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The Role of Marketing Contracts in the Adoption of Low-Input Production Practices in the Presence of Income Supports: An Application in Southwestern France

Aymeric Ricome, Karim Chaïb, Aude Ridier, Charilaos Képhaliacos, and Françoise Carpy-Goulard

This paper analyzes the link between choices of production technologies and marketing contracts. We first develop an analytical model showing that both decisions are linked and influenced by risk and direct payments. Then, a numerical application based on a stochastic farm model is implemented on a representative farm from southwestern France. Among other things, we find that a wide availability of marketing contracts reduces the impact of agricultural policies on agricultural practices. Moreover, marketing contracts can encourage farmers to adopt green practices, which are—in France—riskier than conventional techniques.

Key words: crop farming, forwarding contracts, multiperiodic farm model, risk analysis, stochastic simulation

Introduction

Grain farmers use marketing contracts as a risk management tool to manage market and income instability. These are verbal or written agreements between buyers and producers that set a price or an outlet for a commodity before harvest or before the commodity is ready to be marketed (Harwood et al., 1999). In European Union (EU) countries, especially in France, several types of marketing contracts are offered to farmers by grain co-operatives. In "pool contracts," co-operatives offer their members a mean price smoothed over the co-operative's yearly grain supply. In the French grain sector, these pool contracts used to be the most common and the most adopted contract type. However, successive reforms of the Common Agricultural Policy (CAP) have exposed EU farmers to volatile grain markets, particularly in recent years,[1] causing several new types of marketing contracts—such as forward and storage contracts—to be developed and offered to grain farmers since the mid-2000s. Farmers have become increasingly more vulnerable to market risk, and so hedging against it has become important. As there are no revenue insurance programs in the EU, marketing contracts are the only existing tools for farmers to protect against price instability.

At the time this study was conducted, Aymeric Ricome was an economist at the Université de Toulouse - LEREPS. Karim Chaïb is an associate professor in the Ecole d'Ingénieurs de Purpan at the Université de Toulouse. Aude Ridier is an associate professor at the AgroCampus Ouest INRA. Charilaos Képhaliacos is a professor at the Université de Toulouse - ENFA. Françoise Carpy-Goulard is an economist at the Agence de l'eau Adour-Garonne, Toulouse, France.
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[1] Successive CAP reforms have led to a step-wise reduction in grain price support, which used to protect farmers against world commodity price fluctuations but was strongly coupled to production decisions. The reduction in price support began in 1992 and was first offset by Arable Area Payments (AAP) and then—in 2005—by Single Farm Payments (SFP), which are direct payments with no linkage to any production decisions or price levels.

At the same time, EU grain farmers have been encouraged to convert from conventional farming practices to more sustainable ones by using lower levels of chemical inputs. However, low-input technologies are generally perceived by farmers to be riskier than conventional ones because chemical inputs may reduce yield risk (Feder, 1979; Uri, 2000; Lien and Hardaker, 2001).[2] Hence, farmers might be less inclined to adopt low-input practices,[3] especially when they have to cope with uncertain or hard-to-predict prices in addition to yield risk (Feder, Just, and Zilberman, 1985; Abadi Ghadim and Pannell, 1999).

Thus, the aim of this paper is to analyze how marketing contracts, some of which allow farmers to reduce their exposure to market risk, could encourage the use of greener, but riskier, practices.[4] This analysis requires testing the interactions between marketing and production decisions.

The first theoretical studies of the links between marketing and production decisions were proposed by Danthine (1978), Holthausen (1979), and Feder, Just, and Schmitz (1980), who extended the theory of the firm under conditions of uncertainty proposed by Sandmo (1971) by adding a forward contract (hedging decision) to the model. They showed that when the market price is the unique source of risk, the decision on the quantity produced is completely separated from the hedging decision and also independent of any risk consideration. This separation property implies that, under price uncertainty and when a hedging market exists, insurance and wealth effects do not affect production decisions (Hennessy, 1998). In other words, marketing contracts and policy supports that mitigate risk may not influence the quantity produced.

Anderson and Danthine (1983) and Grant (1985) showed that the decision on the quantity produced is not separable from the hedging decision if farmers are subject to both price and production risks. This is because hedging cannot be perfect under joint price and production risks and cannot rule out all sources of risk at the farm scale. Viaene and Zilcha (1998) obtained the same result when both input and output prices are random. Lapan, Moschini, and Hanson (1991) and Lapan and Moschini (1994) showed that, in the case of futures and option contracts, the separability property does not hold due to the presence of a basis risk that cannot be eliminated.[5] It can be derived from these theoretical findings that production and marketing decisions are not separable and must be analyzed jointly when the hedging tool is not perfect.

Nevertheless, applied economic studies that assess the impact of agricultural policy changes on production and technological choices *ex ante* do not consider marketing decisions (e.g., Ridier and Jacquet, 2002; Di Falco and Perrings, 2005; Mosnier et al., 2009; Serra et al., 2009). Others examine the impact of different farm support systems on hedging demands but ignore possible interactions with production decisions (Coble et al., 2004; Wang, Makus, and Chen, 2004). To the best of our knowledge, there is no *ex ante* (or even *ex post*) assessment of agricultural policy including both production and marketing decisions in the same empirical framework, even though the use of specific marketing contracts may act as a buffer and strongly reduce the adoption of a technology expected under a new agricultural policy.

Relying on these literature and observations, we analyze the impact of different farm supports on both marketing decisions and choices of production technologies and the extent to which marketing contracts could help farmers to adopt greener practices, even in an unfavorable economic context. The green technology considered is meant to decrease the use of chemical inputs but increases exposure to production risk.

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[2] This point is debatable and may vary according to place and technology. For an in-depth discussion on the economics of pest control in agriculture, see Pannell (1991).

[3] Farmers also perceive low-input practices to be riskier than conventional ones because they lack experience with these new practices, which are complex, knowledge-intensive, and site-specific.

[4] The CAP budget dedicated to the direct promotion of green practices through subsidies (agro-environmental policy schemes) is too low to significantly encourage the use of green practices on a large scale.

[5] Basis risk arises because of the imperfect relationship between spot and futures prices.

Table 1. Decision Variables and Main Parameters of the Model

Parameter/Variable	Definition
L	Total arable land
α	Share of land cultivated under *li* technology (conversion rate)
y_c	Crop yield under *c* technology
$\tilde{y}_{li}$	Crop yield under *li* technology
$C(L)$	Total production cost under *c* technology
$C_{li}(\alpha L)$	(negative) extra-cost due to the use of the *li* technology
$\tilde{p}_p$	Harvest spot price
p_f	Forward price
h	Quantity sold under the forward contract
D	Direct payment (single farm payment)

Theoretical Approach

A farmer produces on a given area (L) a single crop with yield y using two technologies: a conventional one (c) and a low-input one (li).[6] Technology li is riskier than technology c, and the stochastic yield is noted $\tilde{y}_{li}$.[7] Technology c is assumed not risky, and crop yield is $y_c = f(x_c)$; x_c is the quantity of input used. The expected yield under technology li is lower than that under technology c, $\overline{y}_{li} < y_c$. We assume that yield risk and price risk are negatively correlated.

The total variable cost of farming area L under conventional technology is $C(L)$. The share of area L under li technology is noted α; it is a conversion rate. When share α of land L is cultivated under li technology, the total production cost is reduced by $C_{li}(\alpha L)$ since li technology is chemical-input saving and the extra labor costs do not totally compensate for the drop in chemical costs (see appendix A). It is assumed that $C'(L) > 0$, $C''(L) \geq 0$, $C'_{li}(\alpha L) < 0$, and $C''_{li}(\alpha L) \geq 0$, where C' and C'' are the first and second derivatives.

The farmer has to choose between two marketing options. The first one is a cash transaction at harvest, where the farmer sells the crop at harvest at the current random spot price, $\tilde{p}_p$. The second option is a forward contract that binds the farmer to deliver at harvest a specified quantity, h, of grain at price p_f agreed upon before harvest. The price is fixed at the sowing date. The forward price is lower than the expected harvest price, $\overline{p}_p \geq p_f$; the difference, $\overline{p}_p - p_f$, represents the risk premium that enables the farmer to avoid market risk through the forward contract (hedging cost).

A direct payment, D—which is independent of price, yield, and the farmer's decisions—is distributed to the farmer. The different components of the decision problem are summarized in table 1. The profit π is given by

$$\pi = L(\alpha\tilde{y}_{li} + (1-\alpha)y_c)(hp_f + (1-h)\tilde{p}_p) - c(L) - C_{li}(\alpha L) + D. \quad (1)$$

The von Neumann-Morgenstern utility function, U, is defined on profit. It is strictly increasing, concave, and twice continuously differentiable on α and h. The optimization program is the maximization of the expected utility of profit. Because the stochastic variables (yields and prices) can take all positive values, it can be written as

$$\max_{\alpha,h} EU(\pi) = \int_0^\infty \int_0^\infty U(\pi) f(\tilde{y}_{li}, \tilde{p}_p) dy_{li} dp_p, \quad (2)$$

[6] Technology *li* consists of decreasing pesticide applications while increasing labor input (chemical treatments are replaced by mechanical operations and longer monitoring time).
[7] In the short run, pesticides reduce yield risk.

where $f(\tilde{y}_{li}, \tilde{p}_p)$ is the farmer's joint probability density function on yield and spot prices. The first-order conditions can be written

$$\text{(3a)} \qquad \frac{\partial EU}{\partial \alpha} = EU'(\pi)[L(\tilde{y}_{li} - y_c)(hp_f + (1-h)\tilde{p}_p) - LC'_{il}(\alpha L)] = 0;$$

$$\text{(3b)} \qquad \frac{\partial EU}{\partial h} = EU'(\pi)[L(\alpha \tilde{y}_{li} + (1-\alpha) y_c)(p_f - \tilde{p}_p)] = 0.$$

The second-order conditions for the maximum are given by

$$\text{(4)} \qquad \begin{aligned} H_{11} &= \frac{\partial^2 EU}{\partial \alpha^2} < 0, \\ H_{22} &= \frac{\partial^2 EU}{\partial h^2} < 0, \\ |H| &= H_{11}H_{22} - (H_{12})^2 > 0, \end{aligned}$$

where $H_{12} = \frac{\partial^2 EU}{\partial \alpha \partial h}$.

