The Production Effects of Crop Diversification Requirements under the European Union

Greening Policy

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Abstract

This paper explores the potential production and land use effects of making subsidy payments subject to crop diversification. We first derive a theoretical model for a rational farmer who receives subsidies contingent on the degree of crop diversification. A state-contingent framework is used to show that crop diversification decisions are independent of risk preferences if farmers have access to off-farm opportunities, such as financial markets.

Pricing equations for land allocation and output decisions are derived from the theoretical model and used in a Generalized Method of Moments framework to estimate parameters of interest. We use a panel of crop farms from France, Germany, Poland, and the UK obtained from the EU Farm Accounting Data Network (FADN).

In 2013, the European Union (EU) amended its 2003 agricultural policy by making part of the direct payments subject to additional environmental compliance: the maintenance of ecological focus areas, conservation of grassland, and crop diversification (Europe, 2013). The latter requires farms with more than 10 ha, but less than 30 ha of arable land, to grow at least two distinct crops during the reference period to qualify for the full amount of green direct payments, which are 30% of total direct payments. Additionally, the main crop cannot exceed 75% of the total arable land. To be eligible for subsidy payments, farms with more than 30 ha of arable land must cultivate at least three crops and the two main crops cannot exceed together 95% of the total cropland available. Farms with less than 10 hectares cropland and organic farms are exempt from these rules.

While the policy is aimed at enhancing the environmental sustainability of farming in the EU, concerns are being voiced regarding its efficiency in reaching the environmental goals. In 2016, European Commission has concluded that only a small percentage of land in the EU is subject to the diversification requirements (Europe, 2016). However, in regions with a high concentration of crop diversification violations, farming practices can have severe consequences on soil quality (Munkholm, Heck, and Deen, 2013). This begs the question to what extent a 30% deduction of direct payments is enough to incentivize farmers, who are currently not applying the diversification rules, to change their production patterns.

This paper explores the potential production and land use effects of making subsidy payments subject to crop diversification. We first derive a theoretical model for a rational farmer who receives subsidies contingent on the degree of crop diversification. A state-contingent framework is used to show that crop diversfication decisions are independent of risk preferences if farmers have access to off-farm opportunities, such as financial markets.

To the extent that greening constraints are binding, the crop diversification will induce a change in the relative price of inputs. In a riskless framework, the pro-

duction effects will depend on the flexibility of the available production technology in substituting inputs. However, farmers rarely operate in risk free environments, and crop diversification has long been recognized as a risk mitigating mechanism (Johnson, 1967; Pope and Prescott, 1980; Mishara, El-Osta, and Sandretto, 2004; Falco and Chavas, 2009; Chavas and Falco, 2012). Previous studies have either assumed a risk-free environment or restrictive risk preferences specifications due to data constraints (Louhichi et al., 2016). In addition to crop diversification, at least in developed countries, farmers have access to off-farm risk mitigating tools (Chambers and Quiggin, 2009; Chambers and Voica, 2017). Everything else constant, for the purpose of consumption, farmers are indifferent between income generated from the agricultural production or off-farm activities, such as financial markets. Farmers, as rational agents, act to eliminate any arbitrages between farm and off-farm activities while maximizing their utility over stochastic consumption. This observation is essential in extending prior arguments valid only for the case of riskless scenarios or a handful of restrictive preference specifications to a framework capable of accommodating general preferences. We proceed by providing a theoretical model of a rational decision maker, mnemonically called the farmer, who maximizes consumption over two periods in the presence of a stochastic agricultural technology and incomplete financial markets. Preferences over stochastic consumption are assumed to be strictly monotonic, but no other functional specification is imposed. In addition, the farmer receives a subsidy contingent on the degree of crop diversification. We show that crop diversification is motivated by profit maximizing behavior and not risk mitigation considerations. It is further demonstrated that the land demand is not linear under crop diversification requirements, which is why traditional models estimating elasticity of demand for land under area-based subsidies are not suitable if these payments are subject to diversification obligations. Our model subsumes the EU's crop diversification as a special case.

