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Are the Federal Crop Insurance Subsidies Equitably Distributed? Evidence from a Monte Carlo Simulation Analysis

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This study hypothetically analyzes the distribution of the premiums paid and thus the subsidies received by farmers participating in the Risk Management Agency (RMA) multi-peril crop insurance program. The results show a wide spread in the effective subsidy levels, to where some producers might not be receiving any subsidies at all (i.e., they actually pay close to their full actuarially fair premium), while others only pay a small fraction of their actuarially fair premium. More importantly, the results show that "shrinkage" estimators such as the one used by the RMA have the unintended negative consequence of disproportionally subsidizing farmers who are less effective in managing risk. Producers whose farms exhibit higher downside yield variability receive much more generous subsidies than those with lower levels of yield variability.

Key words: agricultural subsidies, crop insurance premiums, farmer welfare, risk management agency

Introduction

The federal crop insurance program provides U.S. agricultural producers with important tools for managing yield and revenue risks in their farm operations (Harwood et al., 1999). In 2013, the program covered close to 296 million acres, or 90% of insurable crop land, assuming nearly $124 billion in liabilities through 1.22 million individual policies (U.S. Department of Agriculture, Risk Management Agency, Federal Crop Insurance Corporation, 2014). The Risk Management Agency (RMA), a division of the United States Department of Agriculture, is charged with administering this program. High participation has been achieved through large subsidies, with farmers as a whole now paying less than 40% of the total amount of premiums required to cover all of the program's indemnities (U.S. Department of Agriculture, Risk Management Agency, Federal Crop Insurance Corporation, 2014).

The traditional product offered by the RMA, which for the purpose of simplicity is the focus of this paper, is a farm-level, multiple-peril, crop yield insurance policy (MPCI). This policy protects against low yield and crop quality losses due to adverse weather and unavoidable damage from insects and disease (Barnett, 2000). The rate-setting process for the MPCI can be divided into two major steps. The first step computes a county-level premium based on historical county-wide indemnities and liabilities. The second step sets farm-level rates based on the county-level premium and the producer's historical farm-level yield records using an exponential "shrinkage" procedure that compresses the premium estimates implied by the individual farm yield data toward the county mean (Josephson, Lord, and Mitchell, 2000).

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Recent research shows that the RMA's premium estimates are subject to substantial errors relative to the "true" (i.e., the actuarially correct) farm-level premiums. These inaccuracies in the RMA estimation of crop insurance premiums could, by themselves, account for most of the subsidies that are being required to pay for the program's indemnities (Ramirez and Carpio, 2012). Ramirez and Carpio's 2012 results also suggest that under the current rate-setting protocols, producer uncertainties about their own actuarially fair premiums (AFP) could have as much of a negative impact on program performance as insurer error and that producer uncertainty on top of the insurer's errors can exacerbate the need for subsidies. A recent U.S. Government Accountability Office report on crop insurance concludes that the subsidy costs are greater in areas with higher production risks, to the extent that the premiums may not be sufficient to cover expected losses (U.S. Government Accountability Office, 2015).

This study more specifically focuses on exploring the impact of the inaccuracies in premium estimation by the insurer (RMA) as well as producer uncertainty on the distribution of the premiums paid and thus the subsidies received by farmers participating in the MPCI. Specifically, using an exponential "shrinkage" estimator akin to the RMA's, given a particular intended subsidy level (e.g., 50%), we estimate the probabilities that a producer would end up paying various percentages of his or her true AFP and thus receiving different effective subsidy levels. We also explore other economic welfare implications of using this estimator.

The results presented in this paper show a surprisingly wide spread in the effective subsidy levels, to the point where some might not be receiving any subsidies (i.e., they actually pay close to their full actuarially fair premium) while others pay only a small fraction of their AFP. More importantly, the results show that "shrinkage" estimators such as the one used by the RMA have the unintended negative consequence of disproportionally subsidizing producers who are less effective in managing risk. That is, those whose farms exhibit higher yield variability receive a much larger percentage subsidy than the producers with lower levels of yield variability.

Data

Unfortunately, the only way to obtain the program performance statistics presented in this paper is using simulated data. Unless the yield data are simulated from assumed or known probability distributions, the actuarially fair premium for any particular farm unit is unknown, and the differences between the premium estimates and the AFP are what determine all the indicators of program performance discussed in this study. Farm-level yield data from prototypical Midwestern corn-producing counties is thus repeatedly simulated (NR=Number of Runs=1,000 per scenario, SS=Sample Size=10- and 20-yield observations per farm) under the assumption of normal and non-normal (left-skewed) yield distributions. Each county is assumed to comprise NF farms (NF=Number of Farms= 50 and 200), whose yields exhibit low (CC=Correlation Coefficient=0.25) and moderate (CC=0.50) levels of linear correlation with one other. The true means and standard deviations of the farm-level yield distributions are drawn to randomly range from 150 to 170 and 30 to 40 bushels per acre (wide-range scenario) and 155 to 165 and 32.5 to 37.5 bushels per acre (narrow-range scenario) according to a simple uniform (i.e., equal probability) distribution. In the case of the non-normal scenario, the underlying skewness and kurtosis measures of the distributions are assumed to randomly range from 0 to −3.25 and 0 to 23.5, also according to a uniform distribution.