Optimal Conversion Rate

From the first- and second-order conditions of the optimization problem, we find that the optimal share α^* under *li* technology is dependent on the level of risk and on the farmer's risk aversion. To show this, we consider the expression $\frac{\partial EU}{\partial \alpha} - h\frac{\partial EU}{\partial h}$, which is

$$\text{(5)} \qquad EU'(\pi)[\alpha(\tilde{y}_{li} - y_c)(hp_f + (1-h)\tilde{p}_p) - C'_{li}(\alpha L) - h(\alpha \tilde{y}_{li} + (1-\alpha)y_c)(p_f - \overline{p}_p)] = 0,$$

and can be rearranged to be

$$\text{(6)} \qquad \begin{aligned} &\alpha(\overline{y}_{li} - y_c)\overline{p}_p - hy_c(p_f - \overline{p}_p) + \alpha cov(\tilde{y}_{li}, \tilde{p}_p) = \\ &C'_{li}(\alpha L) - (h-\alpha)\left[\frac{y_c cov(U'(\pi), \tilde{p}_p)}{EU'(\pi)}\right] - \alpha\left[\frac{cov(U'(\pi), \tilde{y}_{li}\tilde{p}_p)}{EU'(\pi)}\right]. \end{aligned}$$

The terms of the left side of equation (6) give the Expected Marginal Return (*EMR*), which depends on yields, prices, and on the yield-price correlation and is decreasing in α, since $\overline{y}_{li} < y_c$ and $cov(\tilde{y}_{li}, \tilde{p}_p) \leq 0$. On the right side, $C'_{li}(\alpha L)$ is the marginal cost of *li* technology; it is assumed to be decreasing in α. The last two terms of equation (6) represent the Marginal Risk Premium (*MRP*) linked to *li* technology and to the cash-to-harvest transaction.

The optimal conversion rate, α^*, corresponds to the level beyond which the cost saving from *li* technology is lower than the loss in gross returns due to lower yields (figure 1). The level of risk represented by the *MRP* acts as a cost, lowering the optimal conversion rate if the *MRP* is positive (see α_1^* to α_2^* in figure 1). From equation (6) we have $MRP \gtreqless 0 \Rightarrow C'_{li}(\alpha L) \lesseqgtr EMR$. Thus, at the optimum, the *MRP* gives the spread between the *EMR* and $C'_{li}(\alpha L)$.[8] The *MRP* term depends on $U'(\pi)$ and the covariance term. Thus, it depends on farmer's risk aversion and on the farmer's risk perception.

In sum, the optimal use of *li* technology depends on (i) the level of price and production risks and its covariance, (ii) the level of risk aversion, and (iii) the forward contract decision. As such, there is no separability between the use of *li* technology and the use of a forward contract.

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[8] If the farmer is risk neutral, $U'(\pi)$ is constant and $-(h-\alpha)\left[\frac{y_c cov(U'(\pi), \tilde{p}_p)}{EU'(\pi)}\right] - \alpha\left[\frac{cov(U'(\pi), \tilde{y}_{li}\tilde{p}_p)}{EU'(\pi)}\right] = 0$. Then, MRP is zero and $EMR = C'_{li}(\alpha L)$.

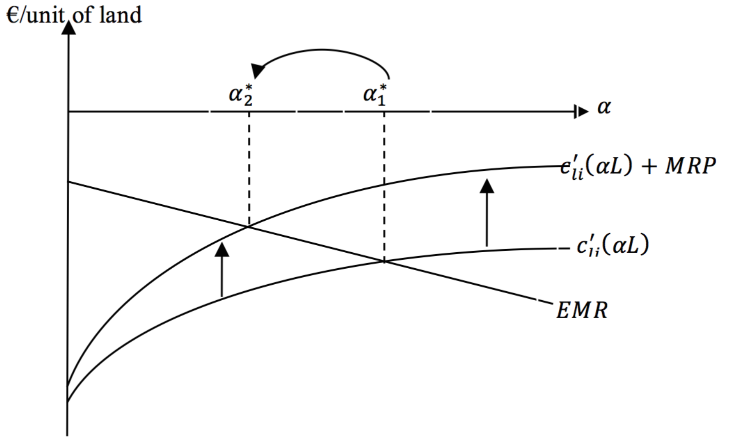

Figure 1. Optimal Use of the Low-Input (li) Technology

The Impact of Direct Support and Price Risk

In the changing context of grain production, EU farmers are expected to become increasingly more exposed to price risk while increasingly less supported by CAP direct payments. It is essential to discuss the potential effects of these changes on production technology and marketing choices. Comparative statics have been performed and can be summarized as follows.

LEMMA 1. *Under decreasing absolute risk aversion (DARA) preferences we have:* $\frac{\partial h}{\partial D} \leq 0$ *and* $\frac{\partial \alpha}{\partial D} \geq 0$ *(see proof in appendix B).*

This lemma means that under DARA preferences, an increase in direct payment (D) increases the optimal conversion rate (α^*) and decreases the optimal demand for forwarding contracts (h^*). This effect on farmers' choices can be explained by the wealth effect described by Hennessy (1998). Direct payments enhance farmers' wealth and encourage them to bear more risk by increasing the level of production. Our result is based on the same argument and shows that direct payments might encourage DARA farmers to use riskier technology by increasing the adoption rate of *li* technology and to restrict the use of hedging tools.

LEMMA 2. *Let* η_p *be the standard deviation for harvest spot price. Suppose that* y_{li} *is certain. Under DARA-Constant Relative Risk Aversion (CRRA) or DARA-Increasing Relative Risk Aversion (IRRA) preferences we have:* $\frac{\partial h}{\partial \eta_p} \geq 0$ *and* $\frac{\partial \alpha}{\partial \eta_p} \leq 0$ *(see proof in appendix B).*

The second result obtained through comparative static is that under the assumption of DARA-CRRA or DARA-IRRA preferences, and if yield risk from the *li* technology is assumed away, an increase in price risk decreases the optimal conversion rate (α^*) and enhances the optimal demand for forwarding contracts (h^*).

The effect of an increasing exposure to price risk is opposite to an increase in direct payments. As expected, farmers will be less inclined to use *li* practices that increase yield risk. This is due to the insurance effect caused by greater price instability, which puts a brake on risk-inducing choices. The insurance effect also has an impact on the forward decision since higher fluctuations in output prices lead to greater quantities hedged.

The main conclusions to be drawn from this model are that the use of *li* technology is influenced by farmers' hedging decisions. Moreover, agricultural policy changes affect the use of *li* technology both directly and indirectly. The wealth and insurance effects directly impact production decisions. Indirectly, these effects also influence hedging decisions, which affect technological choices in return since hedging and technological decisions are not separable. The supply of hedging tools acts

Table 2. Attributes of Marketing Contracts

	Average Price	Price Risk Exposure	Effect on Cash Flow Constraint
Pool contract	Medium	Medium	Medium
Storage contract	Strong	Strong	Strong
Forwarding contract	Weak	Weak	Weak

Notes: The earlier and the higher the payment, the less the effect on the cash-flow constraint.

as a buffer and smooths the effect of agricultural policies on farmers' technology choices. These two decisions have to be considered jointly to assess the extent to which agricultural policies have an impact on the willingness of farmers to lead the transition toward greener practices. Eventually, other types of marketing contracts can be considered. For example, higher direct payments might provide an incentive to speculate on grain markets through storage.

In the next section we turn to a numerical application to test our hypothesis. We built a mathematical programming risk model and apply it to a representative farmer of the Midi-Pyrénées region to consider a large set of crops and marketing contracts.

Empirical Application

Case Study Area

The case study is located in the Midi-Pyrénées region, which is the largest French region in terms of agricultural land and crop farming. But this region faces serious water quality problems as a result of pesticide contamination. In 2012, the regional water quality agency, which annually monitors the concentration of water pollutants, detected 71 types of pesticide molecules (of over 140 checked), especially herbicides, in both surface and groundwater. In surface water, 75% of stations found at least 0.1 microgram per liter of one pesticide molecule, which is the regulatory norm. In groundwater, 45% of the observed stations detected pesticide molecules, of which 11% were above the regulatory norm (Agence de l'Eau, 2013).

The two main crops are durum wheat and sunflower, which account for 26% and 27% of the total French supply (Agreste, 2009) but do not benefit from futures markets. Marketing contracts issued by co-ops are thus critical to helping farmers cope with price fluctuations. Three main marketing contracts are supplied to farmers. First, pool contracts require the producer to deliver his grain at harvest; the quantity is priced at the average sale price received by the co-op. The first payment is made just after harvest, when the co-op pays the farmer an average deposit based on its forecasts (minus administrative costs). If the price at the end of the marketing season is higher than the forecasted price, the co-op pays the farmers the price difference. Therefore, a pool contract smooths intra-annual price risk and protects against downward price movements while still giving farmers the opportunity to benefit from upward price fluctuations. Second, storage contracts allow the farmer to store the grain after harvest in the co-op's collection silos and decide the sale date on his own. Third, forward contracts bind the farmer to deliver at harvest a specified quantity of grain at a price agreed upon before harvest. Table 2 presents how the main attributes of these contracts compare.

Since a pool contract sets an average annual price, the degree of risk exposure is expected to be lower than that under a storage contract but higher than that under a forward contract. However, a higher average price is expected from a storage contract and a lower one from a forward contract. The payment under a forward contract occurs at harvest, while the average price from a pool contract is paid over two periods (just after harvest and at the end of the marketing campaign). In terms of cash flow, this means that a forward contract is slightly more attractive in terms of cash flow than a pool contract and much more attractive than a storage contract (where the payment occurs only when the grain is sold).

The Risk Programming Model

A farm model combining mathematical programming and risk simulation tools is built and simulated over one planning horizon (one year). The year is divided into twelve one-month periods. The model is multiperiodic and static since all decisions are in the first period for the whole planning horizon. Decision variables relate to production (crop mix and technology), marketing contract choice, and short-term financing (short-term borrowing). A detailed description of the model and equations are provided in the online supplement.

