Evaluating the potential of whole-farm insurance over crop-specific insurance policies

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Abstract

The rationale of whole-farm insurance (WFI) is to pool all farm's insurable risks into a single policy. This paper compared separated multi-peril crop-specific insurance policies (CSI) with WFI. It first compared the loss ratios of frequent buyers of agricultural insurance in Spain to confirm whether data provide support for combining separate premia in WFI policies. Actuarial data showed that loss ratios are lower for farmers that sign up for different insurance groups or insure more than one crop. Secondly, using the records of farmers who bought CSI for three crops during 1993-2004, Monte-Carlo simulations were carried out to evaluate premium differences, revenue, and farmers' utilities (DARA-CRRA) of CSI and a WFI designed to cover the same risks than do the CSI policies. Results showed that premiums are reduced by 20% and farmer's certainty equivalents are slightly larger. Farmers would benefit from WFI and governments would enhance the efficiency of their insurance subsidies.

Additional key words: agricultural insurance, crop risks, Monte-Carlo simulation, Spanish agriculture.

Resumen

Evaluación del potencial de seguros de explotación frente a seguros de cosecha

La ventaja de un seguro de explotación es agrupar todos los riesgos de una explotación en una prima única. En este trabajo se compararon seguros multirriesgo de cultivo con seguros de explotación. Primero, se compararon los ratios de pérdidas de usuarios frecuentes de seguros en España, con los que confirmar si los resultados actuariales aconsejan agrupar las pólizas separadas en una de explotación que las englobe. De acuerdo con los registros de los seguros, se demuestra que los ratios de pérdidas son significativamente menores para agricultores que contratan más de un seguro. En segundo lugar, se utilizaron los registros de agricultores que contrataron seguros de cosecha para tres cultivos entre 1993-2004, para realizar simulaciones Monte-Carlo al objeto de evaluar las diferencias de prima, ingreso y utilidad de los agricultores. Bajo el supuesto de aversión absoluta al riesgo decreciente y aversión relativa al riesgo constante, se pudo comparar las opciones de asegurar los cultivos por separado o agrupados en una prima única de seguro de explotación. En este caso, se diseñó para proporcionar la misma garantía que separadamente proporcionan los seguros de cosecha. Los resultados revelan que la prima sería un 20% menor y el equivalente cierto ligeramente superior. De esta forma los productores se beneficiarían del seguro de explotación y las subvenciones públicas del seguro serían más eficientes.

Palabras clave adicionales: agricultura española, riesgos de cosechas, seguro agrario, simulación Monte-Carlo.

Abbreviations used: AGR (adjusted gross revenue), CAIS (Canadian Agriculture Income Stabilization), CE (certainty equivalents), CRC (crop revenue coverage), CSI (crop-specific insurance), CV (coefficient of variation), DARA – CRRA (Decreasing absolute risk aversion – Constant relative risk aversion), ENESA (Spanish Insurance Agency), FII (farm income insurance), GRIP (Group Risk Income Protection), IP (income protection), MCI (multi-crop insurance), NISA (Net Income Stabilization Account), NMI (Whole Farm Negative Margin Insurance Pilot Program), RA (revenue assurance), WFI (whole-farm insurance).

Introduction

Whole-farm insurance policies are meant to provide overall coverage to all farms' crops. Since most crop risks do not perfectly covariate, whole-farm insurance (WFI) provides a more efficient coverage than insuring each crop or animal with a specific policy. This is because WFI provides coverage for the whole farm's revenue or margin, which are good proxies of farmers' profitability. Its rationale is based on simple diversification and portfolio management (Mahul and Wright, 2003). Following Hennessy *et al.* (1997), if a farm grows two crops, A and B, a policy insurance based on the farm's total revenue will be cheaper than the sum of the premia of two individual insurances for crops A and B which provides the same expected revenue; the savings being inversely proportional to the correlation between contemporaneous crops' revenues. In principle, the lower is the correlation, the greater the premium rebate that WFI results over crop-specific insurance (CSI).

WFI has been developed and applied following two different formats. First, farm income insurance (FII) provides coverage against farm's margin losses. In the examples that will be briefly reviewed, farmers can purchase insurance against reduced or negative margins, evaluated accordingly with certain cost and revenue accountant rules. With the second format, farmers can purchase multi-crop insurance (MCI) policies (or portfolio insurance for other authors). These result from a combination of multiple-peril, yield or revenue crop-specific insurance, in such a way that the combined revenue coming from the eligible crops is guaranteed against any source of losses. If all farm's crops would be included in the MCI, and this would provide coverage not only for crops' revenue but also for crops' income, then MCI would be equivalent to FII.

