Econometric Analysis of the Effects of Subsidies on Farm Production in Case of Endogenous Input Quantities

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Abstract

The effect of subsidies on farm production has been a major topic in agricultural economics for several decades. We present a new approach for analyzing the effects of different types of coupled and decoupled subsidies on farm production with econometric methods. In contrast to most previous studies, our approach is entirely based on a theoretical microeconomic model, explicitly allows subsidies to have an impact on input use, and takes linkages between the farm and the farm household into account.

Introduction

Most industrialized countries pay agricultural subsidies to increase the incomes of their farmers. The main argument for these subsidies is that without some financial supports from the government, domestic farmers would not be able to compete with foreign imports. Removing subsidies would therefore increase the income gap between rural and urban areas and drive domestic farmers out of farming. The loss of the domestic farming industry is often seen as undesirable on a variety of grounds, including increases of unemployment and loss of a traditional way of life. Furthermore, a country that is not self sufficient in food production may be more vulnerable to trade pressure and global food crises.

Subsidies paid to farmers can be coupled to the production of outputs or to the use of inputs (e.g. land, fuel) or can be fully decoupled. The effect of these subsidies on farm production has been a major topic in agricultural economics for several decades. For instance, researchers and (some) politicians would like to know whether the subsidies have indeed the intended effects and if there are undesirable side effects. Furthermore, the effects of different types of subsidies on farm production determine their trade-distorting effects and hence, are important in the World Trade Organization (WTO) negotiations. Only subsidies that have no, or at most a minimal effect on farm production and hence, do not distort trade are in the so-called "green box," which means that they are allowed without limitations.

Studies that quantitatively analyze the effects of agricultural subsidies use either programming models or econometric methods. Both modeling strategies have pros and cons. In this study we use an econometric approach, because it has several important advantages compared to usual programming models. For instance, it does not require detailed *a priori* information on the production technology and does not rely on profit maximization behavior, which is questionable for small family farms with close linkages between the farm and the household.

Most previous econometric studies analyze either the effects of subsidies on time allocation (e.g. Mishra and Goodwin 1997; El-Osta et al. 2004; Ahearn et al. 2006; Dewbre and Mishra 2007), on productivity (e.g. Guan and Oude Lansink 2006; Bezlepkina and Oude Lansink 2006; Skuras et al. 2006; McCloud and Kumbhakar 2008), or on efficiency (e.g. Piesse and Thirtle 2000; Giannakas et al. 2001; Karagiannis and Sarris 2005; Hadley 2006; Kleinhanß et al. 2007), or analyze the transfer efficiency of subsidies (e.g. Dewbre and Mishra 2007). The empirical specifications used in these studies model subsidies rather *ad hoc*, e.g. they estimate reduced-form equations or treat subsidies as inputs, facilitating inputs, or as factors influencing efficiency in a production function. Furthermore, these approaches generally use input quantities and the total amount of received subsidies as regressors, but do not account for the endogeneity of these variables, although theoretical microeconomic models and practical experience suggest that coupled subsidies (and eventually also decoupled subsidies) have an impact on input use and the amount of coupled subsidies received by the farmer depends on production decisions. Hence, the estimation results presented in these studies are likely biased by the well-known simultaneity bias. In contrast, our approach is entirely based on a theoretical microeconomic model, takes linkages between farm and farm household into account, and allows for endogeneity of input quantities and of the amount of received subsidies. With our approach, we can also analyze if the linkages between the farm and the household are so close that decoupled payments have an impact on farm production.

Theoretical Model

Standard microeconomic firm model

As a start, we assume that standard assumptions of microeconomic theory hold, i.e. all markets are perfect, all goods are homogeneous, and farm profit is maximized:

$$(1) \quad \max_{L,x_V} (P_Y + S_Y)Y - LP_L - (p_X - s_X)' x_V + S_D - C_F, \text{s.t.}$$

$$(2) \quad Y = f^F(L, x_V, x_F, z_F)$$

The farm profit depends on the output price (P_Y), coupled subsidies per unit of output (S_Y), the output quantity (Y), the amount of labor deployed on the farm (L), the price of labor (P_L), a vector of prices of n other variable inputs (p_X), a vector of coupled subsidies per unit of the variable inputs (s_X), a vector of variable input quantities (x_V), the amount of fixed decoupled subsidies (or subsidies coupled to fixed inputs) (S_D), and fixed costs (C_F). The production function of the farm $f^F(.)$ in (2) relates the output quantity (Y) to the amount of labor deployed on the farm (L), a vector of variable input quantities (x_V), a vector of fixed input quantities (x_F), and a vector of farm characteristics influencing farm production (e.g. soil quality, farm manager's (agricultural) education) (z_F).