The Farmer's Decision Problem

Farmers make production, marketing, and financing decisions so as to maximize the expected utility of stochastic profit over the planning horizon, Z. These preferences over profit distribution, π, are represented by a power utility function of DARA-CRRA type noted $U(\pi)$,[9] where the coefficient of relative risk aversion is noted r:

$$Z = EU(\pi) \quad \text{with} \quad U(\pi) = \left(\frac{1}{1-r}\right)\pi^{1-r}. \tag{7}$$

The literature suggests that the coefficient of relative risk aversion with respect to wealth level (W), $r(W)$, varies between 0 (for risk-neutral farmers) and 4 (extremely risk-averse farmers) (Hardaker, Huirne, and Anderson, 2004). But as far as the utility of profit $U(\pi)$ is considered, the relative risk aversion with respect to profit $r(\pi)$ has to be included. Considering $E(\pi)$ as the expected profit, the link between $r(W)$ and $r(\pi)$ is given by (see Hardaker, Huirne, and Anderson, 2004):

$$r(\pi) = \frac{E(\pi)}{w} r(W). \tag{8}$$

The stochastic profit (π) is defined as the difference between the receipt minus the costs. The total receipt is composed of the total value of sales of outputs and CAP supports that consist of arable area payments and decoupled single farm payment (SFP).[10] The costs are composed of (i) variable costs (seeds and chemical inputs purchases, labor and mechanization costs), (ii) storage costs (a fixed fee plus a payment per month of storage), (iii) credit costs, and (iv) a fixed cost.

Crop Production Choice

The production choice consists of allocations between each land type (irrigated and non-irrigated) and across the six main crops of the study area (soft wheat, durum wheat, non-irrigated corn, irrigated corn, sunflower, and rapeseed). Crops are cultivated using either conventional or low-input techniques. The conventional technique is the most widespread in the region. The low-input technique increases labor in exchange for chemical inputs and modifies some technical operations (tillage operations, sowing date). The cost decrease linked to the reduction of chemical inputs compensates for more than the loss due to lower average yields and higher labor costs (appendix A). In the optimization model, the technology choice is arbitrated under structural constraints (land resource) and agronomic constraints (crop rotation).

Marketing Contract Choice

In the model, the harvested crop can be sold through one or more marketing contracts. Three types of contracts (K) are proposed: pool contracts (K1), storage contracts (K2), and forward contracts

[9] The wealthier the farmer is, the less averse to intratemporal variations he is.

[10] We assume that all of the land on the farm is eligible for the SFP so that the number of payment entitlements equals the area of land held.

Table 3. Model Parameters

Parameter	Value
AAP[a]	Durum area: €30/ha; other crops: €0/ha
SFP[a]	€300/ha
Storage costs[b]	€6/t plus €0.6/t/month
Interest rate[b]	4%
Discount factor	3%
Fixed charges[a]	€45,290
Maximum short-term credit[a]	€39,800

Notes: [a] Data provided by the regional extension service. [b] Assumed at commercial rate.

(K3). French grain farmers who want to sell at harvest cannot use a cash transfer at harvest but must use the pool contract, which has a price setting very close to the cash transaction at harvest.

Our risk model accounts for three main attributes of the contracts: the average price, the price risk content, and the payment date. Depending on the level of each attribute, the contract choice will be more or less influenced by price enhancement, price volatility, and cash flow considerations.

The quantities stored can be sold at only two periods, which differ according to crop.[11] The stock of grain available at the end of period is entirely transferred at the beginning of the next period.

Short-Term Financing Decision

The level of cash available on the farm at the beginning of each period is the balance of receipts (from grain sales and CAP subsidies) and withdrawals (purchases associated with crop-growing activities) plus any remaining cash from the previous period. Moreover, short-term borrowing can be used with repayment of the principal plus interest in the last period of the year.

Farm Data and Risk Assessment

Farm Data

The parameters of the regional farm as well as the observed crop activities choice were set according to the Farm Accountancy Data Network (FADN), the official European database gathering annual physical, structural, economic, and financial data from approximately 5 million EU farms and covering approximately 90% of the agricultural land. Estimates were obtained after selecting in the database the 240 arable farms of the study area for the year 2008. The representative farmer has an average arable area of 107 hectares, of which 14 hectares are irrigated (table 3). The observed crop-allocation choices of the representative farm were also obtained from the FADN and allowed us to check the consistency between simulated and observed crop choices.

Cost and return data for crop activities were obtained from regional references for the year 2007 provided by the regional extension services (Regional Chamber of Agriculture). These references have been also validated by interviewing regional experts.

Relative Risk-Aversion Coefficients

Based on the classification proposed by Hardaker, Huirne, and Anderson (2004), we used four levels of coefficients for relative risk aversion: risk neutral ($r(W) = 0$), normally risk averse ($r(W) = 1.1$), rather risk averse ($r(W) = 2.1$) and very risk averse ($r(W) = 3.1$). According to the FADN database, the expected profit, $E(\pi)$, in the region is about €46,950 and the mean value of wealth is €241,280.

[11] To choose the two periods for selling from storage, we selected the periods with the highest average price (net of storage costs) by calculating the seasonal coefficients for each crop price series. After the choice of periods was made, average prices and empirical cumulative density functions were computed.

The ratio of wealth to income can be viewed as rather low (5.1), but it is actually rather high according to other studies that used the same method to compute the relative risk-aversion coefficient in terms of income $r(\pi)$. Lien and Hardaker (2001) used a ratio of 4.5 for Norwegian farms, and Havlík et al. (2005) used a ratio of 3.2 for suckler cow farms in central France. The resulting coefficients are $r(\pi) = 0$ (risk neutral) $r(\pi) = 0.2$ (normally risk averse), $r(\pi) = 0.4$ (rather risk averse) and $r(\pi) = 0.6$ (very risk averse) (see equation 6).

Risk Simulation

Stochastic simulations have been performed to introduce income variability and possible correlations between price and yield distributions. We followed the semi-parametric Monte Carlo procedure proposed by Richardson, Klose, and Gray (2000), who estimated and simulated a multivariate empirical probability distribution function of yields and prices using a normal copula function.

This approach deals with three important aspects of risk in agriculture. First, it assumes that yield and price distributions might be asymmetric (Just and Weninger, 1999). This point is particularly relevant since farmers' decisions are supposed to be influenced by asymmetric distribution (Di Falco and Chavas, 2006). Second, the procedure accounts for correlations among random variables. Third, the heteroskedasticity of random variables is controlled over time and several levels of price risk can be simulated.

This procedure is particularly well adapted to simulating several levels of price risk, unlike the direct use of historical data, which provide only actual past price risk. Furthermore, Lien et al. (2009) showed that it is useful to smooth sparse data out using a non-parametric procedure.

Implementing this method requires data on: (i) the mean and the cumulative density functions of both conventional and *li* crop yields, (ii) the mean and the cumulative density functions of crop prices under each specific marketing contract, and (iii) the correlation matrix for all the random variables. We used time-series observations of regional average yields (1975–2008) and national monthly product prices (1993–2006).[12] The use of aggregated yield data at the regional level may underestimate the production risk to which farmers are exposed. We estimated parameters and simulated the multivariate empirical distribution from detrended yields and price series to correct for technical progress and inflation, respectively. Crop yields were detrended by regressing yield against time. Prices were corrected by using the inflation index of prices. It is important to note that we deliberately left out observations related to the commodity price peak of 2007–2008. Therefore, the baseline scenario corresponds to a weak price risk, as experienced by farmers before 2007.

Finally, a Latin-Hypercube Sampling (LHS) was used to generate fifty equally probable states of nature.[13] The simulated set is not presented here, but we display means and coefficients of variation (CV) of gross margins for each alternative resulting from simulations (appendix C).

Data on Low-Input Practices

During a workshop, agricultural experts designed low-input technologies that contribute to enhance water quality.[14] We relied on the opinion of these experts to estimate the level of yield risk linked to these *li* technologies. The density function of *li* technology was elicited during this workshop using the visual impact method (Hardaker, Huirne, and Anderson, 2004). It is worth noting that the estimation of yield risk under *li* technology reflects the subjective probability determined by the experts rather than the objective probability, as in the case of the conventional technology. But the elicitation of subjective beliefs is a reasonable alternative, even if it might overestimate the yield

[12] Data derived from regional (AGRESTE) and national (FranceAgriMer) statistics departments.

[13] Lien et al. (2009) show that fifty states of nature generated by Latin-Hypercube sampling are sufficient to ensure the stability of the farm model's solution.

[14] This workshop was held in February 2010 in Toulouse with agronomists (from INRA) and teachers (from the two agricultural universities in Toulouse).

risk, given the lack of objective data about yield risk. Nevertheless, because the technology is new to them, farmers are likely to overestimate the risk compared to both reality and the experts.

Scenarios and Results

Two scenarios test whether the use of specific marketing contracts could act as a buffer to smooth the impact of new public policies on technological choice. The baseline scenario is modified to explore two new scenarios: a pure policy scenario and a mixed policy and technical adjustment scenario. Under the former, an increase in price risk and/or a decrease in direct payments are simulated. The price risk is enhanced by 50% and then by 100% compared to the baseline scenario with an expansion factor (E) with a value of 1.5 (+50%) and 2 (+100%). As a reference, introducing the crop prices for 2007 and 2008 leads to an expansion factor of 1.8 (+80%). Therefore, the baseline scenario (E=1) corresponds to a weak price risk (before the price peak of 2007), the scenario where E=1.5 gives an intermediate price risk level, and the scenario where E=2 corresponds to a high price risk level, which is realistic and reasonable. The drop in single farm payment is simulated from €300 to €150 in intervals of €50.