The ranges assumed for the mean, standard deviation, skewness, and kurtosis parameters are consistent with the estimates from parametric models of Illinois farm-level corn yields presented in Ramirez, McDonald, and Carpio (2010). Their model was based on empirical data (twenty to forty-five farm-level observations) obtained from the University of Illinois Endowment Farms database, which includes twenty-six corn farms located in twelve counties across that state.

In addition, since the only available empirical evidence (Goodwin, 1994) suggests weak and mixed-sign farm-level mean-variance correlation in a variety of crops, including dryland and

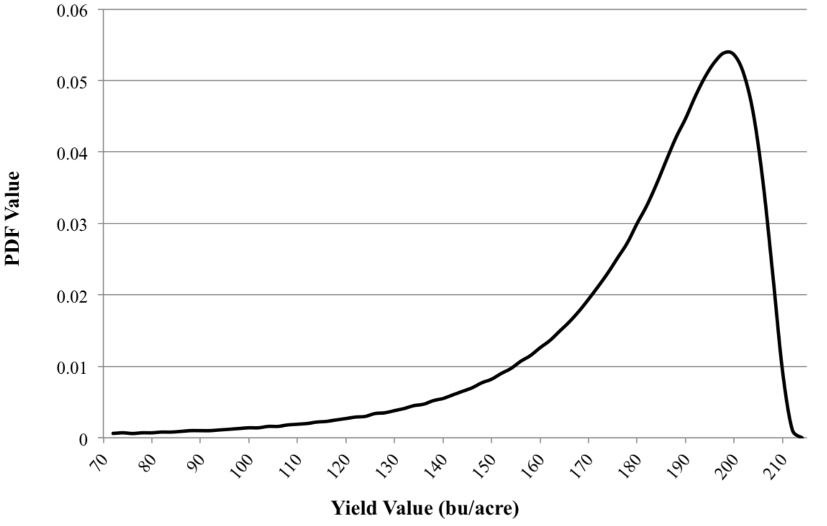

Figure 1. Hypothetical Yield Density

irrigated corn, the moment parameters are drawn independently from one other. This allows us to mimic the most likely county-level situation in which the farm unit yields can exhibit a wide variety of distributional shapes. We then reduce the ranges of the mean and standard deviation parameters to simulate a situation in which the farms within the county are more homogeneous in nature, which is expected to improve program performance due to the "shrinkage" nature of the RMA estimator. As described in the following section, the expanded S_U distribution (Ramirez, Misra, and Field, 2003) is utilized to simulate non-normal yields with those characteristics.

The yield simulation scenarios are designed to resemble the characteristics of corn production in the Midwestern United States. For example, when yields are assumed to be normally distributed, at the highest mean of 170 bu/acre and the lowest standard deviation of 30 bu/acre, the probability of observing a yield value under 120 bu/acre or over 220 bu/acre is only 10% (5% under and 5% over). This would have to be a superior farmer with a limited downside and a substantial upside yield potential. At the lowest mean of 150 bu/acre and the highest standard deviation of 40 bu/acre, the 5% probability bounds are 85 and 215 bu/acre. This could be a farmer with a sizable downside but also a high upside yield potential.

Alternatively, when yields are assumed to follow a substantially left-skewed S_U distribution, at the highest mean of 170 bu/acre and lowest standard deviation of 30 bu/acre and skewness and kurtosis values of −3.25 and 23.5, the 5% probability boundaries are 115 and 195 bu/acre (figure 1). These expand to 95 and 205 bu/acre at the highest mean and standard deviation of 170 and 40 bu/acre. In other words, the upside yield potential from the mean of 170 bu/acre is less than half as much as the downside potential. It is believed that these distributions are more representative of the behavior of farm-level corn yields in the Midwest (Ramirez, 1997; Ramirez, Misra, and Field, 2003; Lu et al., 2008; Ramirez, McDonald, and Carpio, 2010).

Simulation Methods

Correlated normal and non-normal yield series are required for the purposes of this study because the RMA premium-rating protocol is based on yield information from all farms in the county. Also, while normality is the usual assumption, it has been shown that Midwest corn yields are substantially left skewed (Ramirez, 1997). To this effect, a (1×NF) vector of standard normal draws ($\boldsymbol{V}_t$) is first correlated by multiplying it by the Cholesky decomposition of the desired (NF×NF) cross-farm correlation matrix (Ramirez, 1997). To simulate normal yields, the resulting (1×NF) vector ($\boldsymbol{VC}_t$) is element-by-element multiplied by the (1×NF) standard deviation vector ($\boldsymbol{\sigma}$) and the result is added to the (1×NF) mean vector ($\boldsymbol{\mu}$).

The process is repeated until the desired sample size (SS) is achieved. As previously discussed, the elements of $\boldsymbol{\mu}$ and $\boldsymbol{\sigma}$ are randomly drawn from uniform distributions to range from 150 to 170 and 30 to 40 bu/acre (wide-range scenario) and 155 to 165 and 32.5 to 37.5 bu/acre (narrow-range scenario). The assumption of independence between the $\boldsymbol{\mu}$ and $\boldsymbol{\sigma}$ draws is based on Goodwin (1994), who only found weak and mixed-sign evidence of mean-variance correlation in a variety of crops, including dryland and irrigated corn.

