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## Discussion paper

# Optimal agricultural policy and PSE measurement: an assessment and application to Norway

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# Optimal agricultural policy and PSE measurement: an assessment and application to Norway

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**Abstract:**

*The producer support estimate (the successor to the producer support equivalent) calculated by the OECD is widely used as an indicator of distortions created by agricultural policies. In this paper we demonstrate that changes in the relative (percentage) PSE are not an accurate indicator of the implications of policy reform for domestic welfare or for trade distortions. We demonstrate that it is important to consider the implications of changes in both the level and the form of support in evaluating the impact of policy reform. Using a model of Norwegian agriculture we show that reforms indicated towards the provision of public goods, while apparently leading to an increase in relative support, are actually superior to existing agricultural policies or to a policy aimed at eliminating subsidized exports both in terms of reducing trade distortions and increasing domestic economic welfare.*

1. **Introduction**

The producer subsidy estimate (PSE) is a measure of the monetary transfer to producers from consumers and taxpayers through existing agricultural policies. Its conceptual basis is as a summary of the incidence of government policies through an equivalent subsidy. Originally the acronym PSE stood for producer subsidy equivalent. The theoretical foundation for the PSE was established by Corden (1971); Josling (1973 and 1975) applied the concept to agricultural policies and coined the term producer subsidy equivalent.

Since the mid 1980s the OECD has published data on the PSE for OECD members and for some non member countries. OECD's annual estimates provide the only readily available and consistent source of internationally comparable information on levels of support for agriculture. Cahill and Legg (1989-90) and Legg (2003) provide an overview of the definitions and use of the OECD's support measurements.

The publication of internationally comparable PSE figures has increased transparency on the nature and incidence of agricultural policies in OECD countries. The PSE concept has also contributed to establishing a base for internationally binding commitments on domestic support through the Aggregate Measure of Support (AMS) in the Uruguay Round of trade negotiations of the World Trade Organization (WTO).[1]

Given the prominence of the OECD, and the WTO connection, it is not surprising that PSE estimates have attracted much public attention and received wide media coverage. The summary measure, relative PSE or %PSE (expressed as a percentage of the value of gross farm receipts) is frequently cited in the international debate on agricultural policies, and used as a yardstick of policy "misconduct", i.e., unfair competition with farmers in unsubsidizing countries. The higher a country's relative PSE, the more likely that the country's agricultural policy will be criticised by other countries (e.g., Oxfam, 2005)..

Nevertheless, as indicated by Tangermann (2005), the relative PSE is merely a measure of monetary transfers from consumers and taxpayers, and thus an indicator of policy effort in favor of farmers. It was never intended to be an indicator of protection or trade impact, and high relative PSEs do not necessarily indicate such effects.

Whether a high relative PSE is indicative of policy misconduct cannot be determined from the PSE figure alone, but hinges fundamentally on whether the welfare benefits of policies exceed their costs. This is the thread that we follow in this paper. We examine welfare theory and investigate how a switch in the direction of policies with a better

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[1] The principal difference between the AMS and an equivalent calculation in the PSE is that the former uses fixed international reference prices derived from a specific base period, while the latter uses current international reference prices.

theoretical foundation will affect PSE figures. We also explore the relationship between the PSE and trade distortions.

## 2. Agricultural support and trade distortions

It is widely accepted that there are externalities and public goods related to agricultural activity. Examples cited are the amenity value of the landscape, food security, and preservation of rural communities and rural lifestyle (see Winters, 1989–1990 and OECD, 2001). The implications for agricultural policy are controversial, in particular, whether the provision of support can be justified to ensure the production of non-commodity outputs, and what policy instruments are efficient in achieving desired output levels. In the current WTO negotiations, for example, some high-cost countries have used alleged non-commodity outputs (the so-called "multifunctionality" of agriculture) to argue for the maintenance of import protection. Low-cost exporting countries reject such arguments. Their view is supported by studies that demonstrate that efficient policies for multifunctional agriculture do not depend on import protection (e.g., Chang et al., 2005; Peterson et al., 2002).

If we accept that the central role of agricultural policy is to correct for market failure, Pigouvian subsidies equal to marginal benefits should be used whenever agricultural activities, through production or input use, affect the supply of public goods and positive externalities (Blandford and Boisvert, 2002). However, such subsidies would clearly be counted in the PSE.

Consider the case of no subsidies, no tariffs and no non-tariff trade restrictions, and consequently a PSE equal to zero. With positive externalities this would clearly be suboptimal, as production and/or input use would fall short of optimal levels. Correcting this through Pigouvian subsidies would result in a positive PSE, but that would not indicate policy misconduct. On the contrary, it would be the result of an optimal policy that internalizes externalities. If support were initially provided by means other than Pigouvian subsidies, a switch to an optimal policy might well result in a reduction in the total PSE since prices and, most likely, production would decline. However, the relative PSE might be unchanged or even increase. To investigate this formally we use a simple partial model.

We assume the following production function for agriculture:

(1) $\quad Y = L^\alpha K^\beta$, $\qquad \alpha + \beta \le 1$,

where $Y$ is agricultural production, $L$ is land, and $K$ is an aggregate of other factors of production, which for simplicity we refer to as capital. The Cobb-Douglas function is chosen mainly for expositional clarity. In the appendix we provide derivations for the more general Constant Elasticity of Substitution (CES) case.

Producer surplus as defined by the profit function is:

(2)  $\Pi = pY - wL - rK$,

where $p$ is the price of the agricultural good and $w$ and $r$ are the prices of land and capital respectively. Using the small country, small sector argument we assume that output and factor prices are given, and we further assume that there are no tariff or non-tariff trade barriers so that $p$ is the world market price.