The mixed policy and technical adjustment scenario proposes the same set of policy changes as the pure policy scenario but also assumes that adjustments that would reduce the production risk of *li* technology to the same level as the conventional one are technically feasible. This scenario is considered so that we do not take for granted that *li* technology will definitely lead to an increase in production risk. First, different risks associated with pesticide uses (e.g., uncertainties about the level of pest infestation, chemical efficacy, pesticide damage to crops, level of crop yield loss caused by pests) may tend to cancel out so that the exact impact of a reducing pesticide use on risk level is not necessary negative (Pannell, 1991). Actually, while the subjective yield distributions of *li* technology elicited from experts are in accordance with other papers showing that the use of this technology leads to higher production risk in France and more generally in Europe (Antle, 1988; Carpentier, 1995; Pingali and Carlson, 1985; Uri, 2000), it is much less systematic in other regions such as in the United States. This is because conventional practices for arable farming in Europe are much more intensive than in the United States, leading to a higher risk of pest infestation (Aubertot et al., 2005). Second, farmers' perception of production risk may drop as farmers gain experience in the new technology and have a better knowledge of its returns (Abadi Ghadim and Pannell, 1999). To simulate the reduction in production risk, for each crop (j) we take the corresponding simulated yield series under the low-input technology (li) and reduce its standard deviation ($SD_{j,li}$) to a new value ($SD^{new}_{j,li}$), so that

$$(9) \qquad CV_{j,c} = \frac{SD^{new}_{j,li}}{\bar{y}_{j,li}} \Rightarrow SD^{new}_{j,li} = CV_{j,c} \times \bar{y}_{j,li},$$

where $CV_{j,c}$ is the coefficient of variation of the yield series for crop j under conventional technology c and $\bar{y}_{j,li}$ is the average yield of the crop j under technology li. The ratio $F_j = \frac{SD^{new}_{j,li}}{SD_{j,li}}$ can be viewed as an expansion factor (e.g., $F_j = 0.5$ supposes a 50% reduction of the production risk for the crop j under technology li).

Eventually, two cases are examined under each scenario: (i) a case where only pool contracts are made available and (ii) a case where all marketing contracts are made available. Case 1 corresponds to the period before the mid-2000s when farmers had no choice but to use pool contracts. Marketing decisions were delegated to the co-op, and farmers only had to deal with production decisions. Case 2 corresponds to the current situation in which farmers can choose among several marketing arrangements to mitigate price risk or to speculate thanks to storage contracts. By comparing both cases we can test for the specific impact on farm cropping decisions of the availability of a wide range of marketing contracts and then empirically assess interactions between marketing and production decisions under both price and production risks. Table 4 summarizes the simulations performed.

Table 4. Set of Experimental Patterns

	Baseline		Pure Policy Scenario		Mixed Policy and Technical Adjustment Scenario	
	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
Price risk	Weak (E=1)		Intermediate (E=1.5) ; High (E=2)			
SFP	€300/ha		€300/ha to €150/ha, by intervals of €50/ha			
Production risk of *li* technology	As elicited from regional experts: $F_j = 1$					Same CV as conventional technology: $F_{soft\ wheat} = 0.45$, $F_{durum\ wheat} = 0.51$, $F_{non-irrigated\ corn} = 0.47$, $F_{irrigated\ corn} = 0.36$, $F_{sunflower} = 0.5$, $F_{rapeseed} = 0.54$

Notes: Case 1: pool contracts only; case 2: all contracts.

Table 5. Baseline Scenarios for Case 1 (Pool Contracts Only)

	Level of Risk Aversion			
Relative risk aversion (r)	0	0.2	0.4	0.6
Average Gross Margin (€)	54,622	54,526	54,503	54,455
Coefficient of variation of GM	26.1	18.8	18	17.9
Simulated conversion rate (%)	87	74	69	67
Optimal Cropping Plan (ha)				
Conventional practice:				
Irrigated corn	14	14	14	14
Sunflower		14.3	19.3	21
Low-input practice:				
Soft wheat		20.8	24.4	25.7
Durum wheat	55.8	35	31.4	30.1
Non-irrigated corn	13.9	13.9	13.9	13.9
Rapeseed	23.3	9	4	2.3

Notes: Only the crop activities selected in the optimal crop mix are shown in the table.

Baseline Scenario

Case 1: Availability of Pool Contracts Only

Economic and agronomic results for the four levels of risk aversion are given in table 5. Not surprisingly, while risk-neutral farmers choose the most profitable crops, risk-averse farmers diversify their crop mix: they partially replace durum wheat and soybean with soft wheat and sunflower, respectively, which are less risky. This result is similar to the finding made by Di Falco and Perrings (2005), which revealed that risk aversion is an important driving force for crop diversity.

We present the Simulated Conversion Rate (SCR), defined as the proportion of area cultivated using *li* practices over total area cultivated. The value of SCR is high, revealing the economic attractiveness of the *li* practice when compared to the conventional one, even if it decreases with the level of risk aversion.

Case 2: Availability of All Marketing Contracts

Here, all the marketing contracts are available and can help to manage price risk. Sales are shared between storage and pool contracts (see table 6). As expected, the higher the level of risk aversion,

Table 6. Baseline Scenario for Case 2 (All Contracts)

	Level of Risk Aversion			
R	0	0.2	0.4	0.6
Average Gross Margin (€)	56,162	56,150	55,905	55,730
Coefficient of variation of GM	27.8	27.8	23	20.4
Simulated conversion rate (%)	87	87	78	74
Optimal Cropping Plan (ha)				
Conventional practice:				
Irrigated corn	14	14	14	14
Sunflower			10.2	14.3
Low-input practice:				
Soft wheat			9.5	16.3
Durum wheat	55.8	55.8	46.3	39.5
Non-irrigated corn	13.9	13.9	13.9	13.9
Rapeseed	23.3	23.3	13.1	9
Optimal Marketing Contract Choices (%)[a]				
Pool contract	14	14	21	28
Storage contract	86	86	79	72
Forward contract				

Notes: Only the crop activities selected in the optimal crop mix are shown in the table.
[a] Percentage of the production (in value) sold under a given marketing contract.

the larger the share of pool contracts, since the latter type of contract enables price risk to be mitigated. Forward contracts, which eliminate exposure to price risk, are not used at any level of risk aversion.

Except for the risk-neutral farmer, the cropping plan is somewhat modified compared to case 1. In fact, the availability of marketing contracts makes risk-averse farmers able to preserve risky cropping systems such as rapeseed cultivated under *li* technology rather than conventional sunflower. Hence, the drop of the SCR with the level of risk aversion is much less pronounced than under case 1, which shows that it is more profitable for a producer to manage risk through safer marketing contract, and to keep cropping systems with higher returns rather than the other way around. It also reveals interdependency between marketing and production choices.

Comparison between Observed and Simulated Crop Choice

To compare observed and simulated land use we select the simulated normally and rather risk-averse farmers. We also aggregate activities per crop type since no disaggregated data exist at the technological level. Simulated crop choices are reasonably close to the observed data (see table 7), especially for the case where the simulated farmer is rather risk averse. The model adequately simulates the choice of the crop even if it favors rapeseed over sunflower in case 2. Sunflower is usually used by farmers as a precedent crop to improve wheat yield the following years, but such dynamic aspects of the crop decision are not included in the model.

Pure Policy Scenario: Testing the Impact of an Increase in Price Risk and a Decrease in CAP Subsidies

Case 1: Availability of Pool Contracts Only

To compare the effect of marketing contract availability on the farmer's technological choice, we graphically compare the value of the simulated conversion rate (SCR) for each simulation and each

Table 7. Comparison between Observed and Simulated Crop Mix (in ha)

		Simulated			
		Case 1 (Pool Contracts Only)		Case 2 (All Contracts)	
	Observed	R=0.2	R=0.4	R=0.2	R=0.4
Soft wheat	21.39	20.8	24.4	0	9.5
Durum wheat	25.11	35	31.4	55.8	46.3
Non-irrigated corn	9.3	13.9	13.9	13.9	13.9
Irrigated corn	14	14	14	14	14
Sunflower	23.25	14.3	19.3	0	10.2
Rapeseed	13.95	9	4	23.2	13.1

Source: FADN.

Table 8. Impact of a Reduction in Single Farm Payment (SFP) under a Given Scenario and Price Risk Level

Relative Risk Aversion	Price Risk Level	Case	Pure Policy Scenario	Mixed Policy & Technical Adjustment Scenario
r= 0.2	Low (E=1)	1	−5	−2
		2	0	−1
	Intermediate (E=1.5)	1	−6	−2
		2	0	0
	High (E=2)	1	−25	0
		2	−3	0
r= 0.4	Low (E=1)	1	−8	−3
		2	−2	0
	Intermediate (E=1.5)	1	−4	−3
		2	−2	0
	High (E=2)	1	−15	−3
		2	−2	0
r= 0.6	Low (E=1)	1	−6	−2
		2	−2	−3
	Intermediate (E=1.5)	1	−3	−3
		2	−2	−2
	High (E=2)	1	−11	−4
		2	−1	−2

Notes: Values indicate changes in percentage points between a €300 SFP to a €150 SFP (e.g., under the pure policy and low price risk scenario, the reduction in the SFP from €300 to €150 decreased the SCR by five percentage point when only pool contracts are available (case 1).

case. Figure 2 shows results for normally, rather, and very risk-averse farmers. The bar charts on the left side of figure 2 (case 1) show that the SCR decreases as price risk increases and/or as the SFP decreases, particularly for rather and very risk-averse farmers. This decrease is explained by the insurance effect (due to a higher price risk) and the wealth effect (due to lower SFP) that induce a reallocation of crop activities toward less risky (i.e., conventional) farming practices that require more chemical inputs. Even if *li* technology is still very attractive under each simulation, there is a significant downturn of the SCR for all levels of risk aversion. For example, we report for the rather risk-averse farmer a decrease of 15 percentage points in the SCR (69% to 54%) from the baseline scenario to the scenario with a high price risk exposure (E=2) and a decrease of the SFP of 50% (SFP=€150). All the changes in percentage points of the SCR are given in table 8.