The main disadvantage of FII stems from the requirement to measure the farm's revenue or margin in a manner that avoids moral hazard and is acceptable for insurers. As a result, WFI is more often developed along the MCI format, but there are also examples of FII that will be reviewed in the following section.

Using Monte-Carlo simulations, Hennessy *et al.* (1997) show that MCI provides a similar, albeit cheaper revenue protection than insuring corn (*Zea mays* L.) and soybeans (*Glycine max* L.) with separate premia for the case of an Iowa representative farm. Babcock and Hayes (1999) show that a corn and soybeans producer could purchase relatively cheaper insurance for the same crops if the policy includes coverage against revenue losses in hogs' production. Hart *et al.* (2003) developed several whole-farm crop revenue insurance programs to include livestock. Their whole-farm insurance product covered crop revenues from corn and soybeans and livestock revenues from pig production. They found that at coverage levels of 95% or lower, the fair insurance premiums for this product offered to an Iowa pig farm are much lower than the fair premia for the corn alone on the same farm.

From an actuarial point of view, the premium reduction that is achieved by WFI is based on pooling the risks of the crops included in the policy. For the insuree, this means that the distribution of pay-offs will be more concentrated around the mean, reducing the size of both tails. As the negative outcome of one crop may be fully compensated by the positive one of another crop, WFI may not yield any indemnity in cases where specific-crop premia might do so. Yet, if government subsidizes the premia, the efficiency of support, in terms of increase of certainty equivalent per euro spent in subsidies, may be significantly larger with WFI than with crop-specific premia.

To evaluate the benefits of WFI for a farmer that grows and purchases insurance for more than one crop, one has to assume that he/she would maintain the same acreage allocations, because WFI premia and outcomes depend on them. In addition, as the distribution of benefits exhibit a reduction of mean-preserving spread, WFI would only appeal to risk-averse farmers. Further, since total liability is reduced with WFI with respect to specific-crop insurance for the same coverage, re-insurance may be less costly.

The objective of this paper is to evaluate WFI policies of the MCI type for farmers that have shown consistent and sustained crop-specific insurance strategies. Using the farm-level records of the Spanish Insurance Agency (ENESA) for 12 years (1993-2004), two separate analyses were conducted to evaluate the potential of WFI. First, comparisons were made between the loss ratios of frequent buyers of insurance, who are grouped accordingly to their insurance strategies. To our knowledge, this is first the time individual loss ratios are used to conduct an evaluation of agricultural insurance, except for Garrido and Zilberman (2008) who used the same database used in this work. In the second approach, an evaluation of the premium of WFI was carried out for farmers who have purchased more than one crop-specific multiple-peril policy. The comparisons of total paid premium and farmers' revenue and utility,

with WFI and with various insurance policies, were based on Monte-Carlo simulations, using probability density functions evaluated from ENESA records. WFI was designed to deliver exactly the same expected revenue than does the combined effects of three crop-specific multiple-peril insurance policies, providing coverage for the same risks. In contrast with previous work, the possibility of damages not covered by the insurance policy was taken into account considering three stochastic effects: crops' yields, the magnitude of the indemnities and the probability of experiencing crop losses or failures due to non-insurable risks. The parameters of these distributions are estimated from actual data pertained to the selected farmers and to their *comarcas* (as counties are called in Spain).

Previous experiences with whole-farm insurance

Since 1996, various models of revenue insurance have been developed in USA. Crop Revenue Coverage (CRC) and Income Protection (IP) were initiated in 1996; Revenue Assurance (RA) became available in 1997; and Group Risk Income Protection (GRIP) was marketed in 1999 for the first time. Until 1999, the only revenue insurance available for the whole-farm was a variant of RA (Babcock and Hayes, 1999). For this, actuarially fair premia were evaluated using a similar procedure as that developed by Hennessy *et al.* (1997), giving it a format of portfolio insurance providing a coverage against revenue losses[1]. In 2000 a new revenue WFI policy, Adjusted Gross Revenue (AGR), was offered. It is FII-type policy, but it provides coverage against losses below the average farm "gross revenue" of the previous five years, which include sales from crops, livestock, or fish-farm production (within some limits) together with other farm income. It was initially offered experimentally in Northeast States, but presently is eligible for farmers of West Coast and Idaho (USDA, 2005a). Since 2004, *AGR-Lite* is offered in eleven Northeast States. It includes all revenues originating from the same crops eligible with AGR, plus livestock (with no limits) and horticultural crops. It was especially designed for medium-size and small farms, since total liabilities can not exceed $250,000 (USDA, 2005b).