Pricing equations for land allocation and output decisions are derived from the

theoretical model and used in a Generalized Method of Moments framework to estimate parameters of interest. We use a panel of crop farms from France, Germany, Poland, and the UK obtained from the EU Farm Accounting Data Network (FADN). The FADN is a harmonized survey carried out by each Member State of the European Union, and it is representative of commercial agricultural holdings based on stratification according to region, type of specialization and economic size. The countries were chosen because they cover the spectrum of crop diversification needs in the EU. Germany and France have a higher percentage of non-compliant farms that are affected by the greening policy, while the remaining countries, everything else constant, form a baseline.

1   Theoretical Model

A rational agent, whom we mnemonically refer to as the farmer, maximizes consumption over two periods. The first period (the decision period), 0, involves no uncertainty. The second period, 1, is uncertain. Uncertainty is modeled by a finite state space, described by a finite set, Ω, where each element of Ω, referred to as a state, is a complete and mutually exclusive description of the world. [1] For example, in a two-states representation of the world, a state could be "rain" and another could be "no rain". Uncertainty is resolved by Nature, choosing from Ω. That choice, however, is only revealed to the farmer after the farmer's choices have been made in period 0. [2]

The farmer is competitive and takes inputs and state-contingent output prices as given. Preferences over consumption in the two periods, $k_0 \in \mathbb{R}_+$ and $k_1 \in \mathbb{R}_+^\Omega$, are continuous and strictly increasing in each argument, and represented by $W(k_0, k_1)$.

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[1]The theoretical framework used here is the state-contingent approach to uncertainty. An accessible treatment to the state-contingent approach is Chambers and Quiggin (2000).

[2]To interpret later results in terms of expectations, we assume that agents have well defined subjective probability vectors over the realization of the states of the Nature.

The initial wealth endowment, $\omega > 0$, is nonstochastic. In period 0, the farmer can undertake production and financial activities that generate state-contingent income in the next period. Agricultural production is characterized by a stochastic technology and the farmer can plant two crops.[3] In period 0, the farmer chooses the level of state-contingent period 1 output for each of the two crops, $z \in \mathbb{R}^\Omega_+$ and $y \in \mathbb{R}^\Omega_+$, and the amount of land allocated to each crop, $l_z \in \mathbb{R}_+$ and $l_y \in \mathbb{R}_+$. The associated variable cost is $c(w, z, y; l_z, l_y)$ where $w \in \mathbb{R}^N_{++}$ is the vector of variable input prices in period 0.[4] Cost is assumed to be convex in z, y, l_z and l_y. A farmland rental market pays in period 0 the rental rate r per unit of land. The farmer has an endowment of $L \in \mathbb{R}_{++}$ units of land.

The farmer can also buy and sell assets in the financial market. In period 0, the farmer can purchase $J \in \mathbb{R}_+$ financial assets that pay off in period 1. The period 1 payoffs for the J assets are given by the payoff matrix $A \in \mathbb{R}^{\Omega \times J}$ and the period 0 price of the jth asset is denoted $v_j \in \mathbb{R}_{++}$. The portfolio vector for the assets is denoted $h \in \mathbb{R}^J$. It is assumed that A is of full column rank and that $J < S$.

In period 0, the government pays the farmer a land based subsidy depending on the level of crop diversification. For each crop planted, the farmer receives a fixed subsidy a per unit of farmland allocated to the crop weighted by the ratio of the land allocated to all remaining crops and the total farmland. For example, for an allocation of l_z and l_y units of farmland to the crops z and y, the farmer receives the subsidy $(l_y/(l_z+l_y))al_z$ for the farmland allocation l_z, and the subsidy $(l_z/(l_z+l_y))al_y$ for the allocation l_y.

The total subsidy paid to the farmer equals the sum of payments across all farmland utilization, $2a(l_y l_z/(l_z+l_y))$. To contrast with the case of no crop diversification requirement, when the farmer receives the subsidy $a(l_z + l_y)$, the total subsidy re-

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[3]In reality, farmers can plant more than two crops. However, no additional insight is gained from modeling more than two crops.

[4]For an axiomatic study of cost functions see Chambers and Quiggin (2000).

ceived under diversification is multiplied by two. [5] Thus, the total subsidy paid to the farmer is equal to $4a(l_y l_z/(l_z + l_y))$. If the farmer specializes in the production of only one crop, say z, then $l_y = 0$ and the subsidy received will be zero. If the farmer wishes to maximize the subsidy received conditional on the farmland constraint, $l_z + l_y \leq L$, the optimal land allocation will be $l_z = l_y$, thus complete crop diversification, and the total subsidy will be $a(l_z + l_y)$.