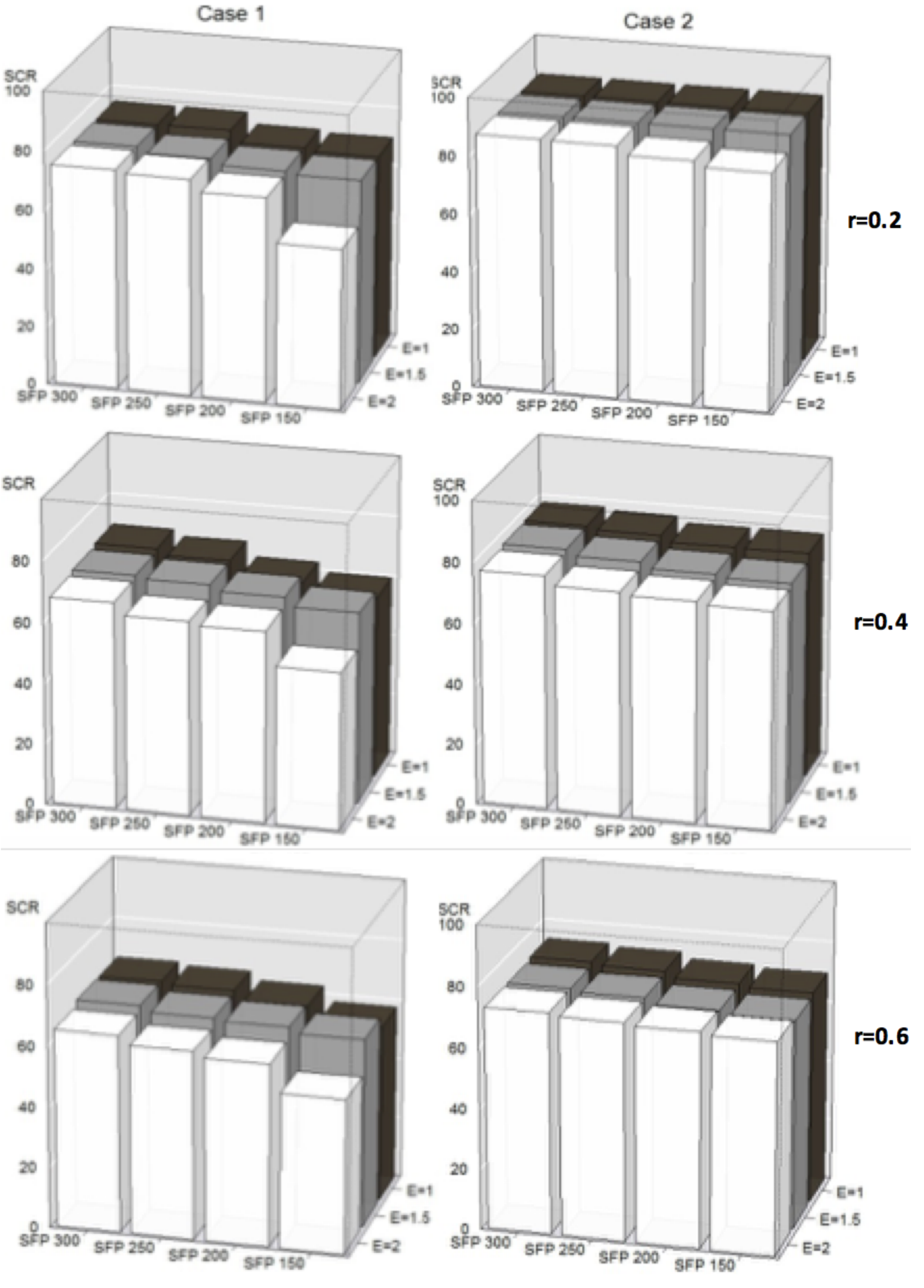

Figure 2. Changes in the Simulated Conversion Rates under the Pure Policy Scenario

Notes: The SCR on the vertical axis are functions of price risk exposure (E=1; E=1.5;E=2) and the level of SFP (varies from €300 to €150) under case 1 - only pool contracts are available (left side) - and case 2 - all contracts are available (right side)—and for three levels of risk aversion: r=0.2 (top), r=0.4 (middle), r=0.6 (bottom).

Case 2: Availability of All Marketing Contracts

The bar charts on the right side of figure 2 give the values of the SCR under each scenario when all the marketing contracts are available. We observe that whatever the farmer's risk-aversion level, the response of the SCR to increasing price fluctuation or decreasing direct payments is weak. Values given in table 8 confirm this result; while changes can be up to −25 percentage points, under case 2 changes in the SCR do not exceed −3 percentage points. The adoption of *li* technology is thus much more robust in relation to policy changes than in the case where only pool contracts are available. For the rather risk-averse farmer, the scenario with a high price risk exposure (E=2) and a decrease of the SFP of 50% (SFP=€150) induces a decline of only 2 percentage points in the SCR from the baseline scenario (compared to −5 points in case 1). This robustness of the SCR is observed for all levels of risk aversion. This result means that insurance and wealth effects induced by agricultural policies on production choices are lower when farmers can spread their sales among several marketing contracts. The different marketing alternatives contribute to the stabilization of production choices. Furthermore, the sales of grain under the different marketing arrangements (see figure 3) show that farmers react to higher price risk exposure or vulnerability (decrease in SFP) by modifying their marketing choices. Indeed, the use of storage contracts declines steadily when price risk increases and/or SFP decreases (from 74% of the sales to 58% for the rather risk-averse farmer) while the proportion of the production sold under pool contracts increases (from 26% to 38% for the rather risk-averse farmer). When the drop in SFP is combined with a higher price risk, forward contracting emerges as an appropriate marketing strategy to mitigate price risk (until 4% of the sales for the rather risk-averse farmer).

Mixed Policy and Technical Adjustment Scenario

Under this scenario, the level of risk between the two technologies is the same, so that the simulated farmers will make technological choices only with respect to gross margin considerations. When only pool contracts are available (case 1), we observe that the SCR is very stable. But in case 2, there is no significant difference between the two scenarios apart from the fact that a higher level of risk aversion does not induce a lower SCR (see table 8 and the figures in the online supplement). Once again, the menu of marketing contracts allows simulated farmers to curb changes to the cropping system. Regarding these marketing choices, we notice that changes are less marked relative to the previous scenario (figure S2) in the online supplement shows the least use of pool and even forward contracts as price risk increase and the value of SFP drops). This may be because there is no more need to suffer a higher risk at the farm level in order to adopt the most profitable technology (*li* technology). Thus, the necessity of protecting against adverse price levels is reduced.

Discussion and Conclusion

For several years now, direct payments allocated to European cash crop farmers have been declining, while the exposure of those farmers to world commodity markets has been increasing. These changes are already perceived at the supply chain level, with grain collectors offering farmers new types of marketing contracts. In parallel, farming systems have had to adapt to the higher pressure for more sustainable agronomic practices. These recent changes in farmers' economic environment make it important to study marketing contracts as tools for the management of price risk and the adoption of low-input practices.

Despite an understanding of the main determinants of the use of risk management tools in general and futures and option contracts in particular (e.g., Pennings and Leuthold, 2000; Pennings et al., 2008; Franken, Pennings, and Garcia, 2012), very few studies have focused on the interaction between these risk management tools and the adoption of new technologies. While some theoretical studies have discussed the separation of production and marketing decisions, here we have focused

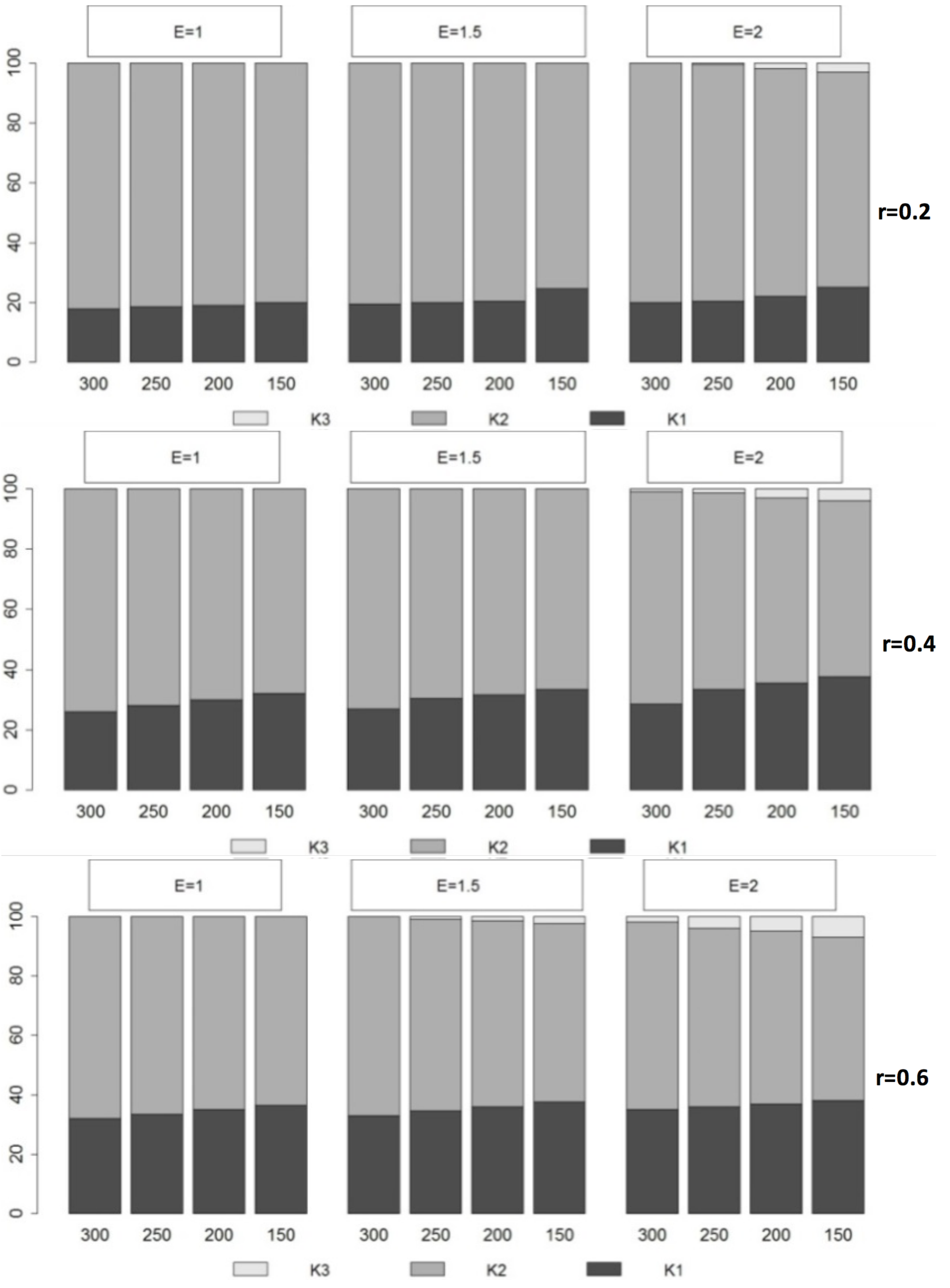

Figure 3. Changes in the Marketing Contract Choices under the Pure Policy Scenario

Notes: Changes (in %) on the vertical axis refer to case 2 - all contracts available for three levels of risk aversion: r=0.2 (top), r=0.4 (middle), r=0.6 (bottom). K1 represents pool contracts, K2 storage contracts, and K3 forward contracts. The level of SFP is given at the bottom of each bar chart.

on these interactions by assessing the extent to which marketing contracts could help farmers adopt greener but riskier practices. The results of the theoretical model presented here advocate the relevance of this issue since they show that adoption of *li* technology is influenced by the use of forward contracts. Results also show that agricultural policies affect the decision to use forward contracts, which in return influences the use of the new technology.