Because of its documented flexibility to generate a wide range of mean-variance-skewness-kurtosis combinations, the expanded form of the S_U family of parametric distributions (Ramirez, Misra, and Field, 2003) is adopted for simulating non-normal yields. Simulation from this distribution is conducted as follows:

$$
\begin{aligned}
\boldsymbol{Y}_t &= \boldsymbol{\mu} + [\{\boldsymbol{\sigma}^2/G(\theta,\delta)\}^{1/2} .* \{\sinh(\theta(\boldsymbol{VC}_t + \delta) - F(\theta,\delta)\}]/\theta, \\
F(\theta,\delta) &= E[\sinh(\theta(\boldsymbol{VC}_t + \delta)] = \exp(\theta^2/2)\sinh(\theta\delta), \text{ and} \\
G(\theta,\delta) &= \{\exp(\theta^2) - 1\}\{\exp(\theta^2)\cosh(-2\theta\delta) + 1\}/2\theta^2,
\end{aligned} \tag{1}
$$

where $\boldsymbol{Y}_t$ is the resulting (1×NF) vector of correlated non-normal crop yields; $\boldsymbol{\mu}$ is the (1×NF) mean vector; $\boldsymbol{\sigma}$ is the (1×NF) standard deviation vector; $-\infty < \theta < \infty$; and $-\infty < \delta < \infty$ are two other scalar distributional parameters exclusively controlling skewness and kurtosis; sinh, cosh, and exp denote the hyperbolic sine and cosine and the exponential function; $\boldsymbol{VC}_t$ is the (1×NF) vector of correlated standard normal draws; and $.*$ denotes element-by-element vector multiplication. According to Ramirez, Misra, and Field (2003), the resulting (1×NF) vector of simulated yields ($\boldsymbol{Y_t}$) exhibits the following characteristics:

$$
E[\boldsymbol{Y}_t] = \boldsymbol{\mu},\ Var[\boldsymbol{Y}_t] = \boldsymbol{\sigma}^2,\ Skew[\boldsymbol{Y}_t] = S(\theta,\delta),\ Kurt[\boldsymbol{Y}_t] = K(\theta,\delta), \tag{2}
$$

where $S(\theta,\delta)$ and $K(\theta,\delta)$ involve simple but lengthy combinations of exponential and hyperbolic sine and cosine functions. In other words, the mean and the variance of $\boldsymbol{Y}_t$ are solely determined by $\boldsymbol{\mu}$ and $\boldsymbol{\sigma}$, respectively, while its skewness and kurtosis are only dependent on θ and δ. If $\theta \neq 0$, as δ approaches 0, the $\boldsymbol{Y}_t$ distribution becomes symmetric but remains kurtotic. Higher absolute values of θ cause increased kurtosis. If $\theta \neq 0$ and $\delta > 0$, $\boldsymbol{Y}_t$ has a kurtotic and right-skewed distribution, while $\delta < 0$ results in a kurtotic and left-skewed distribution. Higher absolute values of δ produce increased skewness. Because of these characteristics, this expanded form of the S_U family is capable of generating a wide range of mean-variance-skewness-kurtosis combinations (see Ramirez, McDonald, and Carpio, 2010, figure 1). More importantly, for the purposes of this study, they make it possible to independently prespecify the desired mean, standard deviation, skewness, and kurtosis values for the simulated yield distributions.

Actuarially Fair Premiums

The actuarially fair premiums (AFP) for the Actual Production History (APH) insurance program under a price guarantee (p_g) of \$5 per bushel and 60%, 65%, 70%, 75%, and 80% coverage levels (CL) are computed for each of the yield distributions in the analyses using standard procedures. Specifically, the analytical formula for computing the AFP is

$$
AFP = \int_0^{\alpha\mu} p_g(\alpha\mu - y) f(y)dy, \tag{3}
$$

where $f(y)$ the is the probability density function of yields (y), α is the coverage ratio (i.e., $\alpha = CL$), μ is the true mean of y, and p_g is the guaranteed price (Ramirez and Carpio, 2012).

For the case of normally distributed yields, the integral in equation (3) exhibits the following closed-form solution:

$$AFP = p_g P(\alpha\mu - \mu) + Z\sigma, \tag{4}$$

where $P = Z(0.4361836T - 0.1201676T^2 + 0.937298T^3)$, $Z = (2\pi)^{-1/2}\exp(-0.5(\mu - \alpha\mu)^2/\sigma^2)$, and $T = (1 + 0.33267(\mu - \alpha\mu)/\sigma)^{-1}$ (Skees and Reed, 1986).

When the yield distribution $f(y)$ is not normal (i.e., S_U), since there is no closed-form solution for the integral in equation (3), the AFP is numerically computed as follows:

$$AFP = \frac{1}{T}\sum_{t=1}^{T} I\{Y_t < \alpha\mu\} p_g(\alpha\mu - Y_t), \tag{5}$$

where $I\{.\}$ is an indicator function that takes a value of 1 if true and 0 otherwise; the Y_t values are simulated from an S_U distribution with the desired mean, standard deviation, skewness and kurtosis characteristics; T = 1,000,000; and p_g, α, and μ are as previously defined.