Applying the Lagrange approach to the maximization problem in equations 1–2, we can see that labor input (L) and other the variable input quantities (x_V) depend on the effective output price $(P_Y^* = P_Y + S_Y)$, the price of labor (P_L), the effective prices of other variable inputs $(p_X^* = p_X - s_X)$, the quantities of fixed inputs (x_F), and farm characteristics (z_F):

$$(3) \quad L = g_L^F(P_Y^*, P_L, p_X^*, x_F, z_F)$$

$$(4) \quad X_{Vi} = g_i^F(P_Y^*, P_L, p_X^*, x_F, z_F) \; \forall \, i = 1, \ldots, n$$

These input demand functions are homogeneous of degree zero in all effective prices (P_Y^*, P_L, p_X^*).

Based on this model, we can calculate the effects of different types of subsidies (S_Y, s_X, S_D) on farm labor use (L), variable input quantities (x_V), output quantity (Y), and farm profit $(\pi = P_Y^* Y - LP_L - p_X^{*\prime} x_V + S_D - C_F)$.[1]

(5) $$\frac{\partial L}{\partial (S_Y, s_X)} = \frac{\partial g_L^F(.)}{\partial (P_Y^*, -p_X^*)}$$

(6) $$\frac{\partial X_{Vi}}{\partial (S_Y, s_X)} = \frac{\partial g_i^F(.)}{\partial (P_Y^*, -p_X^*)} \; \forall \, i = 1, \ldots, n$$

(7) $$\frac{\partial Y}{\partial (S_Y, s_X)} = \frac{\partial f^F(.)}{\partial L} \frac{\partial L}{\partial (S_Y, s_X)} + \sum_{i=1}^{n} \frac{\partial f(.)^F}{\partial X_{Vi}} \frac{\partial X_{Vi}}{\partial (S_Y, s_X)}$$

(8) $$\frac{\partial \pi}{\partial (S_Y, s_X)} = (Y, x_V) + P_Y^* \frac{\partial Y}{\partial (S_Y, s_X)} - P_L \frac{\partial L}{\partial (S_Y, s_X)} - \sum_{i=1}^{n} P_{Xi}^* \frac{\partial X_{Vi}}{\partial (S_Y, s_X)}$$

(9) $$\frac{\partial (L, x_V, Y, \pi)}{\partial S_D} = (0, 0, \ldots, 0, 1)$$

It is obvious from equation (9) that the transfer efficiency of decoupled payments (S_D) is 100%, which means that each monetary unit payed as decoupled subsidy increases farm profit (π) by exactly one monetary unit.

Farm household model

In contrast to the assumptions of the model above, most farms are no usual enterprises but small family farms with close linkages to the household. Furthermore, labor is mostly not a homogeneous good and the labor market is often plagued by market imperfections. For instance, family labor and hired labor might have different marginal products on the farm (e.g. Lopez 1984; Eswaran and Kotwal 1986; Frisvold 1994), the usual wages for farm labor and off-farm labor might be different (e.g. Sadoulet et al. 1998), household members might have different preferences for farm work and off-farm work (e.g. Lopez 1984), and the household might not be able to supply any desired quantity of labor to the labor market at a given fixed wage level (e.g. Henning and Henningsen 2007). We

[1]The derivation of these effects is based on the assumption of a "small and open economy," i.e. subsidies have no effect on (world and internal) market prices. If this assumption is not fulfilled, the indirect effects of subsidies through changes of market prices have to be added to the following formulas.

present a farm household model (Lopez 1984; Singh et al. 1986; Strauss 1986) that accounts for all the above-mentioned departures from traditional microeconomic theory. The farm household is assumed to maximize utility subject to a time, budget, technology, and off-farm income constraint. Therefore, farm households solve the following maximization problem:

(10) $\max_{L_F, L_W, L_H, x_V, c} U(c, L_F, L_W, L_L, z_H)$, s.t.