A numerical model combining mathematical programming and stochastic simulation has been built to empirically assess the significance of interactions among agricultural policies, marketing contracts, and technological choices. It has been applied to a representative farm of the Midi-Pyrénées region. We find that in an income support environment, risk-averse farmers are more likely to use pool contracts, which partially reduce price risk, rather than forward contracts. In our simulations, forward contracts are little used and do not exceed 10% of grain sales at maximum, even with strong risk aversion, a high level of price risk, and a lower direct payment. These results contribute to the ongoing debate on the explanations behind the low use of forward contracts by showing that government policies tend to reduce the demand for hedging (Coble et al., 2004; Woolverton and Sykuta, 2009). They also help explain results from *ex post* analyses showing that forwarding is not used much by risk-averse farmers (Pennings and Garcia, 2001; Simmons, 2002; Pannell et al., 2008; Pennings et al., 2008) and may actually be used together with market advisory service recommendations in order to enhance the selling price (Tomek and Peterson, 2001; Pennings et al., 2004). In other words, farmers do not use forward contracts to mitigate price risk but rather to avoid an expected loss on the basis of their price expectations. This may be the main reason why new contracts relying on fixed prices are developing in France, to the detriment of pool contracts.

Simulation results also show that the wide availability of marketing contracts contributes to steady production choices under price risk change and shed light on the mitigation effect of marketing contract decisions on technological choices when agricultural policies are modified. By choosing a certain level of price risk through the choice of marketing contracts set, farmers can manage the increasing price fluctuation and adopt greener (even if riskier) practices. This result questions the empirical relevance of the impact of direct payments on production decisions through the wealth effect. While the theoretical literature has identified a wealth effect when farmers are given direct payments, empirical *ex post* analyses do not show any significant impact on production decisions (Bhaskar and Beghin, 2009). To account for this gap between theoretical and empirical observations, several arguments have been put forward, including (i) the low proportion of direct payments compared to the total revenue of the farmer (Sckokai and Antón, 2005); (ii) the impact of direct payments on input use, which affects production risk (Serra et al., 2006); (iii) the effect of direct payments on land value, which makes the landowner, rather than the farmer, the final beneficiary (Femenia, Gohin, and Carpentier, 2010). Results obtained here suggest another hypothesis: the direct payment may first affect marketing decisions that "buffer" income risk. As a result, production adjustments are marginal compared to the case where farmers cannot adjust their marketing choices. The underlying explanation may be that agronomic, technical, structural, and financial constraints act on farming systems to make production and technological decisions much less flexible than marketing decisions.

Our study suffers several limitations. We did not account for all existing farm-level constraints, especially scarcity of labor resources, which is often perceived as a barrier to the adoption of low-input technology in the study area (Ridier et al., 2013). Moreover, switching to a new technology is likely to involve indirect costs, such as learning and transaction costs, not included here. This limitation explains the large SCR in our results, which is certainly overestimated. Nevertheless, given that we have built the numerical model to provide insights into the interactions among agricultural policies, technological choices, and marketing decisions rather than to identify specific constraints to the adoption of *li* technology, the likely overestimation of the adoption is not detrimental to the analysis. Moreover, we did not consider recent advances in the behavioral economics and psychological literature that could improve our understanding of how farmers deal with hedging decisions and complex decision problems more generally (Mattos, Garcia, and Pennings, 2008;

Pennings et al., 2008). Addressing the issues related to the interactions between production and marketing decisions using concepts from these frameworks provides interesting scope for further research.

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Appendix A:
Technical Details on the Low-Input Technology

Technical changes under the low-input technology (relative to the conventional technology) used in the analysis are specified as follows:

Before sowing	Substitution of mechanized weeding for herbicide dose (no more use of herbicides) Reduction of fertilizers by 50%
At sowing (for cereal only)	Drop in plant density by 30%
Vegetative phase	Partial substitution of mechanized weeding for herbicide dose (−60% of herbicide)
	Reduction of fungicides and insecticides by −60%
	Reduction of fertilizers by −20%
	Reduction of irrigated water by −20% (irrigated corn only) compensated by a new varietal choice and an early sowing

This technology consists of a new combination of production factors. Furthermore, there are no specific substitutes to the strong reduction of fungicides and insecticides (at least for the technology studied here) and the substitute to herbicide (mechanical weeding) is only partial. Given also that the Midi-Pyrénées region is exposed to strong climatic risk, the use of low-input technology is expected to lead to a higher perceived yield risk for the farmers who adopt it.

Appendix B: Proofs Related to an Increase in Direct Payment and Price Risk

The following proofs are based on Sandmo (1971) and Dalal and Alghalith (2009).

LEMMA 1. *Under DARA preferences we have:* $\frac{\partial h}{\partial D} \leq 0$ *and* $\frac{\partial \alpha}{\partial D} \geq 0$.

Proof that $\frac{\partial h}{\partial D} \leq 0$. First derivation of equation (3b) with respect to the direct support D gives

$$\frac{\partial h}{\partial D} = \frac{-\frac{\partial^2 EU}{\partial h \partial D} H_{11}}{|H|}. \tag{B1}$$

From the second-order conditions, we know that $|H| > 0$ and $H_{11} < 0$, so the sign of $\frac{\partial h}{\partial D}$ is the same as $\frac{\partial^2 EU}{\partial h \partial D}$.

$$\frac{\partial^2 EU}{\partial h \partial D} = LEU''(\pi)[(a\tilde{y}_i + (1-\alpha)y_c)(P_f - \tilde{P}_p)]. \tag{B2}$$

We have to show that equation (B2) is non-positive. Let $\overline{\pi}$ be the profit when $\tilde{B}(P_f - \tilde{P}_p) = 0$, with $\tilde{B} = \alpha\tilde{y}_i + (1-\alpha)y_c$. Since the farmer is DARA, we have

$$\tilde{B}(P_f) - \tilde{P}_p = 0 = \Leftrightarrow \pi \geq \overline{\pi} \Rightarrow r_a(\pi) = -\frac{U''(\pi)}{U'(\pi)} \leq r_a(\overline{\pi}), \tag{B3}$$

which implies $-U''(\pi) \leq r_a(\overline{\pi})U'(\pi)$.

Moreover, for $\tilde{P}_p \geq P_f$, we have

$$-U'(\pi)(\tilde{B}P_f - \tilde{B}\tilde{P}_p) \geq 0. \tag{B4}$$

Multiplying equation (B3) by equation (B4), we obtain

$$U''(\pi)(\tilde{B}P_f - \tilde{B}\tilde{P}_p) \leq -r_a(\overline{\pi})U'(\pi)(\tilde{B}P_f\tilde{B}\tilde{P}_p) \quad \forall \quad \tilde{P}_p. \tag{B5}$$

Take expectations of both sides yields:

$$E[U''(\pi)(\tilde{B}P_f - \tilde{B}\tilde{P}_p)] \leq -r_a(\overline{\pi})E[U'(\pi)(\tilde{B}P_f - \tilde{B}\tilde{P}_p)] = 0, \tag{B6}$$

where the last equality is implied by equation (3b). We thus have proved the wealth effect on the optimal farmer's hedging demand.

Proof that $\frac{\partial \alpha}{\partial D} \geq 0$. First derivation of equation (3a) with respect to the direct support D gives

$$\frac{\partial \alpha}{\partial D} = \frac{-\frac{\partial^2 EU}{\partial \alpha \partial D} H_{22}}{|H|}. \tag{B7}$$

From the second-order conditions, we know that $|H| > 0$ and $H_{22} < 0$, so the sign of $\frac{\partial \alpha}{\partial D}$ is the same as $\frac{\partial^2 EU}{\partial \alpha \partial D}$.

$$\frac{\partial^2 EU}{\partial \alpha \partial D} = EU''(\pi)[L(\tilde{y}_i - y_c)(hP_f + (1-h)\tilde{P}_p) - Lc_i'(\alpha L)]. \tag{B8}$$

We have to show that equation (B8) is non-negative. Let $\overline{\pi}$ be the profit when $c_i'(\alpha L) = \tilde{Z}$, with $\tilde{Z} = (\tilde{y}_i - y_c)(hP_f + (1-h)\tilde{P}_p)$. Because the farmer is DARA, we have

$$\tilde{Z} - c_i'(\alpha L) \geq 0 \Leftrightarrow \pi \geq \overline{\pi} \Rightarrow r_a(\pi) = -\frac{U''(\pi)}{U'(\pi)} \leq r_q(\overline{\pi}). \tag{B9}$$

The rest of the proof follows immediately on the ground of the previous one.

Remark

Given that the coefficient of relative risk aversion $r_r(\pi) = \pi r_a(\pi)$, it can be also shown, following the same steps, that for a producer IRRA

(B10) $$E[\pi U''(\pi)(BP_f - B\tilde{P}_p)] \geq 0$$

and

(B11) $$E[\pi U''(\pi)(\tilde{Z} - c_i'(\alpha L))] \leq 0.$$

For a producer CRRA we have

(B12) $$E[\pi U''(\pi)(BP_f - B\tilde{P}_p)] = 0$$

and

(B13) $$E[\pi U''(\pi)(\tilde{Z} - c_i'(\alpha L))] = 0.$$

These results are useful for the proofs given below.

LEMMA 2. *Let η_p be the standard deviation for harvest sport price. Suppose that y_i is certain. Under DARA-CRRA or DARA-IRRA preferences we have*

(B14) $$\frac{\partial h}{\partial \eta_p} \geq 0 \quad \textit{and} \quad \frac{\partial \alpha}{\partial \eta_p} \leq 0.$$

We suppose the following relation between forward and harvest' spot prices: $\tilde{p}_p = \delta_p p_f + \eta_p \tilde{\varepsilon}_p$, where δ_p is a scalar such that $\delta_p > 1$, η_p is a positive shift parameter, and $\tilde{\varepsilon}_p$ is a random variable with $E(\tilde{\varepsilon}_p) = 0$, $Var(\tilde{\varepsilon}_p) = 1$. A higher price risk is thus represented by an increase in η_p. We will give here the proof related to the effect of η_p on h^*. The proof related to α^* follows immediately.