Select statistics about the actuarially fair premiums corresponding to various coverage levels and the different yield simulation scenarios outlined in the previous section are presented in table 1. For the scenarios (i.e., counties) with normal yields and the wider range of true means and standard deviations (150 to 170 and 30 to 40 bu/acre), at the 65% coverage level, the AFPs range from \$1.45 to \$8.72 and average \$4.56 per acre. Additionally, the average frequency of claims is 18.9 years, with a range of 10.7 to 39.3 years. That is, the riskiest of the 200 farmers in this particular set of $\boldsymbol{\mu}$ and $\boldsymbol{\sigma}$ value drafts would, on average, have one claim every 11 years or so, while the least risky will only have a claim about every 40 years, on average. In contrast, at the 85% coverage level, the AFPs range from \$16.97 to \$35.63 and average \$26.55 per acre, and the frequency of claims ranges from 3.5 to 5 and averages just about 4 years. In the left-skewed yield scenarios, the AFPs seem more consistent with what is observed in reality. At 65% coverage, they range from \$1.85 to \$15.48 and average \$8.60 per acre, while at 85% coverage they range from \$18.62 to \$37.97 and average \$28.86 per acre.

When a narrowed dispersion of true means (155 to 165 bu/acre) and standard deviations (32.5 to 37.5 bu/acre) is assumed, the average premiums and claim frequencies remain about the same while their ranges are somewhat tighter, as expected. Nevertheless, the wide range of AFPs observed in these scenarios, particularly at the lower (65% to 75%) coverage levels, offers an insight to a potential pitfall of the RMA's "shrinkage" estimator. As shown in the following sections, the RMA estimator yields farm-level premium estimates that are substantially "shrunk" toward the county average. Thus, if no subsidies were provided, those producers whose AFPs are close to the lower bound of the county range would inevitably end up paying quite a bit more than what is actuarially fair. With subsidies, however, those close to the upper bound for the county could end up paying only a small fraction of their AFP.

The RMA "Shrinkage" Estimator

The RMA estimator for the APH premiums is based on historical yield, loss, and indemnity information from all farms in a particular county. In order to make the desired comparisons between the actuarially fair premiums and the estimates obtained when using an RMA-like estimator, premium estimates are repeatedly computed on the basis of simulated normal and non-normal yield samples following the experimental design described in the data section. While the exact ratemaking protocol utilized by the RMA is not publically available, the manner in which the rates are generally established has been amply discussed in the literature. Specifically, for each farm i, the procedure involves: 1) computing farm-level indemnities and liabilities; 2) computing county-level rates using farm-level indemnities and liabilities; and 3) estimating farm-level premiums using county rates (CPR) and farm- and county-level yields.

Table 1. Select Premium ($/acre) and Coverage Statistics for the Main Scenarios in the Analysis

Normal		**CL**	**AFPMIN**	**AFPAVE**	**AFPMAX**	**ESTPMIN**	**ESTPAVE**	**ESTPMAX**	**%BIAS**	**CORREL**	**FREMAX**	**FREAVE**	**FREMIN**
# farms	200	65%	1.454	4.560	8.720	3.789	4.195	4.727	-8.0	0.412	39.308	18.901	10.709
mean	150/170	70%	2.940	7.445	12.884	6.343	6.903	7.639	-7.3	0.382	21.212	11.963	7.753
sigma	30/40	75%	5.594	11.756	18.548	10.249	10.997	11.986	-6.5	0.348	12.235	7.965	5.780
skew	0	80%	10.028	17.959	26.025	16.012	16.958	18.214	-5.6	0.311	7.550	5.558	4.440
kurtosis	0	85%	16.967	26.547	35.630	24.204	25.303	26.777	-4.7	0.264	4.969	4.055	3.499
Left-Skewed		**CL**	**AFPMIN**	**AFPAVE**	**AFPMAX**	**ESTPMIN**	**ESTPAVE**	**ESTPMAX**	**%BIAS**	**CORREL**	**FREMAX**	**FREAVE**	**FREMIN**
# farms	200	65%	1.851	8.599	15.481	7.234	7.584	8.095	-11.8	0.211	33.193	16.158	10.501
mean	150/170	70%	3.568	11.661	19.214	9.958	10.423	11.108	-10.6	0.166	18.671	11.639	7.760
sigma	30/40	75%	6.522	15.817	23.843	13.737	14.355	15.267	-9.2	0.142	12.204	8.534	5.791
skew	0/-3.25	80%	11.309	21.413	30.133	18.898	19.755	20.988	-7.7	0.125	9.251	6.354	4.443
kurtosis	0/23.5	85%	18.615	28.860	37.972	25.981	27.073	28.637	-6.2	0.114	6.955	4.800	3.507
Normal		**CL**	**AFPMIN**	**AFPAVE**	**AFPMAX**	**ESTPMIN**	**ESTPAVE**	**ESTPMAX**	**%BIAS**	**CORREL**	**FREMAX**	**FREAVE**	**FREMIN**
# farms	200	65%	2.532	4.052	5.889	3.330	3.532	3.768	-12.8	0.282	25.906	18.799	14.003
mean	155/165	70%	4.625	6.792	9.276	5.724	6.036	6.402	-11.1	0.261	15.397	11.999	9.577
sigma	32.5/37.5	75%	8.053	10.952	14.142	9.461	9.923	10.466	-9.4	0.236	9.644	8.018	6.762
skew	0	80%	13.362	17.008	20.883	15.047	15.677	16.438	-7.8	0.204	6.399	5.600	4.973
kurtosis	0	85%	21.141	25.464	29.911	23.037	23.836	24.812	-6.4	0.164	4.464	4.081	3.773
Left-Skewed		**CL**	**AFPMIN**	**AFPAVE**	**AFPMAX**	**ESTPMIN**	**ESTPAVE**	**ESTPMAX**	**%BIAS**	**CORREL**	**FREMAX**	**FREAVE**	**FREMIN**
# farms	200	65%	2.520	7.498	13.572	6.328	6.513	6.729	-13.1	0.201	26.100	16.640	12.324
mean	155/165	70%	4.607	10.409	16.869	8.886	9.146	9.466	-12.1	0.091	15.445	11.840	9.353
sigma	32.5/37.5	75%	8.013	14.444	20.984	12.477	12.877	13.366	-10.8	0.032	11.171	8.588	6.852
skew	0/-3.25	80%	13.299	19.970	26.139	17.503	18.097	18.863	-9.4	0.009	8.632	6.338	5.108
kurtosis	0/23.5	85%	21.075	27.422	33.526	24.436	25.285	26.345	-7.8	0.018	6.597	4.755	3.854