In period 1, the farmer receives the revenue from farming $p_s z_s + q_s y_s$, where p_s and q_s are the output prices in state $s \in \Omega$, and the revenue from the financial markets $A_s h$, where $A_s \in \mathbb{R}^J$ is the vector of assets payoffs in state s.

The farmer's period 0 problem is to choose $k_0 \in \mathbb{R}_+$, $k_1 \in \mathbb{R}_+^\Omega$, $z \in \mathbb{R}_+^\Omega$, $y \in \mathbb{R}_+^\Omega$, $l_z \in \mathbb{R}_+$, $l_y \in \mathbb{R}_+$ and $h \in \mathbb{R}^J$ to

$$\max \left\{ W\left(k_0, k_1\right) : k_1 \leq pz + qy + Ah \right. \tag{1}$$
$$\left. k_0 \leq \omega - c(w, z, y; l_z, l_y) - v^T h - r(l_z + l_y) + 4a \frac{l_z l_y}{l_z + l_y} \right\}$$

In words, the farmer maximizes consumption over two periods subject to $\Omega + 1$ budget constraints. In the first period, the consumption can not exceed the initial wealth, ω, plus the subsidy, $4a(l_y l_z/(l_z + l_y))$, minus the cost of assembling the second period consumption via the agricultural production, $c(w, z, y; l_z, l_y) + r(l_z + l_y)$, and the financial markets, $v^T h$. In the second period, the consumption is bounded by the random income from agricultural production, $pz + qy \in \mathbb{R}^\Omega$, and financial market payoff, $Ah \in \mathbb{R}^\Omega$. The *ex-post* second period consumption can not be larger than the

[5]Under the crop diversification requirement, maximizing the subsidy received is equivalent to solving the problem.

$$V(a) = \max_{l_z, l_y} \left\{ 4a \frac{l_z l_y}{l_z + l_y} : l_z + l_y \leq L \right\}$$

The equilibrium land allocations are $l_z = l_y = L/2$ and the value function V(a) for this optimal land allocations is aL. Of course, subsidy maximization is not the farmer's main objective and crop diversification will depend on more than just the subsidy payments.

agricultural revenue, $p_s z_s + q_s y_s$, plus the financial return, $A_s h$, for each state $s \in \Omega$.

1.1 Optimal Behavior

Because preferences are strictly increasing in consumption, the $\Omega + 1$ budget constraints are binding. Formally, this requires the second period budget constraints be written as

$$k_1 = pz + qy + Ah \tag{2}$$

from where, after a simple algebraic manipulation, $Ah = k_1 - pz - qy$. Thus, the difference between the second period consumption, k_1, and the stochastic agricultural revenue, $pz + qy$, is covered by the farmer's participation in the financial market, Ah. For optimal values of the second period consumption, output levels and farm land allocations, the unique optimal level of financial market participation is[6]

$$h = (A^T A)^{-1} A^T (k_1 - pz - qy) \tag{3}$$

which after substituting in (1) yields:

$$\max_{k_1} W\left(\omega - v^T P k_1 + \Pi(p, q, \omega, v^T P), k_1\right) \tag{4}$$

where $P = (A^T A)^{-1} A^T$ and $v^T P$ is the stochastic discount factor induced by the financial markets. $\Pi(p, q, \omega, P)$ is a profit maximization problem define as

$$\Pi(p, q, \omega, v^T P) = \max_{z, y, l_z, l_y} \left\{ v^T P(pz + qy) - c(w, z, y; l_z, l_y) + 4a \frac{l_z l_y}{l_z + l_y} - r(l_z + l_y) \right\} \tag{5}$$

In (4), preferences over consumption, hence over risk, depend on the second period consumption, k_1, but not on the output levels, z and y, and land allocations l_z and

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[6]The derivation of h is similar to the derivation in Chambers and Voica (2017), page 5, and thus it is omitted.

l_y. For given levels of output prices, p and q, stochastic discount factor, $v^T P$, land rent and subsidy, r and a, and crop diversification rule, the farmer chooses z, y, l_z and l_y to maximize consumption. This requires solving the profit maximization (5).