Proof that $\frac{\partial h}{\partial \eta_p} \geq 0$. First derivation of equation (3b) with respect to η_p gives

(B15) $$\frac{\partial h}{\partial \eta_p} = \frac{-\frac{\partial^2 EU}{\partial h \partial \eta_p} H_{11}}{|H|}.$$

From the second-order conditions, we know that $|H| > 0$ and $H_{11} < 0$, so the sign of $\frac{\partial h}{\partial D}$ is the same as $\frac{\partial^2 EU}{\partial h \partial \eta_p}$. We assume that the production is certain (the case with production risk gives an indeterminate sign). We can write

(B16) $$\frac{\partial^2 EU}{\partial h \partial \eta_p} = L^2 EU''^{(\pi)[(\alpha y_i + (1-\alpha) y_c)^2 (1-h)(P_f - \tilde{P}_p)\tilde{\varepsilon}_p]} - L^2 EU'(\pi)[(\alpha y_i + (1-\alpha) y_c)\tilde{\varepsilon}_p].$$

Let first sign $EU''(\pi)[(\alpha y_i + (1-\alpha) y_c)^2 (1-h)(P_f - \tilde{P}_p)\tilde{\varepsilon}_p]$.

We can split π into a constant and a random part: $\pi = E(\pi) + L(\alpha y_i + (1-\alpha) y_c)(1-h)\eta_p \tilde{\varepsilon}_p$. Thus,

(B17) $$\tilde{\varepsilon}_p L(\alpha y_i + (1-\alpha) y_c)(1-h) = \frac{1}{\eta_p}(\pi - E(\pi)).$$

Using equation (B17) we can write

(B18) $$\begin{aligned} &L^2 EU''^{(\pi)[(\alpha y_i + (1-\alpha) y_c)^2 (1-h)(P_f - \tilde{P}_p)\tilde{\varepsilon}_p]} \\ &= \tfrac{1}{\eta_p} LEU''(\pi)((\alpha y_i + (1-\alpha) y_c)(P_f - \tilde{P}_p))(\pi - E(\pi)) \\ &= y \tfrac{1}{\eta_p} LE\pi U''(\pi)((\alpha y_i + (1-\alpha) y_c)(P_f - \tilde{P}_p)) \\ &- \tfrac{1}{\eta_p} LE(\pi) EU''(\pi)((\alpha y_i + (1-\alpha) y_c)(P_f - \tilde{P}_p)). \end{aligned}$$

From equations (B10) and (B12), we know that the first term is positive (null) for an IRRA (CRRA) farmer. Furthermore, the second term is negative for DARA farmer (equation B6). Thus equation (B18) is positive for a DARA-IRRA or DARA-CRRA farmer (CRRA implies DARA).

Now let sign $-LEU'(\pi)[(\alpha y_i + (1-\alpha)y_c)\tilde{\varepsilon}_p]$. This term can be developed as follows:

(B19)
$$\begin{aligned} -LEU'^{(\pi)[(\alpha y_i+(1-\alpha)y_c)\tilde{\varepsilon}_p]} &= -L(\alpha y_i + (1-\alpha)y_c)E[U'(\pi)\tilde{\varepsilon}_p] \\ &= -L(\alpha y_i + (1-\alpha)y_c)\frac{1}{\eta_p}cov[U'(\pi),\tilde{P}_p] \geq 0. \end{aligned}$$

Thus, we have proved that $\frac{\partial h}{\partial \eta_p} \geq 0$ if the producer is DARA-CRRA or DARA-IRRA. The demand for hedging will increase under higher price risk.

Appendix C: Mean and Coefficient of Variation of Crop Yield and of Alternative's Gross Margins

Crop	Technology	Marketing Contract	Yield Mean[2] (in Tons)	CV of Yield	Average GM (in €)	CV of GM
Soft wheat	Conventional	Pool	6.02	9.1	408	31.6
		StorageA			423	29.6
		StorageB			408	35.8
		Forward			371	19.1
	Low-input	Pool	5.50	19.4	423	38.7
		StorageA			436	37.6
		StorageB			421	41
		Forward			393	36.6
Durum wheat	Conventional	Pool	4.72	11.0	389	28.7
		StorageA			410	32.7
		StorageB			402	31.6
		Forward			362	25.1
	Low-input	Pool	4.25	20.9	427	38
		StorageA			445	39.3
		StorageB			438	39.2
		Forward			406	38.7
Non-irrigated corn	Conventional	Pool	5.95	9.8	308	57.7
		StorageA			327	60.9
		StorageB			350	58.5
		Forward			280	28.5
	Low-input	Pool	5.83	19.9	334	70.1
		StorageA			353	73.9
		StorageB			375	71.1
		Forward			305	55.3
Irrigated corn	Conventional	Pool	10.43	7.0	784	37.3
		StorageA			822	40.2
		StorageB			865	39.7
		Forward			736	13.9
	Low-input	Pool	9.68	18.0	717	53.2
		StorageA			754	55.4
		StorageB			793	54.2
		Forward			669	38.7
sunflower	Conventional	Pool	2.31	10.0	286	31.9
		StorageA			300	40.6
		StorageB			284	38.1
		Forward			258	22.6
	Low-input	Pool	2.18	18.6	268	48.3
		StorageA			280	53.8
		StorageB			265	52.9
		Forward			241	44.4
Rapeseed	Conventional	Pool	2.99	16.8	285	46.2
		StorageA			299	47.5
		StorageB			309	48.8
		Forward			240	46.9
	Low-input	Pool	2.77	29.0	303	66.6
		StorageA			315	66.7
		StorageB			324	67.1
		Forward			263	71.3

Notes: Contracts are defined as follows: StorageA if sales at the first period; StorageB if sales at the second period. Yield means are given per crop and per technology; CV is defined as coefficient of variation of the yield; GM is defined as gross margin.

Online Supplement: Mathematical Programming Model

Equations Related to Crop Activities

The acreage choice comprises the allocation across each land type (Z) of a crop (C) associated with a farming practice (T). The six main crops of the study area are soft wheat, durum wheat, non-irrigated corn, irrigated corn, sunflower, and rapeseed. Irrigated corn can be allocated only to irrigated land. The other crops are cultivated on non-irrigated land. Each crop can be grown using either conventional or low-input practices.

As explained in the article, a first set of constraints concerns the limited availability of land in each land type available:

$$\text{(S1)} \qquad \sum_{C,T} X(N,C,T,Z) \quad \leq \quad Land(Z),$$

where $X(N,C,T,Z)$ is the area allocated to land type Z, in year N, to crop C, under technology T.

A second set of constraints relates to crop rotation, where cropping successions are taken into account with a bounded share of crop acreage:

$$\text{(S2)} \qquad \begin{aligned} 0.7 \times [\textstyle\sum_T X(N,Corn,T,Z) + \sum_T X(N,Sunflower,T,Z)] \quad &\leq \quad \textstyle\sum_T X(N,Wheat,T,Z) \\ &\leq \quad 1.5 \times [\textstyle\sum_T X(N,Corn,T,Z) + \sum_T X(N,Sunflower,T,Z)], \end{aligned}$$

where $Corn$ is dry corn and $Wheat$ is the sum of soft and durum wheat.

Equation (S2) ensures that the simulated farmer does not cultivate wheat under moncropping but that corn and/or oleaginous crops are also cultivated, as is observed.

Equations Related to the Marketing Contracts

Once the farmer has allocated his land to crop activities and technologies, the stochastic output quantities harvested are sold through one or more of three marketing contract types, indexed by K: pool contracts (K1), storage contracts (K2), and forward contracts (K3). The grain harvested is sold during the year using at least one contract type, but the farmer can spread the sales among the three contracts. Thus for each year N,

$$\text{(S3)} \qquad \sum_K Sales(N,C,K,F) \quad = \quad \sum_T \left[\sum_Z X(N,C,T,Z) \times \sum_P Yield(C,T,P,F) \right],$$

where $Sales(N,C,K,F)$ is the quantity of crop C sold in year N under the contract K at the state of nature F (F is the set for states of nature of yields) and $Yield(C,T,P,F)$ is the yield of crop C under technology T at period P under the state of nature F.

In addition, for each contract, the product value per contract K is computed:

$$\text{(S4)} \qquad Val(N,K,C,P,E,F) \quad = \quad Sales(N,C,P,K,F) \times Price(N,C,P-1,K,E).$$

Because payment dates differ among contracts, the set of equations is indexed on each period P. The product value depends also on the state of nature $E = \{1, \ldots, 3\}$ for the prices. The total product value per period is given by the sum over the partial product value of each contract:

$$\text{(S5)} \qquad TotVal(N,C,P,E,F) \quad = \quad \sum_K Val(N,K,C,P,E,F),$$

where $Val(N,K,C,P,E,F)$ is the value of the sales for each contract K, $Price(N,C,P-1,K,E,F)$ represents the crop price under the state of nature E, and $TotVal(N,C,P,E,F)$ is the total value of the sales.

Furthermore, a set of equations ensures that the stock of grain available at the end of period P is transferred at the beginning of period $P+1$. At each period and for each crop, the quantity stored correspond to the previous stock plus crop harvested minus crop sold:

$$\begin{aligned} Stock(N,C,P,F) &= Stock(N,C,P-1,F) + \sum_T \left[\sum_Z X(N,C,T,Z) \times \sum_P Yield(C,T,P-1,F) \right] \\ &\quad - \sum_K Sales(N,C,P-1,K,F). \end{aligned} \tag{S6}$$

Additionally, stored crop products constitute the maximal quantities available to the farmer that can be sold under K3A and K3B contracts (where A and B are the two periods in which grain can be sold under the storage contract):

$$SalesK3A(N,C,P,F) + SalesK3B(N,C,P,F) \leq Stock(N,C,P,F), \tag{S7}$$

where $Stock(N,C,P,F)$ is the quantity of grain stored and $SalesK3A(N,C,P,F)$ and $SalesK3B(N,C,P,F)$ are the amount of grain sold under the contract K3 at the first and second period, respectively.