Notes: CL=Coverage Level; AFP=Actuarially Fair Premium; AFPMIN=Minimum of the 200 AFPs; AFPAVE=Average of the 200 AFPs; AFPMAX=Maximum of the 200 AFPs; ESTPMIN= Minimum of the 200 RMA premium estimates; ESTPAV=Average of the200 RMA premium estimates; ESTPMAX= Maximum of the 200 RMA premium estimates; %BIAS is the % difference between the average of the RMA premium estimates and the average of the AFPs; CORREL= linear correlation between AFPs and RMA estimates; FREMAX=Maximum Frequency of Payment (out of the 200); FREAVE=Average Frequency of Payment (out of the 200); FREMIN=Minimum Frequency of Payment (out of the 200).

Computation of Farm-Level Indemnities and Liabilities[1]

The indemnities paid to farm i with a coverage level of $\alpha = CL$ of its APH yield are computed as follows:

$$FLI_{it} = p_g Y_{it}^*, \text{ where } Y_{it}^* = \begin{cases} \alpha APH_{it} - Y_{it} \text{ if } Y_{it} < \alpha APH_{it} \\ 0 \text{ otherwise} \end{cases}, \tag{6}$$

where FLI_{it} is the indemnity paid to farm i in year t, Y_{it} is the realized yield for farm i in year t, and APH_{it} is the RMA's approved actual production history yield for farm i in year t. The liability for the same farm i in year t (FLL_{it}) is given by

$$FLL_{it} = \alpha p_g APH_{it}. \tag{7}$$

The procedure used in this paper to calculate APH_{it} replicates the method used by the RMA. According to Plastina and Edwards (2014), computing the APH requires unit-yield records for a minimum of four years. If at least four successive years of records are not available, a transition or T yield for each missing year must be substituted. Each county has a different T yield, which is based on the ten-year historical county average yield. Growers with no records are assigned 65% of the T yield as their APH yield. Growers with a record for one year receive 80% of the T yield for the other three years. With two records, they receive 90% of the T yield, and with three records, they receive 100% of the T yield for the one remaining year needed to calculate the APH. Once each year has been assigned a yield, the APH is just a simple average of the four yields.

Computation of County-Level Rates

For any year t, the simulated indemnity, liability, and CPR for the NF group of farms in the county are computed as follows (Josephson, Lord, and Mitchell, 2000):

$$Indemnity_t = \sum_{i=1}^{NF} FLI_{it}, \tag{8}$$

$$Liability_t = \sum_{i=1}^{NF} FLL_{it}, \tag{9}$$

$$CPR_t = \frac{Indemnity_t}{Liability_t}. \tag{10}$$

The simulated CPR using the SS observations (i.e., years) in the sample then is

$$CPR = \frac{1}{SS} \sum_{t=1}^{SS} CPR_t. \tag{11}$$

Estimation of Farm-level Premiums

The main equation underlying the RMA ratemaking procedure for yield insurance is

$$FLE_i = \alpha p_g APH_{iSS} CPR \left(\frac{APH_{iSS}}{Yavc} \right)^{Exp}, \tag{12}$$

[1] In the following calculations it is assumed that none of the land has been converted from native grass.

where FLE_i is the premium estimate for farm i, *Exp* is an exponential factor which value is usually less than -1, APH_{iSS} is the APH yield for farm i, and $Yavc$ is the county average yield (Josephson, Lord, and Mitchell, 2000). Note that in equation (12) both APH_{iSS} and $Yavc$ are calculated using the entire sample of simulated yields (SS). Although this is a somewhat simplified version of the procedure utilized by the RMA, it includes all of the elements central for our analysis.[2] In short, equation (12) establishes individual farm-level premiums using the county rate (CPR) as the baseline. The exponential factor (*Exp*) is used so that farmers with yields that are above the area's average pay lower premiums and vice versa (Knight, 2000).