In Canada, Canadian Agriculture Income Stabilization (CAIS) was initiated in 2003, integrating all available programs and income stabilization instruments.

CAIS, the heir of the old Net Income Stabilization Account (NISA), is not an insurance-type mechanism, and fits better with the notion of self-insurance funds, to which both Provincial and Federal governments match the growers' contributions (Government of British Columbia, 2005a). In the Canadian self-insurance funds, growers can make withdrawals from their individual accounts when their farms' margins fall below the reference margin. In contrast with insurance-type mechanisms, making withdrawals is optional to the farmers, which may provide a smoother flow of revenue and better adaptation to farmers' needs (Turvey *et al.,* 1997). The CAIS program is currently in evolution, but the fact that is based on the farm's income (production margin) remains unchanged. Since 2001, hog farms and horticultural farms from the Province of British Columbia can purchase Whole Farm Negative Margin Insurance Pilot Program (NMI). This program guarantees subscribers complete recovery of their production costs, in case of low product prices, crop losses or unexpected increase of input costs (Government of British Columbia, 2005b).

In Spain, there are various WFI, all of them developed under the format of MCI insurance. Yield and multi-peril WFI policies are offered for field crops farms, differentiating dry-land crops and irrigated crops. Another group of WFI policies is targeted to fruit producers, so that all fruit species, excluding citrus, are included in the same the policy. Citrus specific multi-crop and vegetables specific multi-crop policies provide coverage against multiple perils including hailstorm, freeze, flood, persistent rain, strong winds and fire.

The Spanish Insurance system has thus expanded from CSI policies, grouping them in MCI policies of increasing complexity and coverage variations. This work deals with some of them, looking in more detail at a combination of crops for which there are not WFI policies offered yet.

Analysis of actuarial data of Spanish frequent buyers of insurance

This section shows the comparison of average loss ratios of Spanish farmers that have shown distinctive and consistent insurance strategies during the period 1993-2004. An evaluation of the potential of WFI can be made by grouping farmers accordingly with the type of

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[1] This RA variant is commercially offered by American Farm Bureau Insurance Services, Inc., in six midwestern US States.

purchased insurance and the number of insured crops. If the loss ratios of frequent purchasers are lower with more diverse insurance strategies in terms of groups and crops then a policy of type WFI that combines them all in a single policy should be cheaper.

From a selection of 55,300 farmers of seven Spanish agriculturally diverse *comarca*s (similar to US counties), subsets of farmers formed meeting two criterions. First, farmers must have purchased any type of insurance in at least nine of 12 years (1993-2004). Second, they must follow the same insuring strategy for at least eight out of the 12 years. This means that subsets are formed with farmers who purchased the same number and group of policies in almost all years. 'Insurance group' refers to insurance policies that can be applied to similar crops providing the same type of coverage. An example of group is 'yield insurance for all winter cereals', that is, a group which may encompass several crops for which farmers can insure against common risks. Subsets of farmers were also created with farmers that consistently purchased any type of insurance based on the number of insured crops. As a result of these stringent conditions the size of the subsets was significantly reduced, but the comparisons of loss ratios across groups became more robust. The size of subsets varied between 5 and 4091 farmers.

Table 1 reports two blocks of means comparison tests of loss ratios evaluated in 2004 for the period 1993-2004 across subsets of farmers. In the first set of tests a comparison within groups is made, distinguishing farmers who contracted only one crop from others that insured two or more crops of the same group. Then mean comparison tests were performed for groups 1 and 2. Results show that loss ratios of the farmers that purchased only one crop are significantly higher than those that purchased at least two crops.

In the second block of tests, subsets are based just on the number of crops that were insured, no matter what type of insurance was contracted. Results show that for pairwise comparisons insuring more crops is always accompanied by significantly lower loss ratios. Overall, loss ratios tend to be lower when farmers exhibit more diverse insuring strategies both within groups and by the number of insured crops. This provides actuarial support for offering farmers WFIs that combine their multiple policies at a lower price.