For additional intuition consider the special case of differentiable preferences and cost function. Because preferences are strictly increasing in consumption, the first order conditions for problem 4, at interior solutions, are:

$$\frac{\partial W}{\partial k_{1s}} \Big/ \frac{\partial W}{\partial k_0} = v^T P_s, \ s \in \Omega \tag{6}$$

$$v^T P_s p_s = \frac{\partial c(w, z, y; l_z, l_y)}{\partial z_s}, \ s \in \Omega \tag{7}$$

$$v^T P_s q_s = \frac{\partial c(w, z, y; l_z, l_y)}{\partial y_s}, \ s \in \Omega \tag{8}$$

$$-\frac{\partial c(w, z, y; l_z, l_y)}{\partial l_z} = r - 4a \frac{l_y^2}{(l_z + l_y)^2} \tag{9}$$

$$-\frac{\partial c(w, z, y; l_z, l_y)}{\partial l_y} = r - 4a \frac{l_z^2}{(l_z + l_y)^2} \tag{10}$$

The first order conditions (6) reflect the farmer's optimal choices of stochastic consumption. For each state, the farmer equates the marginal rate of substitution between consumption in that state, say s, and consumption in the first period, W_s / W_0, with the Arrow security prices derived in the financial markets, $v^T P_s$, where $W_s = \partial W / \partial k_{1s}$ and $W_0 = \partial W / \partial k_0$.

The first order conditions (7) and (8) are pricing equations reflecting the optimal agricultural output levels z and y. According to (7), the marginal cost of state contingent output z in state s equals its stochastically discounted price, $v^T P_s p_s$. A similarly interpretation applies to y in (8).

Together, conditions (6),(7) and (8) reflect the separation between the farmer's equilibrium behaviour as a consumer and as a producer in the presence of financial markets. The farmer reacts to the stochastic discount factor $v^T P$ as a consumer in (6)

and as a producer in (7) and (8). Because the farmer's consumption depends on her risk preferences, W_s/W_0, but her production decisions do not, the agricultural output decisions do not depend on the subsidy as far as the risk bearing is concerned.[7] The optimal level of agricultural output z and y may depend on the subsidy considering the subsidy is paid per unit of land and land is an essential input. However, the subsidy payments do not induced production distortions via risk adjustments (i.e. wealth effects).

Additionally, making the subsidy payments contingent on crop diversification will not change the farmer's risk position. The farmer's optimal choices of z and y are driven by profit maximization behavior and not risk mitigation considerations. Sure, crop diversification requirements may influence the costs of producing the agricultural outputs, but at the margin, the farmer will continue to equate the marginal cost with the stochastic discount factor, $v^T P$, which does not change.

The last two conditions, (9) and (10), reflect the optimal land allocation l_z and l_y in the presence of a crop diversification requirement. At the margin, the farmer equates the saving in the cost of producing z and y with the rent minus the subsidy weighted by the crop diversification. In the case of specialization, the subsidy received is zero, while in the case of complete specialization the subsidy is a.

1.2 Crop diversification of the EU agricultural policy

We specialized the model to the case of crop diversification under the greening policy of the EU agricultural policy. For farmers with land holdings between $10 - 30$ ha, the farmland allocated to the main crop can not exceed 75% of the farmland. For farmers with more than 30 ha, the farmland allocated to the main crop can not exceed 75% of the farmland, and the farmland allocated to the main two crops can not exceed 95% of the farmland. Furthermore, only 30% of the area-based subsidies are subject to

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[7] This separation result extends Chambers and Quiggin (2009), Theorem 6, to the present context. A similar result for the case of a stochastic lump-sum transfer is derived by Chambers and Voica (2017)

greening measures, and the penalty for lack of diversification depends monotonically on the degree of divergence from the diversification rule.