Since the RMA procedure for determining *Exp* is unknown, this factor was computed by minimizing the mean root of the squared proportional errors of the farm-level premium estimates (FLE_i) relative to their corresponding AFPs (i.e., by minimizing $\frac{1}{NF}\sum_{i=1}^{NF}\sqrt{\left[\frac{FLE_i-AFP_i}{AFP_i}\right]^2}$). Very similar results were obtained when *Exp* was computed by minimizing the mean proportional errors ($\frac{1}{NF}\sum_{i=1}^{NF}\left[\frac{FLE_i-AFP_i}{AFP_i}\right]$) or the mean absolute proportional errors ($\frac{1}{NF}\sum_{i=1}^{NF}\left|\left[\frac{FLE_i-AFP_i}{AFP_i}\right]\right|$). The logic behind all these methods is to select the *Exp* value that yields the set of NF premium estimates which overall exhibits the lowest level of error.[3]

Characteristics of the RMA Premium Estimates

The procedure discussed above is used to estimate the set of NF farm-level premium estimates corresponding to each of the previously discussed scenarios (i.e., counties). Summary statistics for these premium estimates for the scenarios with NF=200, CC=0.50, and a sample size (SS) of twenty yield observations per farm are also presented in table 1. The premium estimates are biased even in the aggregate (i.e., in repeated sampling, the average of the premium estimates for all NF farms does not equal the average of their AFPs) and, due to the "shrinkage" nature of the RMA's estimator, they are tightly clustered near the county average. The aggregate bias can be as high as -13% (which means that the average of the RMA premium estimates is 13% lower than the average of the AFPs), but it steadily declines with higher coverage levels.[4] The estimates are substantially biased at the individual farm level as well (i.e., in repeated sampling, the average of the NR=1,000 premium estimates for farm i does not equal AFP_i).

In addition, these statistics provide further insight into the problem faced by the RMA. In the arguably more realistic case of left-skewed yields and a wider range of true means and standard deviations, for example, the premium estimates for the 65% coverage level only span from \$7.23 to \$8.10 per acre while the AFPs range from \$1.85 to \$15.48, and the linear correlation between the estimated and the true premiums is only 0.21. The reason for this is that the RMA premium estimates are severely shrunk toward the county average while a relatively small difference in yield variability (e.g., form a standard deviation of 30 to 40 bu/acre) can result in large variation (e.g., from \$2 to \$16/acre) in the AFP. Clearly, if no subsidies were provided, a substantial number of producers would be asked to pay much more than their corresponding AFPs. Such a situation is unacceptable since the RMA is required by law not to charge more than what is actuarially fair. If

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2 The RMA procedure includes other minor elements such as caps on premiums levels, adjusting losses and exposure to a common coverage level, and excess loss adjustments (Josephson, Lord, and Mitchell, 2000).

3 Notably, the only previous study in which *Exp* has been estimated is Knight's 2000, in which an equation similar to equation (12) is fitted using a two-step Heckman procedure. Coble et al. (2010) suggest the use of nonlinear least squares to estimate *Exp*. In both cases, the dependent variable in the model is the average indemnity paid to farmers during the sample period ($\overline{FLI}_i$), which is a nonparametric estimate of the true AFP and therefore subject to substantial sampling error (Ramirez, Carpio, and Rejesus, 2011). Since in our analyses the true AFP for each farm i is known, it seems best to use this information instead of estimating the AFPs.

4 The aggregate biases are negative as a result of *Exp* values obtained from our estimation approach of minimizing the mean root squared proportional errors, which range from -2 to -4. Arbitrarily setting the *Exp* to, for example, -1 yields positive aggregate biases at 65% (~ 0.09) and 75% (~ 0.015) coverage, which turn negative at higher levels.

there were a high level of subsidy to the premium estimate, however, many farmers would end up paying only a small fraction of their AFP.

The situation improves somewhat when a narrower range of true means and standard deviations is assumed, mainly due to the fact that the AFPs are not as dispersed. Further improvement is observed under higher coverage levels. At 85% coverage, for example, the premium estimates span from \$24.44 to \$26.35 while the AFPs range from \$21.08 to \$33.53, although the correlation between the estimated and the true premiums is minimal. In this scenario, only a relatively small percentage premium subsidy would be required to make sure that no producer pays more than what is actuarially fair.

Distribution of Crop Insurance Subsidies

Basic Scenarios

We use the NF×NR matrix of farm-level premium estimates corresponding to each of the scenarios (i.e., counties) to retrieve and assess the characteristics of the distribution of the crop insurance subsidies across participating producers when those premiums are computed using an RMA-like protocol. The insurer (i.e., RMA) and producer premium estimates are denoted by IPE and PPE, respectively, and in some scenarios it is assumed that producers are willing to pay a risk-protection premium (RPP) in excess of their PPE. Further, a government subsidy rate (GSR) to the insurer premium estimate (IPE) is assumed in order to replicate what is done in practice. The farmer's decision rule for participating in the program, thus, is given by

$$PPE \times RPP \geq (1 - GSR)IPE \tag{13}$$

(i.e., his or her own premium estimate adjusted by any risk protection premium he or she is willing to pay is greater than or equal to the subsidized insurer's quote). If $RPP = 1$, the producer is risk neutral. In some of the scenarios we assume $RPP = 1.15$ (i.e., a 15% risk protection premium). This means that the producer is willing to pay 15% more than what he or she thinks is fair (i.e., of his estimate or perception of his or her AFP). More generally, this means that the producer's willingness to pay for insurance is 15% higher than if he or she were risk-neutral. Initially, it is assumed that the producer knows his or her AFP with certainty (i.e., $PPE = AFP$), but scenarios with various levels of producer uncertainty are explored and discussed below.