(11) $L_L = L_T - L_F - L_W$

(12) $p_C\, c = (P_Y + S_Y)Y - P_L L_H - (p_X - s_X)' x_V + S_D - C_F + M_W + M_Z$

(13) $Y = f^H(L_F, L_H, x_V, x_F, z_F)$

(14) $M_W = f_W(L_W, z_H, z_L)$

The utility function $U(.)$ in (10) depends on a vector of consumption quantities (c), household members' work hours on their farm (L_F), household members' work hours outside their farm (L_W), time for leasure (L_L), and a vector of household characteristics (e.g. number of children) (z_H). This specification allows for different preferences regarding farm work (L_F) and non-farm work (L_W) by allowing L_F and L_W to have different effects on utility. The household faces a time constraint (11), where L_T is the household members' total time available. The budget constraint (12) states that the household's consumption expenditures $(p_C\, c)$ must not exceed its monetary income (right-hand side), where L_H is the quantity of hired labor, P_L is the price of (hired) farm labor, M_W is the households income from work outside their farm, and M_Z is exogenous household income (e.g. from capital). The production function of the farm $f^H(.)$ is shown in (13), where the total amount of farm labor (L) is separated into household members' farm work (L_F) and hired farm labor (L_H), where $L = L^F + L^H$. Finally, $f_W(.)$ in (14) relates income from off-farm work (M_W) to household members' off-farm work (L_W), a vector of household characteristics (e.g. education) (z_H), and a vector of labor market characteristics (e.g. regional wage rate) (z_L).

Applying the Lagrange approach to the maximization problem in equations 10–14, we can see that the labor input quantities (L_F, L_H) and the other variable input quantities $(X_{V1}, \ldots, X_{Vn})$ depend on the same variables as in the previous model (3–4) and additionally on total fixed income $(M_Z^* = M_Z + S_D - C_F)$, total time available of the household members (L_T), household characteristics (z_H), and labor market characteristics (z_L):

$$(15) \quad L_F = g_F^H\left(P_Y^*, P_L, p_X^*, x_F, z_F, M_Z^*, L_T, z_H, z_L, p_C\right)$$

$$(16) \quad L_H = g_H^H\left(P_Y^*, P_L, p_X^*, x_F, z_F, M_Z^*, L_T, z_H, z_L, p_C\right)$$

$$(17) \quad X_{Vi} = g_i^H\left(P_Y^*, P_L, p_X^*, x_F, z_F, M_Z^*, L_T, z_H, z_L, p_C\right) \; \forall \, i = 1, \ldots, n$$

These input demand functions are homogeneous of degree zero in all (effective) prices and exogenous income $(P_Y^*, P_L, p_X^*, M_Z^*, p_C)$.

Based on this farm household model, we can calculate the effects of different types of subsidies (S_Y, s_X, S_D) on family labor on the farm (L_F), hired labor (L_H), variable input quantities (x_V), the output quantity (Y), and income from farming $(M_F = P_Y^* Y - P_L L_H - p_X^{*\prime} x_V + S_D - C_F)$.

$$(18) \quad \frac{\partial L_F}{\partial(S_Y, s_X, S_D)} = \frac{\partial g_F^H(.)}{\partial(P_Y^*, -p_X^*, M_Z^*)}$$

$$(19) \quad \frac{\partial L_H}{\partial(S_Y, s_X, S_D)} = \frac{\partial g_H^H(.)}{\partial(P_Y^*, -p_X^*, M_Z^*)}$$

$$(20) \quad \frac{\partial X_{Vi}}{\partial(S_Y, s_X, S_D)} = \frac{\partial g_i^H(.)}{\partial(P_Y^*, -p_X^*, M_Z^*)} \; \forall \, i = 1, \ldots, n$$

