be more elastic than own-wage elasticities of on-farm labour and cross-wage elasticities of off-farm labour supply. The mean of estimates of own-wage elasticities of off-farm labour 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. One could also 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 does not have a likewise opposite effect.

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.

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

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