Each farm i is thus characterized by a set of two premium estimates, one by the producer (PPE_i) and one by the insurer (IPE_i), and a corresponding actuarially fair premium (AFP_i). The distribution of the premiums paid by the participating producers relative to their AFPs (i.e., what they should theoretically be paying) can then be retrieved by comparing the IPE for each of the NF participating farmers (i.e., what they ended up paying) with its corresponding AFP over a large number of repeated samples (NR=1,000).

The NF×NR matrix of RMA premium estimates (IPE_i) and the NF×1 vector of AFPs (AFP_i) corresponding to each particular scenario are the data inputs for this part of the analysis.

The first step then is to compute the expected producer participation rate (PPR), which is a function of PPE_i and IPE_i as well as the RPP and GSR. Specifically, letting $I\{.\}$ denote an indicator function that equals 1 if $\{.\}$ is true and 0 otherwise, the PPR for each sample r is

$$PPR_r = 100\frac{1}{NF}\sum_{i=1}^{NF} I\{PPE_i + RPP \geq (1 - GSR)IPE_i\}. \tag{14}$$

The average of equation (14) across the NR samples (PPR) is utilized to determine the GSR that is required to achieve a target level of participation. Specifically, the average of equation (14) is evaluated at GSRs ranging from 0 to 1 and the value (GSR_{PPR}) that yields the desired producer participation rate (PPR=90% and 98%) is selected.

The next step is to identify the insurer premium estimates and actuarially fair premiums for the farmers that would actually decide to participate in the program. This is done as follows:

$$(15) \qquad IPE_{ip} = IPE_i \times I\{PPE_i + RPP \geq (1 - GSR_{PPR})IPE_i\},$$
$$AFP_{ip} = AFP_i \times I\{PPE_i + RPP \geq (1 - GSR_{PPR})IPE_i\}.$$

If the participation rule is met in equation (15), then $IPE_{ip} > 0$, $AFP_{ip} > 0$, $IPE_{ip} = IPE_i$, and $AFP_{ip} = AFP_i$. Otherwise $IPE_{ip} = 0$ and $AFP_{ip} = 0$. The following set of logical comparisons is then conducted based on all IPE_{ip} and AFP_{ip} sets that exhibit nonzero values:

$$(16) \qquad I_{i,1.2-j} = I\{(1 - GSR_{PPR})IPE_{ip} > (1.2 - j)AFP_{ip}\} \text{ for} j = 0, 0.05, 0.10, \ldots, 1.0,$$

where the subindex $1.2 - j$ specifies the proportion of the AFP being considered. For example, for $j = 0$ if $I_{i,1.2} = 1$, this indicates that farmer i paid more than 100(1.2)=120% of his or her AFP. Thus, the average of $100x \sum_{i=1}^{NFp} I_{i,1.2-j}/NFp$ (where NFp denotes the number of participating farmers in that particular sample) across the NR=1,000 samples computes the overall percentage of producers that ended up paying more than $100(1.2 - j)\%$ of their AFP. For the prespecified target participation rate (PPR),

$$(17) \qquad PFG_{PPR} = 1 - \sum_{i=1}^{NFp} (1 - GSR_{PPR})IPE_{ip} / \sum_{i=1}^{NFp} AFP_{ip}$$

averaged across the NR=1,000 samples calculates the proportion of the total indemnities to be paid out that would not be covered by the premiums collected from the participating producers and thus would have to be funded by the government.

Table 2 presents the statistics resulting from this process using assumptions of a 65% coverage level and a 90% target producer participation rate. The first scenario (SN1a) assumes normally distributed yields, no producer premium estimation error (i.e., $PPE_i = AFP_i$), no risk protection premium ($RPP = 0$), NF=50 farms per county, SS=10 historical yield observations per farm, the wider range (Range=W) of true means and standard deviations, and a correlation coefficient of CC=0.25 across the NF=50 yield distributions. In this scenario, it is determined using equation (14) that a 49% government subsidy rate ($GSR = 0.49$) is required to achieve the target of approximately 90% producer participation ($PPR = 0.901$). The corresponding PFG (0.575) is then computed using equation (17), which means that 57.5% of the indemnities would have to be funded by the government in this scenario. Because it is assumed that $PPE_i = AFP_i$ and $RPP = 0$, none of the participating producers end up paying more than what is actuarially fair. However, as detailed in table 2, while over 15% pay 75% or more of their AFP, in excess of 15% pay less than 25% of it. In other words, 15% of them receive less than a 25% effective premium subsidy while another 15% have over 75% of their AFP subsidized.

Relative to SN1a, the second normal scenario in table 2 (SN2a) raises the cross-farm correlation (CC) from 0.25 to 0.50. This higher correlation reduces the amount of independent yield information available for the RMA to estimate the premiums. Because of the less accurate premium estimates, a higher GSR (58%) is required to achieve 90% participation and the PFG increases substantially as well. Given the larger subsidy level, a full 30% of farmers now pay less than 20% of their corresponding AFP, while nearly 15% pay 70% or more of what is actuarially fair. So it appears that a stronger correlation exacerbates the inequity in the distribution of the subsidies across participating producers.