$$(21) \quad \frac{\partial Y}{\partial(S_Y, s_X, S_D)} = \frac{\partial f^H(.)}{\partial L_F} \frac{\partial L_F}{\partial(S_Y, s_X, S_D)} + \frac{\partial f^H(.)}{\partial L_H} \frac{\partial L_H}{\partial(S_Y, s_X, S_D)} + \sum_{i=1}^{n} \frac{\partial f^H(.)}{\partial X_{Vi}} \frac{\partial X_{Vi}}{\partial(S_Y, s_X, S_D)}$$

$$(22) \quad \frac{\partial M_F}{\partial(S_Y, s_X, S_D)} = (Y, x_V, 1) + P_Y^* \frac{\partial Y}{\partial(S_Y, s_X, S_D)} - P_L \frac{\partial L_H}{\partial(S_Y, s_X, S_D)}$$

$$-\sum_{i=1}^{n} P_{Xi}^{*} \frac{\partial X_{Vi}}{\partial (S_Y, s_X, S_D)}$$

Equation (22) shows that the transfer efficiency of decoupled payments (S_D) is not necessarily 100%, if linkages between the farm and the household and heterogeneity of labor are taken into account.

Data and Empirical Specification

This study is based on data from the Norwegian Farm Accountancy Survey. This is an unbalanced set of farm-level panel data collected by the Norwegian Agricultural Economics Research Institute (NILF). It includes farm production and economic household data collected annually from about 1000 farms, divided between different regions, farm size classes and types of farms. Participation in the survey is voluntary. There is no limit to the number of years a farm may be included in the survey. Approximately 10% of the survey farms are replaced every year. The farms are classified according to their main category of farm product, defined in terms of the standard gross margins of the farm enterprises. Small holdings are somewhat under-represented and large farms are slightly over-represented in the survey sample. The data set used in the analysis is an unbalanced panel with 1616 observations on 184 grain farms from 1991 to 2006. Only those farms for which at least three years of data were available are included in the analysis. In the sample used, the average duration of farms in the survey was 8.8 years. Grain farms usually produce several types of grains (wheat, barley, oats etc.), and should have little (if any) farm activities besides grain farming.

For the econometric estimation of the model described above, we approximate the unknown true production functions (2) and (13) by second-order flexible translog functions:

$$(23) \quad \log Y = f^Q \left(\log L, \log X_V, \log x_F; z_F; \beta_Y^F \right)$$

$$(24) \quad \log Y = f^Q \left(\log(L_F + L_H), \log X_V, \log x_F; z_F, \frac{L_H}{L_F + L_H}; \beta_Y^H \right)$$

For simplification, $f^Q(x^q;x^l;\beta)$ denotes a function that is quadratic in x^q, linear in x^l, and has parameters β. In the above equations, β_Y^F and β_Y^H are vectors of unknown parameters. The effective output price (P_Y^*) is a regional price index for grain; the output quantity (Y) is the value of all outputs divided by P_Y^*. Labor quantities (L, L_F, L_H) are measured in 1000 hours. The price of hired farm labor (P_L) consists of regional mean prices of agricultural labor in NOK per hour. We have identified two fixed inputs (x_F): land and capital. Land is measured in ha and capital is approximated by annual depreciations deflated by a general price index. All other inputs are assumed to be variable and are aggregated to a composite intermediate input, because most components are highly correlated (e.g. seed, fertilizer, pesticides, fuel). The effective price of the composite intermediate (P_V^*) is a price index of these inputs. The quantity of the intermediate inputs (X_V) is calculated by dividing the expenditures on these inputs by P_V^*. Farm characteristics (z_F) include share of arable land, experience of the farm manager in years, and regional dummy variables (for three of the four regions). We do not take the logarithms of these variables and include them as shifters of the production function. Finally, we include a time trend in the production functions to account for technical progress. The specification of family members' farm work (L_F) and hired farm work (L_H) in the production function of the household model (24) has the advantage that the production function of the traditional firm model (23) is a special case. Hence, the homogeneity of the labor inputs (L_F, L_H) can be easily checked by testing if the coefficient of $L_H/(L_F+L_H)$ significantly differs from zero.