Based on these payments scheme, the farmer's period 0 problem is to choose $k_0 \in \mathbb{R}_+$, $k_1 \in \mathbb{R}_+^\Omega$, $z \in \mathbb{R}_+^\Omega$, $y \in \mathbb{R}_+^\Omega$, $l_z \in \mathbb{R}_+$, $l_y \in \mathbb{R}_+$ and $h \in \mathbb{R}^J$ to

$$\max \left\{ W\left(k_0, k_1\right) : k_1 \leq pz + qy + Ah, \; k_0 \leq \omega - c(w, z, y; l_z, l_y) - v^T h \right. \tag{11}$$
$$\left. - (r - (1-\alpha)a)(l_z + l_y) + \alpha a \left[(l_z + l_y)(1 - I) + 4\frac{l_z l_y}{l_z + l_y} I \right] \right\}$$

where $\alpha \in (0,1)$ is the proportion of the subsidy that is subject to the diversification requirements (i.e. $\alpha = .3$ for the EU greening policy) and I is an indicator function defined as

$$I = \begin{cases} 0, & \text{if } \max\left\{ \frac{l_z}{l_z+l_y}, \frac{l_y}{l_z+l_y} \right\} \leq 75\% \\ 1, & \text{otherwise} \end{cases}$$

The case for three or more crops is identical. [8] For the concentrated objective function,

$$\max_{k_1} W\left(\omega - v^T P k_1 + \Pi(p, q, \omega, v^T P), k_1\right) \tag{12}$$

where

$$\Pi(p, q, \omega, v^T P) = \max_{z, y, l_z, l_y} \left\{ v^T P(pz + qy) - c(w, z, y; l_z, l_y) \right.$$
$$\left. - (r - (1-\alpha)a)(l_z + l_y) + \alpha a \left[(l_z + l_y)(1 - I) + 4\frac{l_z l_y}{l_z + l_y} I \right] \right\}$$

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[8]For three crops, the indicator function I is written as

$$I = \begin{cases} 0, & \text{if } \frac{l_i}{l_z+l_y+l_t} \leq 75\% \text{ for all } i \in \{z, y, t\} \text{ and } \frac{l_i+l_j}{l_z+l_y+l_t} \leq 95\% \text{ for all } i, j \in \{z, y, t\}, i \neq j \\ 1, & \text{otherwise} \end{cases}$$

while for more than three crops, the indicator function I is adjusted to reflect the cardinality of the set of crops planted. Aside from the adjustment of the indicator I nothing changes in the optimization problem.

the first order conditions for an interior solutions are

$$\frac{\partial W}{\partial k_{1s}} \bigg/ \frac{\partial W}{\partial k_0} = v^T P_s, \ s \in \Omega \tag{13}$$

$$v^T P_s p_s = \frac{\partial c(w, z, y; l_z, l_y)}{\partial z_s}, \ s \in \Omega \tag{14}$$

$$v^T P_s q_s = \frac{\partial c(w, z, y; l_z, l_y)}{\partial y_s}, \ s \in \Omega \tag{15}$$

$$-\frac{\partial c(w, z, y; l_z, l_y)}{\partial l_z} = r - (1 - \alpha)a - \alpha a \left[1 - I + 4 \frac{l_y^2}{(l_z + l_y)^2} I \right] \tag{16}$$

$$-\frac{\partial c(w, z, y; l_z, l_y)}{\partial l_y} = r - (1 - \alpha)a - \alpha a \left[1 - I + 4 \frac{l_z^2}{(l_z + l_y)^2} I \right] \tag{17}$$

Conditions (13) to (15) are identical to the one derived for problem (4), while land allocations conditions (16) and (17) correspond to the case of crop specialization, if $I = 1$, or full diversification, if $I = 0$. The schedule of subsidy payments induces a "kink" in the land demand for farmers specializing in one crop beyond 75% of the land allocation threshold. This is due to the discontinuity of the subsidy payments in the neighbourhood of 75% threshold. The marginal subsidy is equal to a to the left of the 75% land allocation threshold, while the subsidy equals $(1 - \alpha)a + 4(.25 - \epsilon)^2$ to the right of the threshold. Equality between the two holds only at a land allocation equal to 50%, while for any land allocation exceeding the 75% threshold $(1 - \alpha)a + 4(l_i/(l_z + l_y))^2 < a$ for any $i = z, y$.