The modeling framework

The modeling framework includes the evaluation of CSI premium and the WFI premium for a number of

Table 1. Comparisons[1] of average loss ratios (1993-2004) among Spanish farmers with frequent agricultural insurance participation

	Mean	SD[2]	No. farmers	*p*-value
Comparisons within groups				
Group 1 (1 crop)	0.868	0.779	3022	<0.01
Group 1 (2 crops)	0.697	0.542	1570	<0.01
Group 2 (1 crop)	0.541	0.77	243	<0.01
Group 2 (2 crops)	0.42	0.296	27	<0.01
Comparisons by number of insured crops				
1 crop	0.844	0.856	4091	<0.01
2 crops	0.657	0.531	488	<0.01
1 crop	0.844	0.856	4091	<0.01
3 crops	0.567	0.4062	133	<0.01
2 crops	0.657	0.532	488	<0.01
3 crops	0.567	0.406	133	<0.01
1 crop	0.844	0.856	4091	<0.01
4 crops	0.678	0.478	129	<0.01

[1] Pairwise means comparisons with t-test with unequal variances. [2] SD, standard deviation. Source: ENESA records of all farmers of seven Spanish comarcas who purchased any insurance in at least 10 years during the period 1993-2004.

representative growers who exhibit consistent and stable insuring strategies based on various CSI policies.

Let's suppose that a farmer grows N crops, each crop i with a yield probability distribution function of $f_i(x_i)$. The actuarially fair premium for a multi-peril crop-specific insurance policy for each crop Pr_i would be estimated by:

$$Pr_i = E_i\left[\tilde{I}_i\right]$$

$$\tilde{I}_i = \begin{cases} p_i \times \overline{X}_i \times \tilde{\lambda}_i \times \tilde{l}_i & if \quad \tilde{x}_i < \overline{X}_i \\ 0 & if \quad \tilde{x}_i \geq \overline{X}_i \end{cases}$$

where I_i is the indemnity of crop i; $E[.]$ is the mathematical expectation operator; $\overline{X}_i$ is the guaranteed yield for crop i; $\tilde{x}_i$ is the stochastic yield; p_i is the crop price at which crop losses are paid, assumed non-stochastic; $\tilde{l}_i$ is the stochastic loss eligible for indemnity (which does not always correspond with the loss of the farmer), and $\tilde{\lambda}_i$ gives the probability of getting an indemnity when yields are below the insured level. Essentially, what variable $\tilde{\lambda}_i$ does is to capture the event of experiencing low yields for a reason that does ($\lambda_i=1$) or does not ($\lambda_i=0$) lead to an indemnity, as defined by the insurance policy.

For the WFI policy, fair premium should result from:

$$Pr = E\left[\tilde{I}\right]$$

$$\tilde{I} = \begin{cases} \min\left[\sum_i s_i \tilde{I}_i, (R - \sum_i s_i p_i \tilde{x}_i)\right] & if \quad \sum_i s_i p_i \tilde{x}_i < R \\ 0 & if \quad \sum_i s_i p_i \tilde{x}_i \geq R \end{cases}$$

where R, which is farm-specific, is the insured revenue. It is equal to the expected revenue that the farm would obtain should all crops be insured with crop-specific policies, that is:

$$R = \sum_i s_i p_i \overline{X}_i$$

In the above formulation, note that Pr is idiosyncratic to the farmer because the cropping patterns, s_i, are needed to compute it. Furthermore, since the crops' yields functions are in principle not independent, the numerical computation of Pr and Pr_i needs also the correlations among random variables $\tilde{l}_i$ and $\tilde{x}_i$.

The savings in terms of insurance costs for the same expected revenue can be measured by: $\Delta Pr = Pr - \sum_i s_i Pr_i$.

In addition, utility gains can be evaluated with $\Delta EU = EU(\tilde{\pi}_{WFI}) - EU(\tilde{\pi}_{CSI})$, where $\tilde{\pi}$ accounts for the farm profits with the different insurance possibilities, $U(\pi)$ is a

DARA – CRRA utility function, such as $U(\pi)=\pi^{1-r}/(1-r)$, with r being the coefficient of relative risk aversion. Similarly, the difference of Certainty Equivalents was also computed from $\Delta CE = CE(\tilde{\pi}_{WFI}) - CE(\tilde{\pi}_{CSI})$.