Maximizing profit yields the following supply and factor demand functions under the assumption of perfect competition:

$$Y = \left[ \alpha^\alpha \beta^\beta \frac{p^{\alpha+\beta}}{w^\alpha r^\beta} \right]^{\frac{1}{1-\alpha-\beta}}, \qquad \alpha + \beta < 1$$

(3)  $$L = \left[ \alpha^{1-\beta} \beta^\beta \frac{p}{w^{1-\beta} r^\beta} \right]^{\frac{1}{1-\alpha-\beta}},$$

$$K = \left[ \alpha^\alpha \beta^{1-\alpha} \frac{p}{w^\alpha r^{1-\alpha}} \right]^{\frac{1}{1-\alpha-\beta}}.$$

Now let us assume that agricultural land generates a domestic public good in the form of amenity benefits, for which society has a constant marginal willingness to pay. The social optimum can be found by maximizing the following welfare function:

(4)  $W = \Pi + CS + \gamma L$,

where $\gamma$ is the constant marginal willingness to pay for landscape amenity. $CS$ is consumer surplus, which is constant since the agricultural good can be freely imported or exported at the world market price $p$.

Assuming now that $p = w = r = 1$, we use the competitive, free trade, no subsidy case as a point of reference:

$$\Pi_{MAX}$$
$$Y' = \left[ \alpha^\alpha \beta^\beta \right]^{\frac{1}{1-\alpha-\beta}}$$

$$L' = \left[ \alpha^{1-\beta} \beta^\beta \right]^{\frac{1}{1-\alpha-\beta}}$$

(5)
$$K' = \left[ \alpha^\alpha \beta^{1-\alpha} \right]^{\frac{1}{1-\alpha-\beta}}$$

$$\frac{Y'}{L'} = \frac{1}{\alpha}$$

$$\frac{K'}{L'} = \frac{\beta}{\alpha}.$$

The welfare optimum is characterized by:

$$W_{MAX} \qquad Y* = \left[ \alpha^\alpha \beta^\beta \frac{1}{(1-\gamma)^\alpha} \right]^{\frac{1}{1-\alpha-\beta}} > Y'$$

$$L* = \left[ \alpha^{1-\beta} \beta^\beta \frac{1}{(1-\gamma)^{1-\beta}} \right]^{\frac{1}{1-\alpha-\beta}} > L'$$

(6)
$$K* = \left[ \alpha^\alpha \beta^{1-\alpha} \frac{1}{(1-\gamma)^\alpha} \right]^{\frac{1}{1-\alpha-\beta}} > K'$$

$$\frac{Y*}{L*} = \frac{1-\gamma}{\alpha} < \frac{Y'}{L'}$$

$$\frac{K*}{L*} = \frac{\beta(1-\gamma)}{\alpha} < \frac{K'}{L'}.$$

Comparing (6) with (4) and (5), we see that the welfare optimum can be achieved in a competitive setting by using a Pigouvian subsidy, $s_L = \gamma$, per unit of land. We also see that the welfare optimum requires higher production of the agricultural good and greater land use, but lower production per unit of land than the no-subsidy case. The welfare optimum also requires greater use of capital, but lower capital intensity than the competitive (no-subsidy) case.

In this model the absolute and relative PSEs are:

$$W_{MAX} \qquad PSE* = \gamma L* = \gamma \left[ \alpha^{1-\beta} \beta^\beta \frac{1}{(1-\gamma)^{1-\beta}} \right]^{\frac{1}{1-\alpha-\beta}}$$

(7)
$$\%PSE* = \frac{\gamma L*}{Y* + \lambda L*} = \frac{\alpha\gamma}{1 - \gamma + \alpha\gamma}$$

We now define a measure of trade distortion as the relative difference between production of the agricultural good under no support and with the subsidy.

(8)
$$TD* = \frac{Y*}{Y'} - 1 = \left[ \frac{1}{1-\gamma} \right]^{\frac{\alpha}{1-\alpha-\beta}} - 1 > 0$$

where $TD*$ is the level of trade distortion with respect to the welfare optimum, increasing in $\gamma$. [2]

Now consider the case where agricultural support is proportional to production and the subsidy rate is $s_Y$. This gives the following solution:

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[2] While theoretically sound, an exact measure of trade distortion may be difficult to calculate in practice given that both consumption and production may change and that there can be reversals in net trade. In the empirical example used in the paper we employ an index of changes in production as a proxy measure for trade distortion.

$$s_Y > 0 \qquad \hat{Y} = \left[\alpha^\alpha \beta^\beta (1+s_Y)^{\alpha+\beta}\right]^{\frac{1}{1-\alpha-\beta}} > Y'$$

$$\hat{L} = \left[\alpha^{1-\beta} \beta^\beta (1+s_Y)\right]^{\frac{1}{1-\alpha-\beta}} > L'$$

$$\hat{K} = \left[\alpha^\alpha \beta^{1-\alpha} (1+s_Y)\right]^{\frac{1}{1-\alpha-\beta}} > K'$$

$$\frac{\hat{Y}}{\hat{L}} = \frac{1}{\alpha(1+s_Y)} < \frac{Y'}{L'}$$

(9)

$$\frac{\hat{K}}{\hat{L}} = \frac{\beta}{\alpha} = \frac{K'}{L'} > \frac{K^*}{L^*}$$

$$\widehat{PSE} = s_Y \hat{Y} = s_Y \left[\alpha^\alpha \beta^\beta (1+s_Y)^{\alpha+\beta}\right]^{\frac{1}{1-\alpha-\beta}}$$

$$\%\widehat{PSE} = \frac{s_Y \hat{Y}}{(1+s_Y)\hat{Y}} = \frac{s_Y}{(1+s_Y)}$$

$$\hat{TD} = (1+s_Y)^{\frac{\alpha+\beta}{1-\alpha-\beta}} - 1.$$

In order to compare this to the welfare optimum we set the subsidy rate such that $\hat{L} = L^*$. It then follows from (8) and (9) that:

(10) $\qquad (1+s_Y) = (1-\gamma)^{\beta-1}$ , $\quad s_Y = (1-\gamma)^{\beta-1} -1$ and $\quad \dfrac{s_Y}{(1+s_Y)} = 1-(1-\gamma)^{1-\beta}$,

(11) $\qquad \widehat{PSE} - PSE^* = s_Y \hat{Y} - \gamma L^* = \left[\dfrac{s_Y}{\alpha(1+s_Y)} - \gamma\right]L^* = \left[\dfrac{1-(1-\gamma)^{1-\beta}}{\alpha} - \gamma\right]L^* > 0.$

As this difference is increasing in γ it must always be positive:

(12) $\qquad \%\widehat{PSE} - \%PSE^* = 1-(1-\gamma)^{1-\beta} - \dfrac{\alpha\gamma}{1-\gamma(1-\alpha)}.$

From (12) we see that the size of the relative PSE in the product support case compared to the area support case is indeterminate. The sign depends on willingness to pay ($\gamma$), the scale elasticity ($\alpha+\beta$), the distribution parameter, that is the relative values of $\alpha$ and $\beta$, and, in the more general CES case, on the elasticity of substitution. This is illustrated in Figure 1. For a distribution parameter equal to 0.1 and a scale elasticity of 0.99, that is $\alpha=0.099$ and $\beta=0.891$, we have computed:

$$\frac{\%PSE^*}{\%\widehat{PSE}}$$

for various values of the willingness to pay ($\gamma$) – given on the horizontal axis. For the Cobb-Douglas case we see that for low $\gamma$ the ratio of the %PSE (on the vertical axis) is lower for area support. For $\gamma$ in excess of 0.2 the opposite is the case. In addition we graph the results for a low elasticity of substitution of 0.5, and a high elasticity of substitution of 2. The two curves are based on the CES derivations in the appendix. Again we see that the ratio of the

%PSE is lower for area support when $\gamma$ is low. The critical value of $\gamma$ increases with the substitution elasticity.

Figure 1: Relative %PSE for area support compared to product support
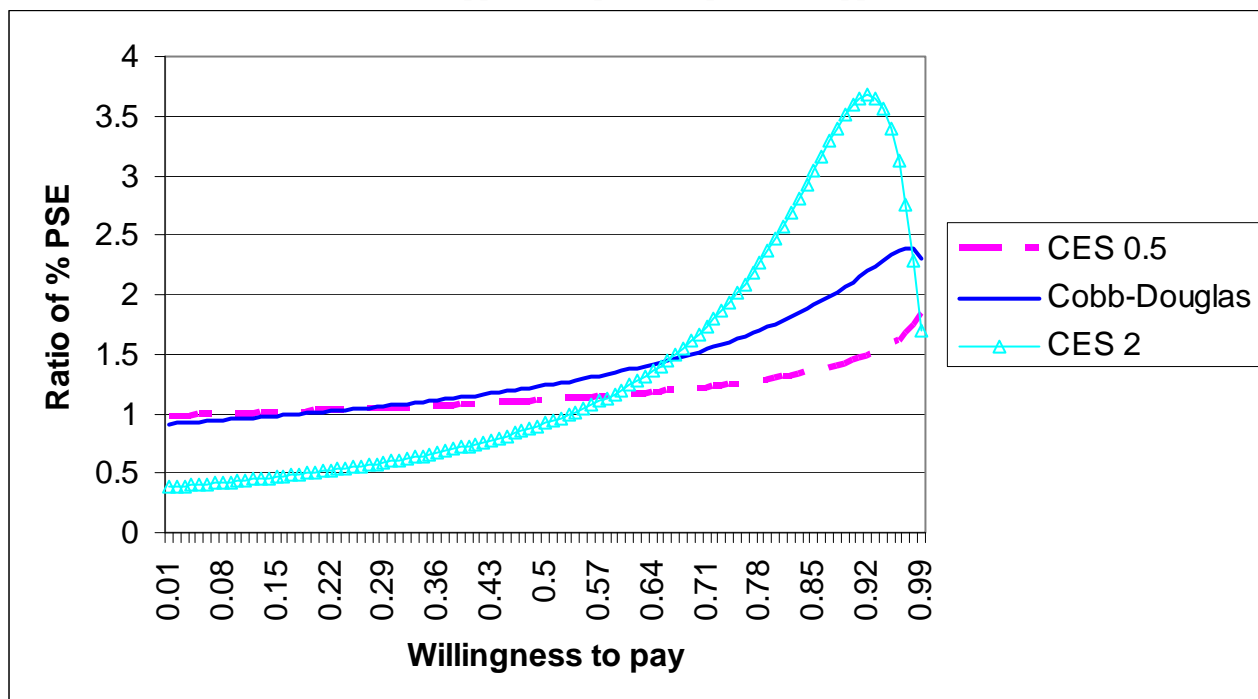