2 Estimation

The available data covers the interval $2004 - 2013$, while the crop diversification requirement of the EU agricultural policy was announced in 2013, but came into effect in 2015. Hence, for empirical purposes, the theoretical model needs to be adjusted to account for the subsidy payment scheme prior to 2015. The farmer determines the

optimal levels of agricultural outputs and farmland allocation by solving the following profit maximization

$$\Pi(p_1, \ldots, p_M, \omega, v^T P) = \max_{z_1, \ldots z_M, l_1, \ldots, l_M} \left\{ v^T P \sum_{m=1}^{M} p_m z_m \right.$$
$$\left. - c(w, z_1, \ldots, z_M; l_1, \ldots, l_M) - (r - a) \sum_{m=1}^{M} l_m \right\}$$

where there are $M \in \mathbb{R}_+$ crops and farmland allocations. The first order conditions for this problem are

$$\frac{\partial c(w, z_1, \ldots, z_M; l_1, \ldots, l_M)}{\partial z_{ms}} = v^T P_s p_{ms}, \ s \in \Omega, m \in \{1, \ldots, M\} \tag{18}$$

$$- \frac{\partial c(w, z_1, \ldots, z_M; l_z, l_1, \ldots, l_M)}{\partial l_m} = r - a, \ \forall m \in \{1, \ldots, M\} \tag{19}$$

The first $M \times \Omega$ conditions can be written in the concentrated form as

$$\frac{\nabla_{z_m} c(w, z_1, \ldots, z_M; l_1, \ldots, l_M)}{p_m} A = v^T, \ m \in \{1, \ldots, M\} \tag{20}$$

where $\nabla_{z_m} c(w, z_1, \ldots, z_M; l_1, \ldots, l_M)/p_m \in \mathbb{R}^M$ is the gradient of the cost function with respect to each crop divided by the output price.[9] For the subjective probability measure, $\pi = (\pi_1, \ldots, \pi_s)$ (20) can be written in expectation form as

$$E\left[\frac{\nabla_{z_m} c(w, z_1, \ldots, z_M; l_1, \ldots, l_M)}{p_m} \tilde{A} \right] = v^T \tag{21}$$

where expectation is take over the discrete subjective probability measure π and $\tilde{A} = A/\pi$. [10] For estimation purposes, it is convenient to write (20) in terms of

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[9] The system (20) was obtained by post-multiplying (18) by A/p_{ms}.

[10] Eq.(21) must hold for every asset j. Thus

$$E\left[\frac{\nabla_{z_m} c(w, z; l)}{p_m} \tilde{A}_j \right] = v_j, \ j = 1, \ldots, J$$

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financial returns $R_j = \tilde{A}_j/v_j$.

$$E\left[\frac{\nabla_{z_m} c(w, z_1, \ldots, z_M; l_1, \ldots, l_M)}{p_m} R - 1\right] = 0, \; m \in \{1, \ldots, M\} \qquad (22)$$

where $R \in \mathbb{R}^{\Omega \times J}$ is a matrix of financial returns (i.e. interest rate, stock exchange). Similarly, the (19) can be written in expectation form as

$$E\left[\left(\frac{\partial c(w, z_1, \ldots, z_M; l_z, l_1, \ldots, l_M)}{\partial l_m} + r - a\right) 1^\Omega\right] = 0, \; \forall m \in \{1, \ldots, M\} \qquad (23)$$

The econometric strategy is to estimate the system of equations (22) and (23) using Generalized Method of Moments (GMM). Based on this estimation, predictions regarding the production effects of crop diversification are proposed using simulations techniques.

The cost function is assumed to take the following form

$$\begin{aligned}
c(w, z_1, \ldots, z_M; l_1, \ldots, l_M) = \tau(w_t) + \phi(w_t)&\left[\sum_{m=1}^{M} \alpha_{z_m} E_t(z_{t+1,m} - z_{t,m})\right. \\
&+ \sum_{m=1}^{M} \frac{\beta_{z_m}}{2} E_t[(z_{t+1,m} - z_{t,m})^2] + \sum_{m=1}^{M} \eta_z E_t(z_{t+1,m} - z_{t,m}) l_m \\
&\left.+ \gamma_{z_{12}} E_t[(z_{t+1,1} - z_{t,1})(z_{t+1,2} - z_{t,2})] + \sum_{m=1}^{M} \alpha_{l_m} l_{t,m} + \sum_{m=1}^{M} \frac{\beta_{l_m}}{2} l_{t,m}^2\right],
\end{aligned}$$
$$m = 1, \ldots, M \text{ and } M = 2 \quad (24)$$

Given this representation of the production cost function, for $M = 2$, it follows