Note that, by the very definition of WFI, the difference of expected profits $\Delta \pi^e = \pi^e_{WFI} - \pi^e_{CSI} = 0$, because:

$$\pi^e_{WFI} = \underset{x_1,...x_N}{E}\left\{\max\left[\sum_i s_i \times p_i \times \tilde{x}_i, \min\left(R, \sum_i s_i \times (p_i \times \tilde{x}_i + \tilde{I}_i)\right)\right] - \sum_i C_i - Pr\right\} = R - \sum_i^N C_i \qquad [1]$$

$$\pi^e_{CSI} = \underset{x_1,...x_N}{E}\left\{\max\left[\sum_i s_i \times p_i \times \tilde{x}_i, \sum_i s_i \times (p_i \times \tilde{x}_i + \tilde{I}_i)\right] - \sum_i C_i - \sum_i Pr_i\right\} =$$

$$= \sum_i \left[s_i \times p_i \times \underset{x_i}{E}\left\{\max\left[\tilde{x}_i, \overline{X}_i \tilde{\lambda}_i\right]\right\} - C_i - Pr_i\right] = R - \sum_i C_i \qquad [2]$$

where C_i is crop i's cost. Both results are equal to the implicit insured revenue (R) minus the crops' production costs, because premium was considered actuarially fair.

Let's observe in Eq. [2] that: (i) when there is no loss, the final yield is x_i; (ii) when there is an eligible loss ($\lambda_i = 1$), the final yield is the guaranteed yield $\overline{X}_i$; and (iii), when the loss is not eligible for an indemnity ($\lambda_i = 0$), yield would be equal to x_i (with $x_i < \overline{X}_i$). Note also in Eq. [2] that variable $\tilde{\lambda}_i$ only applies when $x_i < \overline{X}_i$.

Assumptions and data

With the above stylized model, a three-crop whole-farm insurance was designed for a combination of crops typical in insured farmers from Comarca Val d'Albaida (Valencia, Eastern Spain): a) Irrigated apricot (*Prunus armeniaca* L.); b) Irrigated plums (*Prunus domestica* L.); c) Non-irrigated wine grapes (*Vitis vinifera* L.). The existing crop-specific insurance policies for those crops provide coverage against hailstorms, torrential flood-rain, persistent rain, strong winds, frost, and, only for wine grapes, the risk of premature physiological ripeness. WFI policy is designed to provide coverage for the same risks that the current single-crop insurance policies actually cover. This means that they are not yield insurance but multiple-peril insurance.

The simulation and numerical study was carried out for two representative farmers of Val d'Albaida. The data base originates from ENESA's individual farmers records for the seasons 1993 to 2004. The two representative farmers were selected from ENESA's records amongst those farmers that purchased the three CSI

policies corresponding to the crops mentioned above. The selection was based on the criterion of having purchased insurance for the three considered crops during 10 out of the 12 considered seasons.

Yet, premium (Pr_i and Pr) have been evaluated taking into account all farmers within the Comarca Val d'Albaida who purchased the same three insurance policies at least one of the 12 seasons, and at least one policy in 10 out of the 12 seasons. This allowed for pooling together a much larger data set from which some of the parameters of the distribution functions of $\tilde{x}_i$, $\tilde{l}_i$ and $\tilde{\lambda}_i$ could be estimated. From the records available, it was found that yields (x_i) and eligible losses (l_i) follow beta distribution functions. The loss eligibility parameter (λ_i) yields 0 or 1 from a binomial distribution function, whose frequency is obtained from the data. For each of the two selected farmers, it was taken their individual average yields, but both the maximum and the coefficient of variation (CV) of the crop yields, as well as the correlations were taken from the larger data set containing all *comarca*'s farmers who grow the same crops. They are shown on Table 2. From the same larger dataset was estimated the distribution function parameters of eligible losses, l_i, expressed by the indemnities in relative terms over the liabilities of crop i (also shown on Table 2), the correlations of yields and losses among the crops (on the bottom part of Table 2), and lastly, the frequency of the binomial function of losses $\tilde{\lambda}_i$. It was estimated from the frequency of indemnities over total observations, and was found to be 0.20, 0.23

and 0.09 for apricots, plums and wine grapes respectively. This frequency was doubled to account for its use only on the left half of the distribution (when yields are lower than the average/guaranteed yield). Table 2 also reports the correlation matrix.

The insured acreage, s_i, is taken from the two farmers' in season 2000. Crop price, p_i, is the 5-year average of the prices used by ENESA to compute the indemnities during the seasons 2000 through 2004. Regarding the insurance coverage level, the level offered in season 2004 was taken which amounts to 100% of expected yield (in prior seasons it has been 80% for some of the crops). No production costs were included in the calculations, so benefits are in fact revenue measures. Lastly, the DARA-CRRA function assumes a relative risk aversion level of r=1.2, although sensitivity analyses that assume greater risk aversion preferences will also be reported.