For the trade distortion we have that:

$$\widehat{TD} - TD^* = (1+s_Y)^{\frac{\alpha+\beta}{1-\alpha-\beta}} - \left[\frac{1}{1-\gamma}\right]^{\frac{\alpha}{1-\alpha-\beta}} = \left[\frac{1}{1-\gamma}\right]^{\frac{(1-\beta)(\alpha+\beta)}{1-\alpha-\beta}} - \left[\frac{1}{1-\gamma}\right]^{\frac{\alpha}{1-\alpha-\beta}}$$

13)

$$= \left[\frac{1}{1-\gamma}\right]^{\frac{\alpha+\beta(1-\alpha-\beta)}{1-\alpha-\beta}} - \left[\frac{1}{1-\gamma}\right]^{\frac{\alpha}{1-\alpha-\beta}} > 0$$
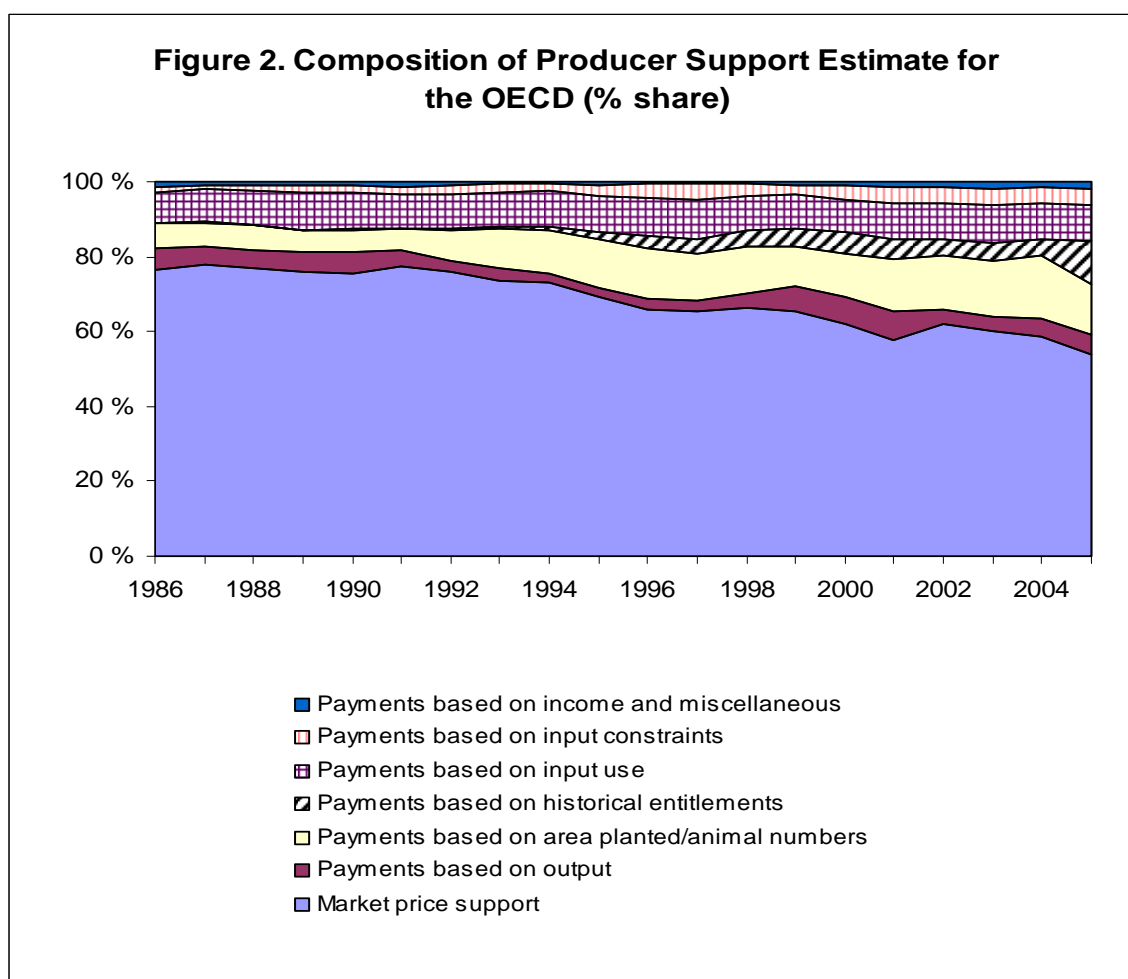
since $\alpha + \beta > 0$.

It follows that it is possible that a switch from a suboptimal (production subsidy) to an optimal (input subsidy) policy may well lead to an increase in the relative PSE rather than a decrease. This is more likely the more closely external effects from agriculture are tied to some, but not all, inputs rather than to production and the lower the elasticity of substitution among inputs. Simulations of such policy changes using a model for the Norwegian agricultural sector, discussed below, seem to indicate that this is a realistic possibility.

Tangermann (2005) argues that even if the overall PSE figures cannot be interpreted as an indicator of policy misconduct, the OECD breakdown of the PSE into various categories provides additional information for assessing existing policies and the impact of reform. Of the total PSE for the OECD area in 2005 more than three quarters was in the form of market price support (that is associated with border protection), payments based on production, and payments based on input use (Figure 2). Another fifth was based on area planted, animal numbers, or historical entitlements. Based on such data Tangermann

concludes: "for the OECD area overall, less than 5% of the PSE is currently in a form that may potentially be targeted to specific public goods." (Tangermann 2005, p. 11).