Since no closed-form solutions of the input demand equations (3–4, 15–17) based on translog production functions exist, we approximate the true input demand functions by quadratic equations.[2]

$$L = f^Q\left(P_Y^*, P_L, p_X^*, x_F; z_F; \beta_L^F\right) \quad (25)$$

[2]Since total fixed income (M_Z^*) and household's net assets (part of z_H, see below) are negative for some farm households and the logarithm of a non-positive number is not defined, a log-linear or translog specification cannot be used for these input demand equations.

(26) $X_{Vi} = f^Q\left(P_Y^*, P_L, p_X^*, x_F; z_F; \beta_{Vi}^F\right) \;\forall\, i = 1, \ldots, n$

(27) $L_F = f^Q\left(P_Y^*, P_L, p_X^*, x_F; z_F, M_Z^*, L_T, z_H, z_L, p_C; \beta_F^H\right)$

(28) $L_H = f^Q\left(P_Y^*, P_L, p_X^*, x_F; z_F, M_Z^*, L_T, z_H, z_L, p_C; \beta_H^H\right)$

(29) $X_{Vi} = f^Q\left(P_Y^*, P_L, p_X^*, x_F; z_F, M_Z^*, L_T, z_H, z_L, p_C; \beta_{Vi}^H\right) \;\forall\, i = 1, \ldots, n$

As defined in the theoretical model, total fixed income (M_Z^*) is fixed household income (M_Z) and decoupled subsidies (S_D) minus fixed costs (C_F); all measured in 1000 Norwegian Crowns (NOK). Decoupled subsidies (S_D) include subsidies coupled to land, because we assume land to be a fixed input. Fixed household income (M_z) consists of income from capital assets. Household members' total time available (L_T) is measured in 1000 hours and is calculated by assuming that all household members in (on-farm or off-farm) labor have 14 hours per day on 365 days per year available for working and leisure. Household characteristics (z_H) include the number of children, the age of the household head, and the households' net assets (assets minus debts). Labor market characteristics (z_L) include the regional unemployment rate and regional mean prices of non-agricultural labor in NOK per hour. Finally, we use the regular consumer price index (CPI) for the prices of the consumption goods (p_C). As derived from the theoretical model, we impose homogeneity of degree zero in all monetary values (P_Y^*, P_L, P_X^*, M_Z^*, net assets, and p_C) by dividing these variables by a numeraire (P_Y^*) and obtaining the coefficient of the numeraire by the homogeneity condition.

We estimate the production functions (23–24) and the input demand equations (25–29) using fixed effects and random effects models for unbalanced panel data. Given the endogeneity of labor (L, L_F, L_H) and intermediate input use (X_V), we estimate the production function with the method of Balestra and Varadharajan-Krishnakumar (1987) and use the regressors of the input demand equations as instrumental variables. If a Hausman test (Hausman 1978) does not reject the Null hypotheses that the random effects model is consistent, we use this model for our analysis; otherwise, we use the less efficient but consistent fixed effects model.

Empirical Results

The Hausman tests rejects the Null hypothesis of a consistent random effects estimator for all estimated equations. Hence, our analysis is entirely based on fixed effects estimators. While the estimation results of the farm household model are very satisfactory and reasonable, the estimation results of the traditional firm model are worse. Furthermore, Wald tests reject the traditional firm model in favor of the farm household model. The coefficient of the proportion of hired labor in the production function of the farm household model (24) is clearly negative indicating a lower productivity of hired labor compared to family labor, but it is not significantly different from zero at the 10% level.

We present the effects of subsidies (5–9 and 18–22) in terms of elasticities to be independent of units of measurement. However, we use a somewhat non-standard concept of elasticities: we do not use the actual values of the subsidies, farm profit, and income from farming $(S_Y, S_X, S_D, \pi, M_Z)$, but effective prices and gross revenue $(P_Y^*, P_X^*, P_Y^* Y, P_Y^* Y, P_Y^* Y)$ as bases for calculating the elasticities.

$$(30) \quad \varepsilon = \frac{\partial(L, L_F, L_H, X_V, Y, \pi, M_F)}{\partial(S_Y, S_X, S_D)} \frac{(P_Y^*, P_X^*, P_Y^* Y)}{(L, L_F, L_H, X_V, Y, P_Y^* Y, P_Y^* Y)}$$

This specification has the advantage that subsidies can be calculated even if an actual subsidy is zero and avoids problems with non-positive farm profits and farm incomes. Furthermore, it is easier to interpret a percentage change of a price and of gross revenue than a percentage change of a subsidy, farm profit, or farm income, because the latter are often hardly known.