The premium, Pr and Pr_i, together with the above mentioned measures of benefits were obtained from Monte-Carlo simulations, using the Latin Hypercube sampling of @Risk (Palisade Decision Tools).

Results

Table 3 reports the average results of the CSI and the WFI cases for farms 1 and 2. For both farms, WFI ensures slightly better average results than CSI. With

Table 2. Distribution functions' parameters and correlation matrix. Yields are in kg ha^{-1}; losses are expressed in relative terms to total liability

	Yields apricot	Yields plums	Yields wine grapes	Losses apricot	Losses plums	Losses wine grapes
CV[1]	0.30	0.39	0.16	0.70	0.72	0.60
Mean[2]	F1: 15603 F2: 6564	F1: 7224 F2: 8226	F1: 12305.92 F2: 13419.89	0.24	0.21	0.37
Max / min	28086 / 0	14808 / 0	18750 / 0	1 / 0	1 / 0	1 /0
Correlation matrix of $\tilde{l}_i$ and $\tilde{x}_i$						
Yields - apricot	1					
Yields - plums	0.173	1				
Yields - grapes	0.550	0.289	1			
Losses - apricot	-0.073	0.087	-0.148	1		
Losses - plums	0.017	0.095	0.028	0.471	1	
Losses - grapes	0.140	-0.054	0.030	1	0.060	1

[1] CV, coefficient of variation. [2] F1, Farm 1. F2, Farm 2.

Table 3. Comparison of the crop-specific insurance (CSI) and whole-farm insurance (WFI) results

	Apricot	**Plums**	**Wine grapes**	**Crop-specific insurance (CSI)**	**Whole-farm insurance (WFI)**	**Differences (WFI-CSI)**
Farm 1						
Surface (ha)	0.77	0.88	1.44	3.09	3.09	
Pure premium (%)	5.00	4.48	3.15	4.04	3.32	-0.72
Liability (€)	3948.08	2174.52	4841.74	10964.35	10964.35	0.00
Pure premium (€)	193	96	154	443	358	-85.00
Expected revenue (€)				10762.00	10762.76	0.76
Certainty equivalent (€)				10536.00	10546.10	10.10
Farm 2						
Surface (ha)	0.75	2.82	0.63	4.2	4.2	
Pure premium (%)	4.92	4.40	3.04	4.19	3.55	-0.64
Liability (€)	1617.68	7935.23	2310.01	11862.92	11862.92	0.00
Pure premium (€)	81	345	71	497	420	-77.00
Expected revenue (€)				11691.77	11691.02	-0.75
Certainty equivalent (€)				11110.37	11127.02	16.65

about the same expected revenue, the Certainty Equivalent improves moving from CSI to WFI. The WFI premia, as expected, would be significantly reduced with respect to the CSI case, the reductions being 19% for farm 1 and 15.5 % for farm 2.

Figures 1a and 1b graph the density functions of both farms' revenues for the three-case analyses. In both cases, insurance reduces the spread of the results with respect to the no-insurance case. Yet, the differences between the CSI and WFI cases are only significant for results near the average, as WFI concentrates more probability around the mean than CSI. This is because of the risks' compensation effect that WFI has embedded on its actuarial evaluation. In this sense, moving from CSI to WFI represents a reduction of a mean-preserving spread, as defined by Rothschild and Stiglitz (1970), but does not contribute to reduce the probability of the left tail. The factor explaining this left tail is that there are some risks for which the CSIs do not provide coverage. Recall that this feature is modeled by means of the stochastic variable $\tilde{\lambda}_i$. As WFI exactly reproduces the same coverage and loss adjustment than does CSI, the left probability tail is neither effectively reduced by WFI.

a)