While we agree that a breakdown of the PSE figures into sub categories can help in assessing policy reforms, we have problems with the sweeping conclusion above. The sub categories of support seem naturally to fall in three groups: that varying directly with production, like market price support and payments based on output, that indirectly related to production, like support based on area planted, animal numbers and input use, and that completely decoupled from production. Tangermann seems to assert that Pigouvian subsidies may only be included in the third group.



**Figure 2. Composition of Producer Support Estimate for the OECD (% share)**

- Payments based on income and miscellaneous
- Payments based on input constraints
- Payments based on input use
- Payments based on historical entitlements
- Payments based on area planted/animal numbers
- Payments based on output
- Market price support

*Source: OECD PSE/CSE database (2005).*

In the final part of the paper we use Norway to provide empirical examples of the impact of changes in policy on the PSE as well as a range of domestic indicators, such as production, land use, employment, and domestic welfare (economic surplus). Norway is particularly well suited to serve as an example in this respect. In 2005 its relative PSE was 64%, a figure exceeded only by Switzerland (68%) and Iceland (67%). Norway's agricultural policies are often criticised as being trade distorting and far from optimal (e.g., Lamy, 2007). We use a numerical model of the Norwegian agricultural sector to simulate the effects of two

policy alternatives - reorientation to the production of public goods and to the elimination of subsidized exports.

## 3. Model simulations

Our analysis is based on a price-endogenous model of the Norwegian agriculture described in appendix 2. The model covers the most important commodities produced by the Norwegian agricultural sector, in all 13 final and 8 intermediate product aggregates. The model is based on the maximization of economic surplus.

In what follows we use the model to show how production and trade vary with the agricultural policy pursued. The first example examines a policy exclusively targeted to the provision of agricultural public goods through the payment of input-based subsidies (primarily on land). The second example focuses on the elimination of production surpluses and subsidized exports. In this case, structural change is permitted and production is achieved at the lowest domestic cost through a move to larger farms and the relocation to the most productive agricultural land.

As a basis for comparison, column 1 in Table 1 presents the model's representation of the existing policy in 1998. In spite of climatic disadvantages[3], production was high and imports were low. Norway is self-sufficient in most of the products listed. For dairy products there is a surplus and the equivalent of roughly 12% of domestic milk production is disposed of through subsidized exports of cheese. The Arctic climate does not permit sufficient production of high-quality grain for bread-making, so roughly half of the wheat used domestically is imported. Agricultural production is generally intensive (with high use of purchased inputs) but takes place on relatively small farms in most parts of Norway.

As may be seen, the present policy is costly. The total PSE for Norway is NOK 20 billions (roughly US$ 3.7 billlion at current exchange rates) and equals 71 % of the value of production at the farm level. Divided by employment and land area support is NOK 250,000 ($46,000) per full-time equivalent worker (FTE)and NOK 20,000 ($3,700) per hectare. A break-down of the PSE into various categories, shows that about 50% of the support is in the form of market price support, generated by import tariffs that range from 300 – 500 % and export subsidies. The rest of the support is through payments based on output (15%), area planted or animal numbers (12%) and input use (25%).

The final row in Table 1 contains an index of distortion associated with current policy. This index is defined as the ratio of the current value of agricultural production valued at world market prices to the value of production under free trade. This indicates that

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[3]For example, on average, wheat and potato yields are about 60% of the levels achieved in central Europe.

production is roughly three times larger under the current support policy in Norway than would be the case under free trade.[4]

Most of the support under the current policy is currently attached to the production of private goods. Even the support that is linked to land, animals or other inputs is only targeted to the provision of public goods to a minor degree, e.g., through requirements for landscape preservation or restrictions on agricultural production practices. Therefore, the present policy is weakly targeted to sources of market failure.

The implications of a policy exclusively aimed at the provision of public goods are illustrated in Column 2 of Table 1, following an approach by Brunstad *et al.* (1999, 2005). In this case, the amenity value of the agricultural landscape is taken into account by incorporating information on willingness to pay, as inferred from contingent valuation studies, in the objective function of the model. On the basis of these studies, the amenity value is higher for grazing and pasture than for tilled land, and the marginal willingness to pay diminishes with increased agricultural activity.

As the results show, when public good provision is the policy aim, agricultural production and employment fall substantially, but a large proportion of land remains in production (64% of the base level solution). A switch towards land-intensive production techniques takes place, represented by extensive sheep meat production. The total PSE falls to roughly 40% of the current level, but as a percentage of the production value support increases from 60% to 67%. This shows that the percentage PSE is not a good indicator of how welfare or trade is affected by the change in policy. In this scenario support is exclusively tied to factors related to the public goods (land, labor and livestock). No market price support or deficiency payments are used. Because of technological interlinkages, production and trade are affected, but to a far lesser extent than under current policies. As a result the index of distortion shows some positive effect of the policy since production is 8% higher than under free trade in the absence of support.

Column 3 of Table 1 shows the results of eliminating subsidized dairy exports (cheese), i.e., a policy oriented to the elimination of the most visible trade distortion. Under this scenario, which relies heavily on the use of direct output subsidies, structural change increases efficiency. The results indicate that current production for the domestic market (the elimination of export surpluses) can be sustained with only 40% of the present employment and 90% of the land. Production takes place on substantially larger farms, and relatively more of the production is concentrated in areas where the best land is located. Economic welfare is

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[4] Norwegian agricultural policies distort both production and consumption, as indicated by the market price support component of the PSE in the table. This index does not capture the additional distortion created through reduced consumption.

therefore considerably higher than in the base solution. Total support is about 40% lower, and the percentage PSE has been reduced from 60% to 50%.