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$$\frac{\nabla_{z_1} c(w, z_1, \ldots, z_M; l_1, \ldots, l_M)}{p_{t+1,1}} =$$

$$\frac{\phi(w_t)}{p_{1,t+1}} \Big[\alpha_{z_1} + \beta_{z_1}(z_{t+1,1} - z_{t,1}) + \gamma_{z_{12}}(z_{t+1,2} - z_{t,2}) + \eta_{z_1} l_{t_1} \Big] \quad (25)$$

$$\frac{\partial c(w, z_1, \ldots, z_M; l_1, \ldots, l_M)}{\partial l_1} = \phi(w_t) \Big[\alpha_{l_1} + \beta_{l_1} l_{t_1} + \eta_{z_1} E(z_{t+1,1} - z_{t,1}) \Big] \quad (26)$$

for $m = 1$, and similarly for $m = 2$. For two crops and this functional form of the production cost, the number of parameters to be estimate is 11. Using suitable instruments ensures that the number of moment conditions is at least as large as the number of parameters to be estimated and helps identify those parameters. If conditional on information available at time t, (25) and (26) hold as identities, then for any set of instruments Z_t predetermined at time t, the law of iterated expectations requires

$$g_m(d_t, \theta) = E\left[Z_t^T \left(\frac{\nabla_z c(w, z_1, \ldots, z_M, l_1, \ldots, l_M; \theta)}{\tilde{p}_{t+1}} R_{jt+1} - 1 \right) \right] = 0, \ m = 1, 2 \quad (27)$$

where $d_t = (w_t, z_{t+1,1}, z_{t+1,2}, l_1, l_2, p_{t+1,1}, p_{t+1,2}, R_{t+1})$, and $\theta = (\alpha_{z_1}, \alpha_{z_2}, \beta_{z_1}, \beta_{z_2}, \gamma_{z_{12}}, \alpha_{l_1}, \alpha_{l_2}, \beta_{l_1}, \ldots, \beta_{l_M})$ is the vector of parameters to be estimated, and

$$h_m(d_t, \theta) = E\left[Z_t^T \left(\frac{\partial c(w, z_1, \ldots, z_M, l_1, \ldots, l_M; \theta)}{\partial l_m} + r - a \right) \right] = 0, \ m = 1, 2 \quad (28)$$

The GMM procedure estimates θ as the solution to the minimization problem

$$J_T(\theta) = [g_1(d_t, \theta), g_2(d_t, \theta), h_1(d_t, \theta), h_2(d_t, \theta)]'$$

$$W[g_1(d_t, \theta), g_2(d_t, \theta), h_1(d_t, \theta), h_2(d_t, \theta)] \quad (29)$$

where W is a positive definite weighting matrix.

2.1 Data Description

In our study, capital and and land are treated as quasi-fixed while labor, crop-specific inputs (seed, fertilizer, and pesticides) and energy are variable inputs. Outputs are the crop groups as described below in the data section.

The greening rules in the EU CAP program 2014–2020 require farms with more than 10 ha but less than 30 ha of cropland to grow at least two distinct crops during the reference period June 1st – July 15th. Additionally, the most common crop cannot exceed a land share of 75%. Farms with more than 30 ha of cropland have to cultivate at least three crops and the two most common crops cannot exceed a land share of 95%. Farms that violate these restrictions are not eligible for subsidies from the direct payment scheme in the current year. The greening regulation is effective starting in 2015 in all EU member countries.

This paper uses data provided by the German Federal Ministry of Food and Agriculture (FMFA). The FMFA data are less aggregated than Farm Accountancy Data Network(FADN) data, which allows a better categorization of individual crops according to the classification made in the greening regulation. For example, summer and winter wheat are considered as two distinct crop cultures, but they are summarized to one variable wheat in the FADN dataset. The following description is based on a representative sample of farms in Bavarian, the largest federal state in Germany, consisting of more than $1,500$ farms over the time period 2000–2014. The total number of observations is $54,626$.