b)
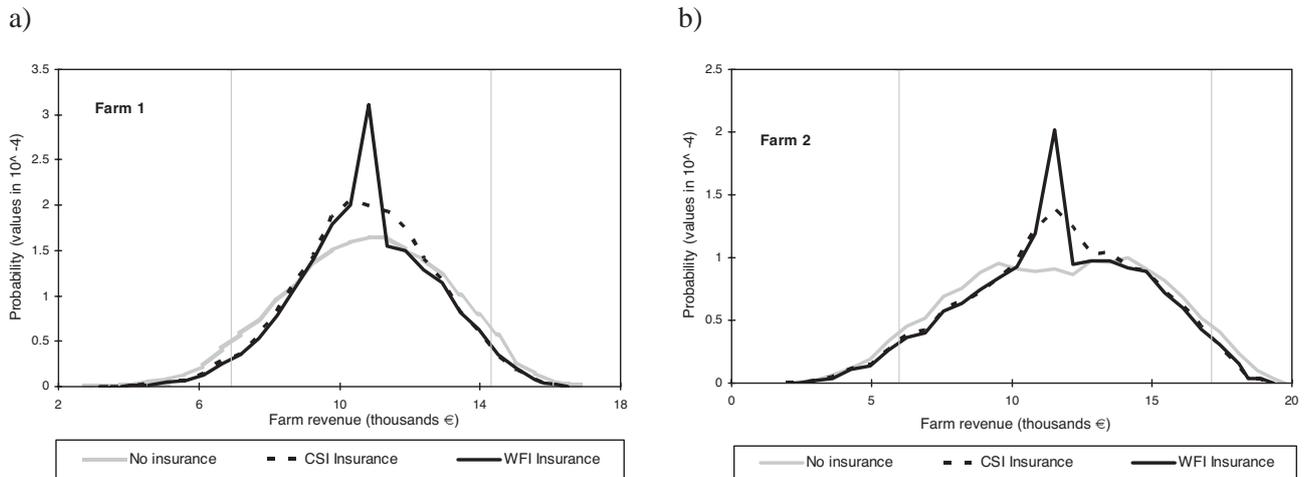
Figure 1. Density functions for revenues of farmers 1 (a) and 2 (b). CSI, Crop specific insurance. WFI, Whole-farm insurance

a)

b)
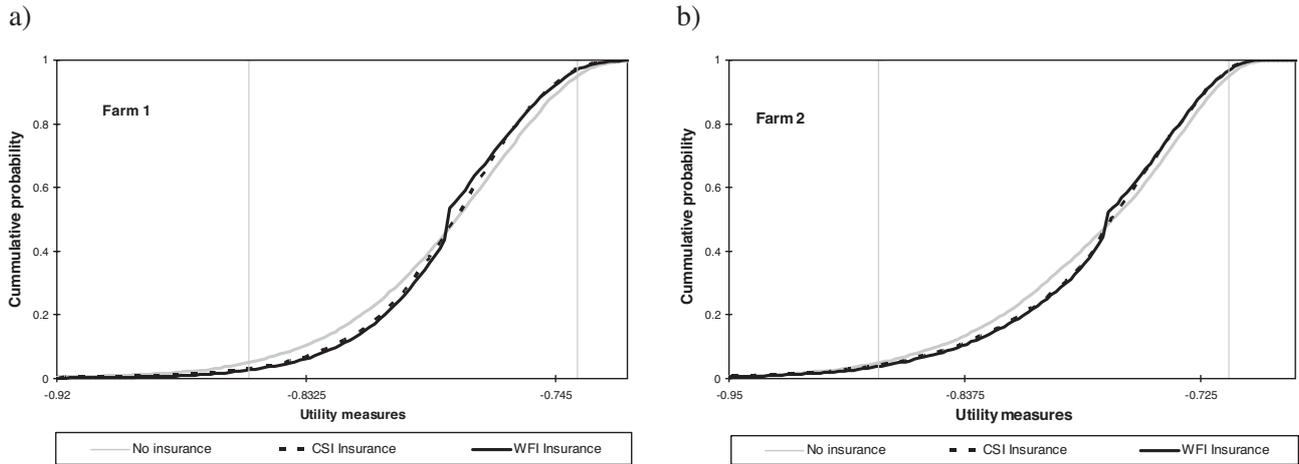
Figure 2. Utility cumulative distribution functions for farms 1 (a) and 2 (b). CSI, Crop specific insurance. WFI, Whole-farm insurance**.**

Slight stochastic dominance of WFI over CSI is shown on the utility measures graphed in Figures 2a and 2b. The differences of WFI and CSI are marked right beyond the Utility values where the cumulative distributions of both insurances' graphs cross the no-insurance case. The kink in the WFI curves corresponds to the spike of the density functions shown on Figures 1a and 1b.

In a final set of results, the effects of various risk aversion levels were simulated on the certainty equivalents of the three-case results. Figure 3 shows that certainty

equivalents are quite similar for low to medium risk aversion rates, and do not differ significantly for different levels of risk aversion, confirming a result widely found in the literature (Lien and Hardaker, 2001).