However, because of the need to maintain production in this scenario support is completely tied to production (85% through deficiency payments and 15% through market price support), which means that only minor advances are made in reducing trade distortions. The index of distortion falls, but only from roughly 3.9 to 3.2 and is much higher than the public goods case. Compared to the public goods option, economic welfare is also lower. Although land use is higher, support is not targeted to the provision of public goods leading to more capital intensive and specialised production patterns. Consequently, in spite of a substantially lower percentage PSE, this policy is inferior to the public goods alternative, both with respect to welfare and to the reduction of trade distortions.

4. **Conclusions**

In this paper we have demonstrated that changes in the relative (percentage) PSE are not an accurate indicator of the implications of policy reform for domestic welfare or for trade distortions. It is important to consider the implications of changes in both the level and the form of subsidies in evaluating the impact of policy reform. The example of Norway shows that reforms oriented towards the provision of agricultural public goods, while apparently leading to an increase in relative support, are actually superior in terms of reducing trade distortions and increasing domestic economic welfare.

Table 1: Model results

| | Base (current policies) | Public goods | Elimination of subsidized exports |
|---|---|---|---|
| **Production** (mill. kg.) | | | |
| Milk | 1,672 | 710 | 1,400 |
| Beef and veal | 82 | 29 | 82 |
| Pig meat | 100 | 0 | 125 |
| Sheep meat | 23 | 30 | 23 |
| Poultry meat | 28 | 0 | 28 |
| Eggs | 44 | 10 | 44 |
| Wheat | 211 | 150 | 211 |
| Coarse grains | 1,021 | 339 | 1,021 |
| Potatoes | 298 | 312 | 298 |
| **Land use** (mill. hectares) | 0.9 | 0.5 | 0.7 |
| **Employment** (1000 person-years) | 60 | 18 | 25 |
| **Economic surplus** (billion NOK) | 14 | 24 | 12 |
| **PSE** (percentage) | 60% | 67% | 50% |
| **PSE** (billion NOK) | 15 | 6 | 9 |
| Market price support | 7 | 0 | 1 |
| Output support | 2 | 0 | 8 |
| Input support | 6 | 6 | 0 |
| **Index of distortion** | 388% | 108% | 324% |

Note: the index of distortion is actual production valued at world market prices relative to estimated production under free trade.

**APPENDIX 1:**

The following equations are numbered as in the main text. The CES production function is:

(1')  $$Y = \left(\alpha L^{\rho} + (1-\alpha)K^{\rho}\right)^{\lambda/\rho} \qquad \lambda < 1,\ \rho \le 1,$$

$\lambda$ is the scale parameter assumed to be less than one, i.e. decreasing returns to scale and $\rho$ is connected to the elasticity of substitution, $\sigma$, through:

$$\sigma = \frac{1}{1-\rho}.$$

It is useful to consider the following special cases:

    *(i)*      $\rho = 1$: linear production function

    *(ii)*      $\rho = 0$: Cobb Douglas, i. e., as in the main text

    *(iii)*      $\rho = -\infty$: Leontief production function.

The profit function is:

(2')  $$\Pi = pY - wL - rK,$$

and the supply and factor demand functions:

$$Y = (p\lambda)^{\lambda/1-\lambda}\left[\alpha^{1/1-\rho}w^{\rho/\rho-1} + (1-\alpha)^{1/1-\rho}r^{\rho/\rho-1}\right]^{(1-\rho)\lambda/(1-\lambda)\rho}$$

(3')  $$L = (p\lambda)^{1/1-\lambda}\left(\frac{\alpha}{w}\right)^{1/1-\rho}\left[\alpha^{1/1-\rho}w^{\rho/\rho-1} + (1-\alpha)^{1/1-\rho}r^{\rho/\rho-1}\right]^{(\lambda-\rho)/\rho(1-\lambda)}$$

$$K = (p\lambda)^{1/1-\lambda}\left(\frac{1-\alpha}{r}\right)^{1/1-\rho}\left[\alpha^{1/1-\rho}w^{\rho/\rho-1} + (1-\alpha)^{1/1-\rho}r^{\rho/\rho-1}\right]^{(\lambda-\rho)/\rho(1-\lambda)}.$$

If output and factor prices equal 1:

$$L' = (\lambda)^{1/1-\lambda}\alpha^{1/1-\rho}\left[\alpha^{1/1-\rho} + (1-\alpha)^{1/1-\rho}\right]^{(\lambda-\rho)/\rho(1-\lambda)}$$

$$K' = (\lambda)^{1/1-\lambda}(1-\alpha)^{1/1-\rho}\left[\alpha^{1/1-\rho} + (1-\alpha)^{1/1-\rho}\right]^{(\lambda-\rho)/\rho(1-\lambda)}$$

(5')  $$Y' = (\lambda)^{\lambda/1-\lambda}\left[\alpha^{1/1-\rho} + (1-\alpha)^{1/1-\rho}\right]^{(1-\rho)\lambda/(1-\lambda)\rho}$$

$$\frac{Y'}{L'} = \frac{1}{\lambda}\left(\frac{1}{\alpha}\right)^{1/1-\rho}\left[\alpha^{1/1-\rho} + (1-\alpha)^{1/1-\rho}\right]$$

$$\frac{K'}{L'} = \left(\frac{1-\alpha}{\alpha}\right)^{1/1-\rho}.$$

We refer to (5') as the perfectly competitive solution.