Table 1: Frequency distribution of crops planted, all farm sizes (2000-2014)

Nr of crops	Frequency	Percent	Cum.
0	6,159	11.27	11.27
1	2,027	3.71	14.99
2	3,043	5.57	20.56
3	5,706	10.45	31
4	7,909	14.48	45.48
5	8,347	15.28	60.76
6	7,699	14.09	74.85
7	5,897	10.8	85.65
8	3,924	7.18	92.83
9	2,314	4.24	97.07
10	1,046	1.91	98.98
11	400	0.73	99.72
12	122	0.22	99.94
13	25	0.05	99.99
14	5	0.01	99.99
15	3	0.01	100

n = 54,626

Table 1 shows that the majority of farms in the sample plants five distinct crops. About 11% of the observations do not produce any crops. These are mainly dairy farms that rely on grassland only. $2,027$ observations in this sample violate the greening requirement of planting more than 1 distinct crop. More than 50% of them exceed the critical size of 10 ha cropland and would thus not be eligible for the subsidy payments, before even taking into account the requirement that the land share of the main crop must be below 75%. The distribution of the land share of the main crop is shown in Fig 1.
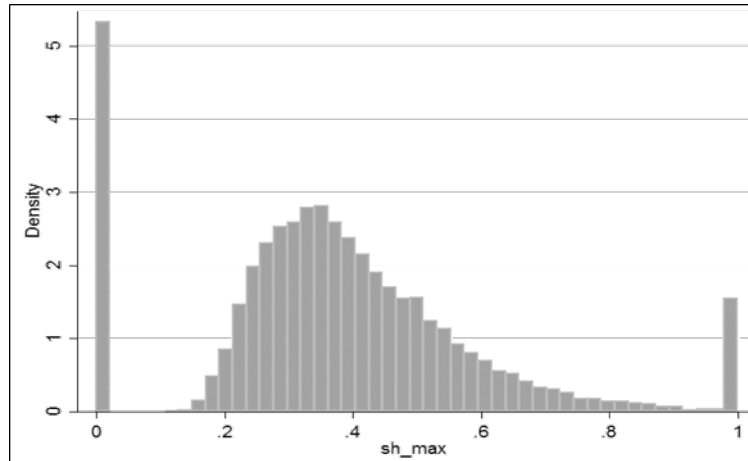
Figure 1: Distribution of the land share of the main crop, 2000 – 2014

The share of the main crop exceeds 75% in $3,006$ observations. To observe patterns over the time, the following table summarizes the greening violations in the sample for each year.

Table 2: Greening violations in the sample

Year	Nr of farms	Farms with only 1 distinct crop	Farms with major crop > 75%	Farms that violate at least one restriction	Thereof farms > 10 ha
2000	3805	3.47%	5.76%	5.76%	57
2001	3652	3.70%	5.75%	5.75%	53
2002	3736	3.88%	5.78%	5.78%	53
2003	3648	3.76%	5.62%	5.62%	45
2004	3833	3.94%	6.13%	6.13%	63
2005	3877	4.13%	6.32%	6.32%	70
2006	3809	4.17%	6.11%	6.12%	65
2007	3771	4.40%	6.13%	6.13%	68
2008	3691	3.60%	4.93%	5.04%	49
2009	3568	3.20%	4.71%	4.71%	57
2010	3531	3.46%	4.84%	4.84%	56
2011	3445	3.57%	5.31%	5.31%	72
2012	3537	3.76%	5.03%	5.03%	60
2013	3399	3.56%	5.09%	5.09%	60
2014	3324	2.89%	4.60%	4.60%	56

It becomes clear that there was a trend towards crop specialization between 2000 and 2007 but the percentage of farms that planted only 1 distinct crop decreased afterwards. However, the share of farms where the main crop exceeds 75% of land share remained stable over the years. Logically, observations that violate the distinct crops condition also violate the 75% restriction and thus the percentage of farms that violate at least one restriction resembles the percentage of farms that violate the 75% conditions. This will be different, if we include the 95% restriction for farms with more than 30 ha cropland.

3 Conclusions

This paper explores the potential production and land use effects of making subsidy payments subject to crop diversification. We first derive a theoretical model for a rational farmer who receives subsidies contingent on the degree of crop diversification.

A state-contingent framework is used to show that crop diversification decisions are independent of risk preferences if farmers have access to off-farm opportunities, such as financial markets.

Pricing equations for land allocation and output decisions are derived from the theoretical model and used in a Generalized Method of Moments framework to estimate parameters of interest. We use a panel of crop farms from France, Germany, Poland, and the UK obtained from the EU Farm Accounting Data Network (FADN).

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