Equations Related to the Short-Term Financing Decision

The last important set of equations relates to the cash available on the farm and its financing. The level of cash is defined as the balance between inputs (receipts from grain sales and CAP supports) and withdrawals (purchases associated with crop-growing activities, etc.) plus the stock remaining from the previous period:

$$\begin{aligned} Cash(N,C,E,F) &= Cash(N,P-1,E,F) - \sum_{C,T} \left[\sum_Z X(N,C,T,Z) \times \sum_P VC(N,C,T,P-1) \right] \\ &- \sum_C Stock(N,C,P-1,F) + Stock_{cost(C,P-1)} + Borrow(N,P-1) \\ &+ \sum_{C,T} \left[\sum_Z X(N,C,T,Z) \times AAP(C,P-1) \right] + SFP(p-1) \\ &+ Sales(N,C,P-1,K,F) \times Price(N,C,P-1,K,E). \end{aligned} \tag{S8}$$

where $Cash(N,P,E,F)$ is the cash flow level at period P, $VC(N,C,T,P-1)$ is the variable costs, and $Stock_{cost(C,P-1)}$ is the storage cost.

Moreover, short-term borrowing can be used with repayment of the principal plus interest during the last period of the year:

$$\textstyle\sum_P Borrow(N,P) \leq \max\_Borrow(N); \tag{S9}$$

$$Repayment(N) \leq \textstyle\sum_P Borrow(N,P)(1+i); \tag{S10}$$

where $Borrow(N,P)$ is short-term borrowing, $AAP(C,P)$ is the arable area payments, $SFP(p)$ is the single farm payment, $\max\_Borrow(N)$ is the borrowing capacity, and i is the interest rate.

Figures Related to the Mixed Policy and Technical Adjustment Scenario

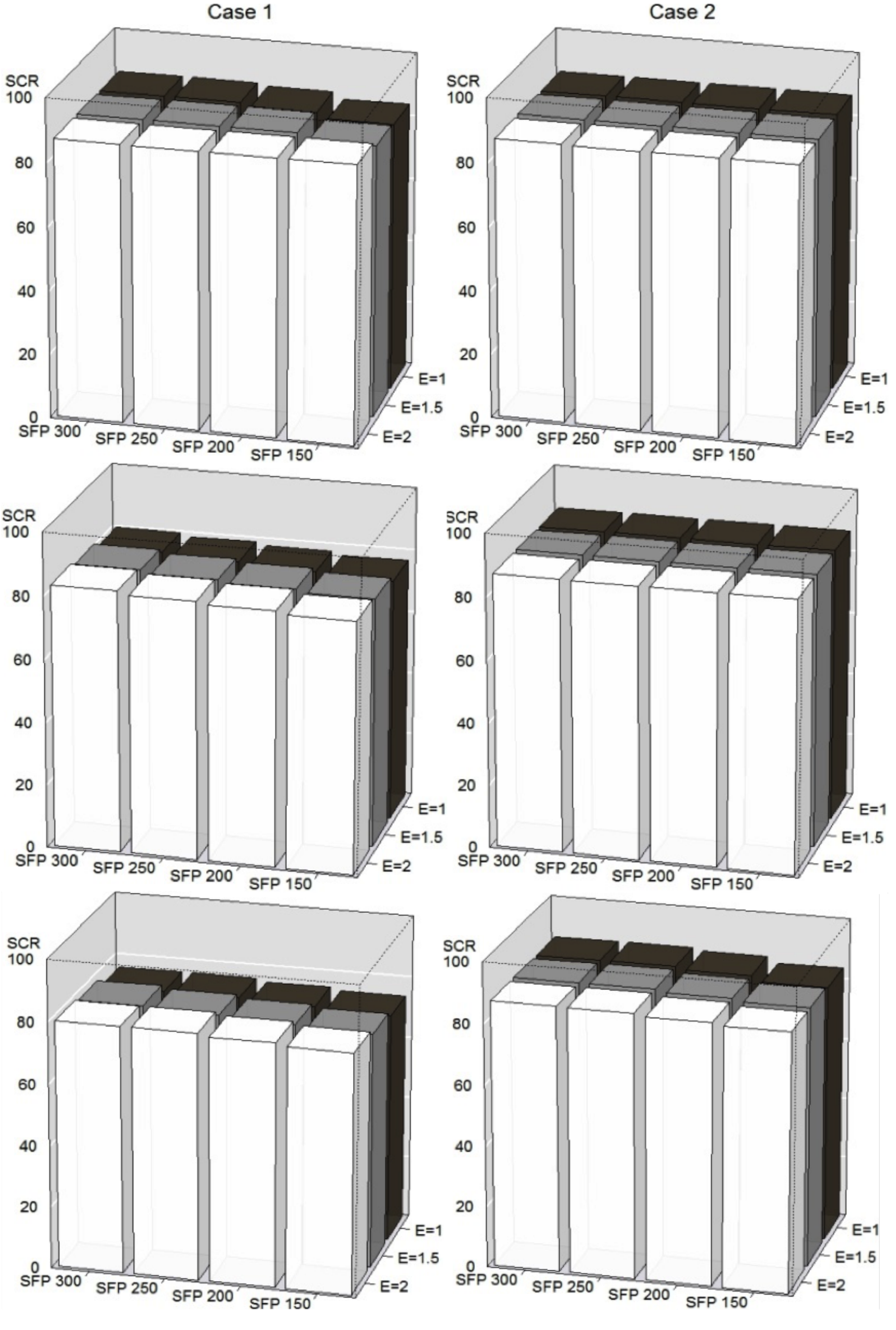

Figure S1. Changes in the Simulated Conversion Rates under the Mixed Scenario

Notes: The SCR on the vertical axis are functions of price risk exposure (E=1; E=1.5;E=2) and the level of SFP (varies from €300 to €150) under case 1 - only pool contracts are available (left side) - and case 2 - all contracts are available (right side) - and for three levels of risk aversion: r=0.2 (top), r=0.4 (middle), r=0.6 (bottom).

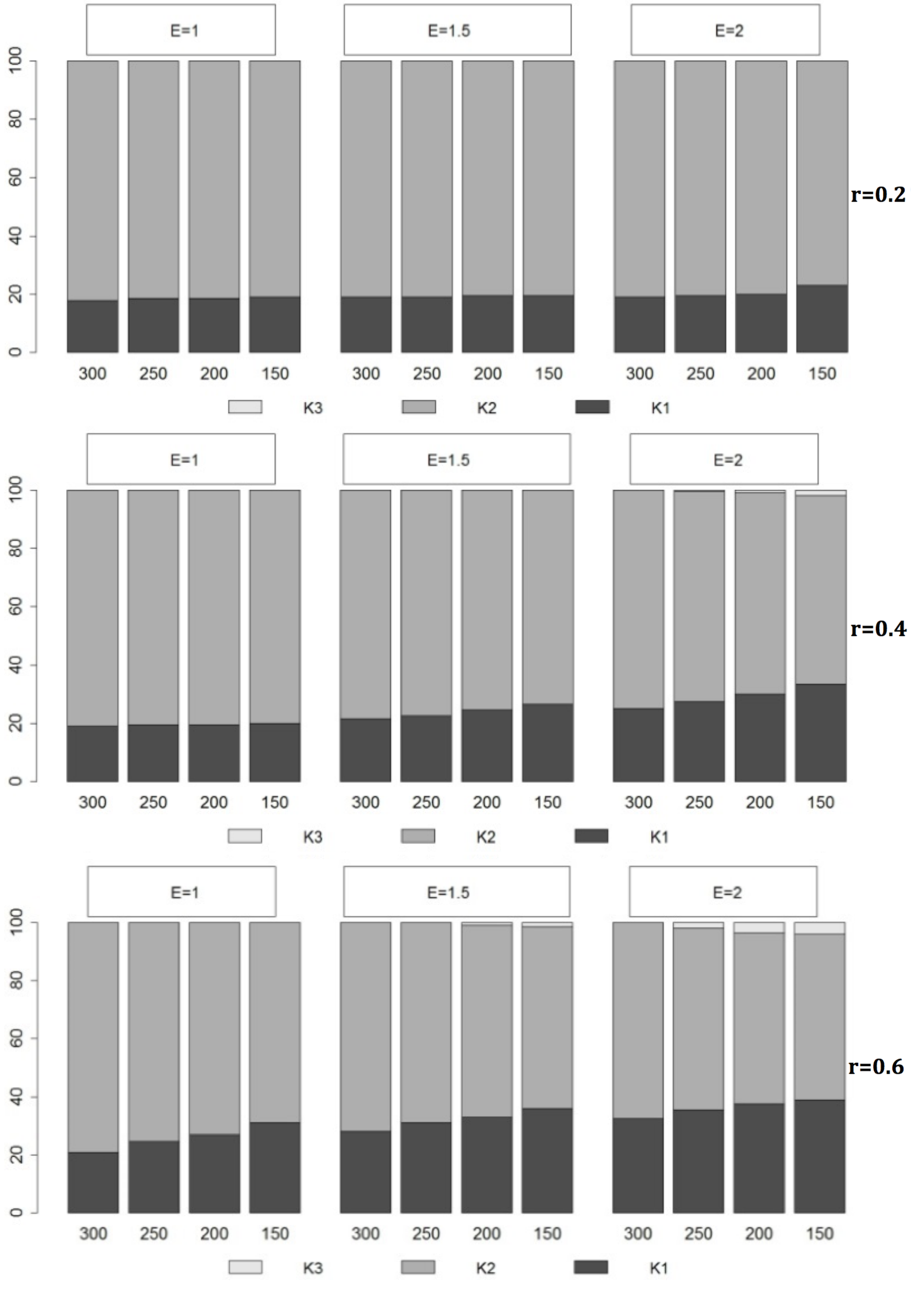

Figure S2. Changes in the Marketing Contract Choices under the Mixed Scenario

Notes: Changes (in %) on the vertical axis refer to case 2 - all contracts available - for three levels of risk aversion: r=0.2 (top), r=0.4 (middle), r=0.6 (bottom). K1 represents pool contracts, K2 storage contracts, and K3 forward contracts. The level of SFP is given at the bottom of each bar chart.