With a constant willingness to pay for landscape amenities, define as $\gamma$ per unit of land, $L$, the welfare optimum yields:

$$Y^* = (\lambda)^{\frac{2}{1-\lambda}}\left[\alpha^{\frac{1}{1-\rho}}(1-\gamma)^{\frac{\rho}{\rho-1}} + (1-\alpha)^{\frac{1}{1-\rho}}\right]^{\frac{(1-\rho)\lambda}{(1-\lambda)\rho}} > Y'$$

(6')
$$K^* = (\lambda)^{\frac{1}{1-\lambda}}(1-\alpha)^{\frac{1}{1-\rho}}\left[\alpha^{\frac{1}{1-\rho}}(1-\gamma)^{\frac{\rho}{\rho-1}} + (1-\alpha)^{\frac{1}{1-\rho}}\right]^{\frac{(\lambda-\rho)}{\rho(1-\lambda)}}$$

$$L^* = (\lambda)^{\frac{1}{1-\lambda}}\left(\frac{\alpha}{1-\gamma}\right)^{\frac{1}{1-\rho}}\left[\alpha^{\frac{1}{1-\rho}}(1-\gamma)^{\frac{\rho}{\rho-1}} + (1-\alpha)^{\frac{1}{1-\rho}}\right]^{\frac{(\lambda-\rho)}{\rho(1-\lambda)}} > L'$$

$$\frac{Y^*}{L^*} = \frac{1}{\lambda}\left(\frac{1-\gamma}{\alpha}\right)^{\frac{1}{1-\rho}}\left[\alpha^{\frac{1}{1-\rho}}(1-\gamma)^{\frac{\rho}{\rho-1}} + (1-\alpha)^{\frac{1}{1-\rho}}\right] < \frac{Y'}{L'}$$

$$\frac{K^*}{L^*} = \left(\frac{(1-\gamma)(1-\alpha)}{\alpha}\right)^{\frac{1}{1-\rho}} < \frac{K'}{L'}.$$

By comparing (6') and (5') we see that welfare optimum requires greater production of the agricultural good, greater land use, but lower production per land unit than the perfectly competitive case. If $\lambda > \rho$, the welfare optimum requires greater use of capital. but capital intensity is always lower than the perfectly competitive case.

The producer subsidy equivalent is given by:

$$PSE^* = \gamma L^* = \gamma(\lambda)^{\frac{1}{1-\lambda}}\left(\frac{\alpha}{1-\gamma}\right)^{\frac{1}{1-\rho}}\left[\alpha^{\frac{1}{1-\rho}}(1-\gamma)^{\frac{\rho}{\rho-1}} + (1-\alpha)^{\frac{1}{1-\rho}}\right]^{\frac{(\lambda-\rho)}{\rho(1-\lambda)}}$$

(7')

$$\%PSE^* = \frac{\gamma L^*}{Y^*} = \gamma\lambda\left(\frac{\alpha}{1-\gamma}\right)^{\frac{1}{1-\rho}}\left[\alpha^{\frac{1}{1-\rho}}(1-\gamma)^{\frac{\rho}{\rho-1}} + (1-\alpha)^{\frac{1}{1-\rho}}\right]^{-1}.$$

Since we have an increasing $\gamma$, this implies an increasing %PSE.

Our measure of trade distortion is:

(8')
$$TD^* = \frac{Y^*}{Y'} - 1 = \left[\frac{\alpha^{\frac{1}{1-\rho}}(1-\gamma)^{\frac{\rho}{\rho-1}} + (1-\alpha)^{\frac{1}{1-\rho}}}{\alpha^{\frac{1}{1-\rho}} + (1-\alpha)^{\frac{1}{1-\rho}}}\right]^{\frac{(1-\rho)\lambda}{(1-\lambda)\rho}} - 1.$$

Hence, an increasing $\gamma$ implies an increasing $TD^*$.

Subsidizing output instead of land yields:

$$\hat{L} = ((1+s_Y)\lambda)^{\frac{1}{1-\lambda}}(\alpha)^{\frac{1}{1-\rho}}\left[\alpha^{\frac{1}{1-\rho}} + (1-\alpha)^{\frac{1}{1-\rho}}\right]^{\frac{(\lambda-\rho)}{\rho(1-\lambda)}} > L'$$

$$\hat{K} = ((1+s_Y)\lambda)^{\frac{1}{1-\lambda}}(1-\alpha)^{\frac{1}{1-\rho}}\left[\alpha^{\frac{1}{1-\rho}} + (1-\alpha)^{\frac{1}{1-\rho}}\right]^{\frac{(\lambda-\rho)}{\rho(1-\lambda)}} > K'$$

(9')
$$\hat{Y} = ((1+s_Y)\lambda)^{\frac{2}{1-\lambda}}\left[\alpha^{\frac{1}{1-\rho}} + (1-\alpha)^{\frac{1}{1-\rho}}\right]^{\frac{(1-\rho)\lambda}{(1-\lambda)\rho}} > Y'$$

$$\frac{\hat{Y}}{\hat{L}} = \frac{1}{(1+s_Y)\lambda}\left[\alpha^{1/1-\rho} + (1-\alpha)^{1/1-\rho}\right] < \frac{Y'}{L'}$$

$$\frac{\hat{K}}{\hat{L}} = \left(\frac{1-\alpha}{\alpha}\right)^{1/1-\rho} = \frac{K'}{L'}$$

where $s_Y$ is the rate of output subsidy. In this case the PSE is:

$$P\hat{S}E = s_Y\hat{Y} = s_Y\left((1+s_Y)\lambda\right)^{\lambda/1-\lambda}\left[\alpha^{1/1-\rho} + (1-\alpha)^{1/1-\rho}\right]^{(1-\rho)\lambda/(1-\lambda)\rho}$$

and

$$\%P\hat{S}E = \frac{s_Y\hat{Y}}{(1+s_Y)\hat{Y}} = \frac{s_Y}{1+s_Y}\ .$$

We see that $\%P\hat{S}E$ is increasing in $s_Y$. The trade distortion is:

$$T\hat{D} = \frac{\hat{Y}}{Y'} - 1 = (1+s_Y)^{\lambda/1-\lambda},$$

and $T\hat{D}$ is also increasing in $s_Y$.