Concluding remarks

Whole-farm insurance (WFI) can provide welfare-increasing outcomes with respect to crop-specific insur-
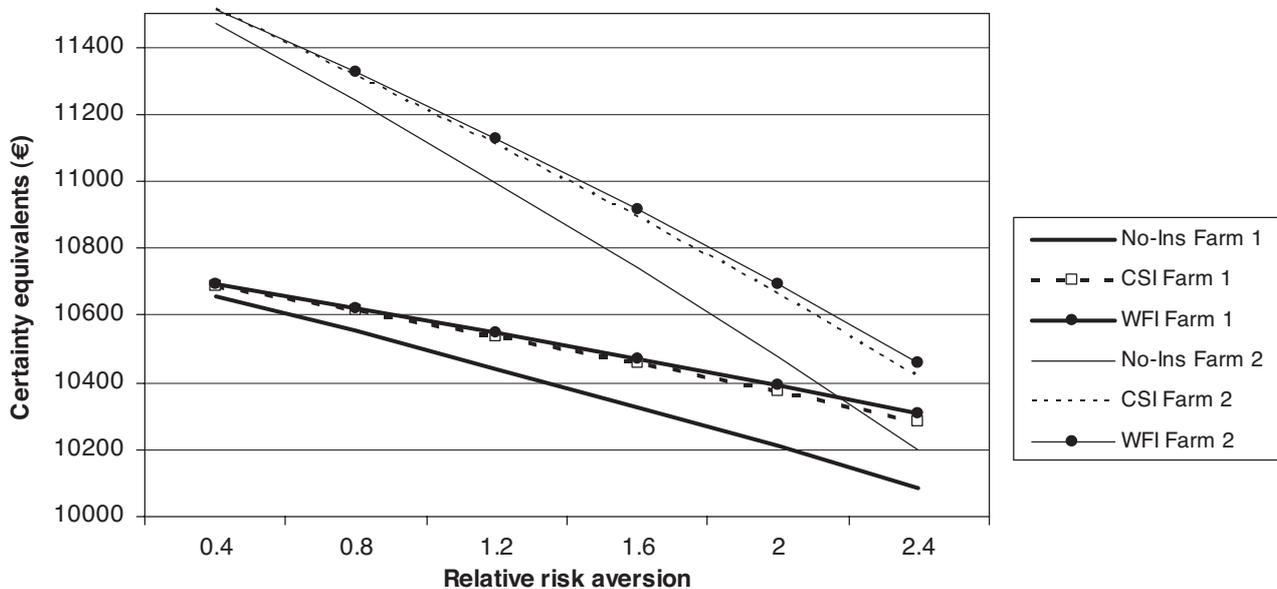
Figure 3. Certainty equivalents for both farms and six levels of relative risk aversion coefficients. No-Ins, no insurance case. CSI, crop specific insurance. WFI, whole-farm insurance**.**

ance (CSI), for the same coverage-guarantees and expected revenue levels. It was found that loss rations of farmers that exhibit more diverse insurance estrategies, either in types of policies or number of insured crops, are lower than those with less insured crops. The simulation worked in a more detailed and specific setting illustrated another advantage of WFI over CSI, that is that WFI concentrated more probability mass around the mean than does CSI. Yet, the differences among WFI and CSI can be small if: a) the left-tails are unaffected by moving from CSI to WFI, because only insurable risks are covered; b) the correlation among all crops' yields and losses are small or positive; and c) for low levels of risk aversion. In fact, WFI provides a gain if and only if farmers exhibit a certain level of risk aversion.

It was shown that fair premium could be reduced by 15 to 20% with WFI with respect to the situation of a set of crop-specific insurance policies. As governments typically subsidize premia based on a proportion of their value, subsidies could be reduced significantly without impairing the risk reduction potential granted to the farmers.

There is an additional potential advantage of WFI over CSI that it was not addressed in this paper. It is fair to assume that farmers only claim indemnities when they expect that the loss adjuster would approve it. As a result, it is very likely that WFI's administrative costs may be lower than with CSI, because farmers would not be interested in reporting losses in one crop when they expect that favorable results from others make up for the losses of the failed one. Should this be the case, lesser loss adjustment costs would also be another advantage of WFI over CSI.

Among some of the disadvantages of WFI is the need to compute individual premia for each farmer and to recompute them every year that the cropping pattern changes. Also, Dismukes and Coble (2006) argue that WFI is more difficult to administer than CSI. Yet, with good information technology systems, this needs not represent a major obstacle.

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