The subsidy elasticities based on the traditional firm model and the farm household model are presented in Tables 1 and 2, respectively. They are calculated at the sample

Table 1. Subsidy elasticities and transfer efficiencies of the traditional firm model

	$S_X[P_X^*]$	$S_Y[P_Y^*]$	$S_D[P_Y^*Y]$
L	-0.039	0.181	0.000
X_V	0.500	0.494	0.000
Y	0.041	0.511	0.000
$\pi[P_Y^*Y]$	0.226	1.297	1.000
Transfer Eff.	0.638	1.297	1.000

Note: variables in brackets indicate the bases used for calculating the relative changes of the elasticities.

Table 2. Subsidy elasticities and transfer efficiencies of the farm household model

	$S_X[P_X^*]$	$S_Y[P_Y^*]$	$S_D[P_Y^*Y]$
L	-0.291	0.348	0.001
L_F	-0.141	0.582	-0.000
L_H	-0.777	-0.412	0.004
X_V	1.034	0.484	0.001
Y	-0.167	0.170	0.000
$M_F[P_Y^*Y]$	-0.141	1.018	1.000
Transfer Eff.	-0.399	1.018	1.000

Note: variables in brackets indicate the bases used for calculating the relative changes of the elasticities.

mean values. As the traditional firm model is clearly rejected in favor of the farm household model, we describe and discuss the results of the farm household model only.

If a subsidy on intermediate inputs (S_X) is increased by 1% of the effective input price (P_X^*), the farmers substitute intermediate inputs for labor. They increase their demand for intermediate inputs by 1.03%, reduce family labor by 0.14%, and reduce hired labor by 0.78%. As a result, the output declines by 0.17% and income from farming decreases by 0.14% of gross revenue. Hence, the subsidy on intermediate inputs has a negative transfer efficiency. However, since the farm income and the use of family labor decrease by the same proportion, farm income per hour of (unpaid) family labor remains constant. Moreover, if the households do not increase leisure but increase their off-farm employment by (at least) the same amount as they decrease farm labor, the subsidy probably increases the household income — as expected.

If a subsidy on outputs (S_Y) is increased by 1% of the effective output price (P_Y^*), the farmers increase their demand for intermediate inputs by 0.48% and increase labor use by 0.35%. As a result, the output quantity increases by 0.17% and income from farming increases by 1.02% of gross revenue. This corresponds to a transfer efficiency of 1.02, i.e. increasing the subsidy by one NOK increases income from farming by 1.02 NOK. At first, this seems to be a great measure that returns more money than it costs. However, the farmers increase their (unpaid) family labor by 0.58% so that a large part of the increase of farm income does not come directly from the subsidy but from increasing farm work. If the household members do not want to reduce their leisure time, they must reduce their off-farm work so that the household income increases much less than 1.02% of gross revenue.

Finally, our estimation results show that decoupled subsidies virtually have no effect on input use and output level. Hence, the transfer efficiency of decoupled payments is one.

Conclusions

We present a new approach for analyzing the effects of different types of coupled and decoupled subsidies on farm production with econometric methods. In contrast to most previous studies, our approach is entirely based on a theoretical microeconomic model, explicitly allows subsidies to have an impact on input use, and takes linkages between the farm and the farm household into account. Preliminary results show that coupled subsidies have a considerable effect on input use and output level, while the production effect of decoupled payments is negligible.

In the future, we will calculate approximate standard errors of the elasticities of the subsidies (30) using the formula of Klein (1953, p. 258). This will allow us to evaluate the accuracy of our results and to test the statistical significance of the estimated effects.

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