A comparison between the two cases, assuming

$$\hat{L} = L*,$$

yields:

$$\left(\frac{1}{1-\gamma}\right)^{1/1-\rho} = (1+s_Y)^{1/1-\lambda}\left[\frac{\alpha^{1/1-\rho} + (1-\alpha)^{1/1-\rho}}{\alpha^{1/1-\rho}(1-\gamma)^{\rho/\rho-1} + (1-\alpha)^{1/1-\rho}}\right]^{\frac{(\lambda-\rho)}{(1-\lambda)\rho}} \ .$$

It now follows that $s_Y$ must be set such that:

$$(10')\quad s_Y = \left(\frac{1}{1-\gamma}\right)^{(1-\lambda)/(1-\rho)}\left[\frac{\alpha^{1/1-\rho}(1-\gamma)^{\rho/\rho-1} + (1-\alpha)^{1/1-\rho}}{\alpha^{1/1-\rho} + (1-\alpha)^{1/1-\rho}}\right]^{(1-\lambda)(\lambda-\rho)/(1-\lambda)\rho} - 1$$

and

(11)

$$P\hat{S}E - PSE* = s_Y\hat{Y} - \gamma L* =$$

$$s_Y\left((1+s_Y)\lambda\right)^{\lambda/1-\lambda}\left[\alpha^{1/1-\rho} + (1-\alpha)^{1/1-\rho}\right]^{(1-\rho)\lambda/(1-\lambda)\rho} - \gamma(\lambda)^{1/1-\lambda}\left(\frac{\alpha}{1-\gamma}\right)^{1/1-\rho}\left[\alpha^{1/1-\rho}(1-\gamma)^{\rho/\rho-1} + (1-\alpha)^{1/1-\rho}\right]^{(\lambda-\rho)/\rho(1-\lambda)}$$

and furthermore that:

$$\%P\hat{S}E - \%PSE* = \frac{s_Y}{1+s_Y} - \gamma\lambda\left(\frac{\alpha}{1-\gamma}\right)^{1/1-\rho}\left[\alpha^{1/1-\rho}(1-\gamma)^{\rho/\rho-1} + (1-\alpha)^{1/1-\rho}\right]^{-1},$$

where $s_Y$ is given by (10').

**Appendix 2**

The model is a partial equilibrium model of the Norwegian agricultural sector. For given input costs and demand functions, market clearing prices and quantities are computed. Prices of goods produced outside the agricultural sector or abroad are taken as given. As the model assumes full mobility of labor and capital, it must be interpreted as a long run model.

The model covers the most important products produced by the Norwegian agricultural sector, in all 14 final and 9 intermediate products. Most products in the model are aggregates. Primary inputs are: land (four different grades), labor (family members and hired), capital (machinery, buildings, and livestock) and other inputs (fertilizers, fuel, seeds, etc.). The prices of inputs are determined outside the model and treated as given.

Supply in the model is domestic production and imports. Domestic production takes place on approximately 400 different "model farms". The farms are modeled with fixed input and output coefficients, based on data from extensive farm surveys carried out by the Norwegian Agricultural Economics Research Institute, a research body connected to the Norwegian Ministry of Agriculture. Imports take place at given world market prices inclusive of tariffs and transport costs. Domestic and foreign products are assumed to be perfect substitutes. The country is divided into nine production regions, each with limited supply of the different grades of land. This regional division allows for variation in climatic and topographic conditions and makes it possible to specify regional goals and policy instruments. The products from the model farms go through processing plants before they are offered on the market. The processing plants are partly modeled as pure cost mark-ups (meat, eggs and fruit), and partly as production processes of the same type as the model farms (milk and grains).

The domestic demand for final products is represented by linear demand functions. These demand functions are based on existing studies of demand elasticities, and are linearized to pass through the observed price and quantity combination in the base year (1998). Between the meat products there are cross price effects, but only own price effects are assumed for other products. The demand for intermediate products is derived from the demand for the final products for which they are inputs. Exports take place at given world market prices.

Domestic demand for final products is divided among 5 separate demand regions, which have their own demand functions. Each demand region consists of one or several production regions. If products are transported from one region to another, transport costs are incurred. For imports and exports transport costs are incurred from the port of entry and to the port of shipment, respectively. In principle restrictions can be placed on all variables in the model. The restrictions that we include can be divided into two groups:

(1)     Scarcity restrictions: upper limits for the endowment of land, for each grade of land in each region.

(2)      Political restrictions: lower limits for land use and employment in each region, for groups of regions (central regions and remote areas), or for the country as a whole; maximum or minimum quantities for domestic production, imports or exports; maximum prices.

In the model, economic surplus (consumers' plus producers' surplus) of the agricultural sector is maximized. This maximization is performed subject to demand and supply relationships and the imposed restrictions. Which restrictions are included depends upon what kind of simulation that is attempted. The solution to the model is found as the prices and quantities that give equilibrium in each market. No restrictions can be violated, and no model farm or processing plant that is active, runs at a loss.

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