Increasing the number of farms (NF) from 50 to 200 (SN3a) only affects the accuracy with which the county-level statistics (equations 8 to 11) required for premium estimation can be computed, and the results suggest that the improvement is only marginal (i.e., a slightly lower GSR and PFG and a minimal shrinking on the spread of the distribution of the subsidies). Doubling the sample size from ten to twenty yield observations per farm (SN4a), however, noticeably increases the accuracy of the farm-level premium estimates, lowers the required GSR and PFG, and somewhat compresses the distribution of the crop insurance subsidies.

Table 2. Government Subsidy Rate (GSR), Producer Participation Rate (PPR), Proportion of Indemnities Funded by the Government (PFG) and Percentiles of the Distribution of the RMA Premium Estimates under Normal Yields, 65% Coverage Level (CL), and Target PPRs of 90% (a) and 98% (b)

	SN1a	SN2a	SN3a	SN4a	SN5a	SN6a	SN1b	SN2b	SN3b	SN4b	SN5b	SN6b
NF	**50**	**50**	**200**	**50**	**50**	**200**	**50**	**50**	**200**	**50**	**50**	**200**
SS	**10**	**10**	**10**	**20**	**10**	**20**	**10**	**10**	**10**	**20**	**10**	**20**
Range	**W**	**W**	**W**	**W**	**N**	**N**	**W**	**W**	**W**	**W**	**N**	**N**
CC	**0.25**	**0.50**	**0.50**	**0.50**	**0.50**	**0.25**	**0.25**	**0.50**	**0.50**	**0.50**	**0.50**	**0.25**
GSR	0.490	0.580	0.560	0.500	0.470	0.250	0.660	0.770	0.760	0.690	0.680	0.420
PPR	0.901	0.904	0.904	0.900	0.904	0.903	0.980	0.981	0.908	0.980	0.981	0.980
PFG	0.575	0.663	0.648	0.601	0.593	0.375	0.697	0.793	0.787	0.733	0.722	0.500
Proportion of AFPs					**Percentiles of the RMA Premium Estimates**							
0.20	0.900	0.700	0.747	0.852	0.751	0.996	0.759	0.468	0.476	0.651	0.588	0.989
0.25	0.832	0.621	0.652	0.770	0.679	0.989	0.644	0.359	0.365	0.535	0.473	0.968
0.30	0.757	0.547	0.566	0.686	0.609	0.976	0.536	0.283	0.284	0.430	0.377	0.927
0.35	0.676	0.479	0.490	0.607	0.538	0.953	0.426	0.224	0.223	0.328	0.287	0.852
0.40	0.596	0.419	0.422	0.532	0.470	0.915	0.341	0.179	0.175	0.261	0.230	0.742
0.45	0.520	0.351	0.357	0.459	0.407	0.855	0.270	0.140	0.138	0.208	0.184	0.619
0.50	0.448	0.300	0.302	0.388	0.351	0.772	0.213	0.112	0.110	0.163	0.147	0.498
0.55	0.366	0.257	0.256	0.317	0.290	0.678	0.166	0.090	0.088	0.129	0.118	0.388
0.60	0.305	0.216	0.214	0.264	0.249	0.580	0.128	0.071	0.070	0.101	0.096	0.288
0.65	0.247	0.181	0.177	0.219	0.214	0.482	0.096	0.056	0.056	0.077	0.077	0.211
0.70	0.198	0.148	0.144	0.178	0.181	0.389	0.071	0.043	0.043	0.058	0.060	0.151
0.75	0.155	0.118	0.114	0.140	0.151	0.302	0.051	0.032	0.032	0.043	0.047	0.105
0.80	0.116	0.089	0.088	0.105	0.121	0.222	0.036	0.024	0.024	0.031	0.036	0.070
0.85	0.082	0.063	0.064	0.076	0.093	0.154	0.023	0.016	0.016	0.020	0.027	0.045
0.90	0.051	0.040	0.043	0.049	0.062	0.095	0.014	0.010	0.010	0.012	0.017	0.025
0.95	0.024	0.020	0.022	0.024	0.033	0.044	0.006	0.004	0.005	0.005	0.008	0.011
1.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Notes: NF=number of farms; SS=sample size; Range: W=wide range, N=narrow range; CC=correlation coefficient; AFPs=Actuarially Fair Premiums.

Narrowing the dispersion (i.e., Range=N) in the true means (155 to 165 bu/acre) and standard deviations (32.5 to 37.5 bu/acre) of the NF farms in the county (SN5a) has a similarly benign effect. The main reason for this improvement is that the AFPs are now more tightly clustered around their mean. Since the RMA estimator substantially shrinks the estimates toward the county average, this reduces premium estimation error. In other words, the RMA estimator works best when the farm-yield distributions are fairly homogeneous.

The most optimistic scenario while still assuming no premium estimation error by the producers and a zero-risk protection premium is SN6a, in which NF=200, SS=20, CC=0.25, and there is a very low level of mean and standard deviation dispersion within the county (Range=N). Even in this overly optimistic scenario, approximately 15% of farmers pay 85% or more of their AFP while another 15% pay 45% or less than what they should (i.e., at least 15% of them receive less than a 15% subsidy while another 15% have over 55% of their AFP subsidized).

Table 2 also contains the statistics for the same scenarios at an increased 98% target producer participation rate. As expected, GSRs and PFGs required to reach this more ambitious target are substantially higher, and farmers thus pay lower percentages of their AFPs across the board. However, the relative dispersion of the premium subsidies remains about the same. In the most optimistic scenario (SN6b), for example, about 15% of the producers receive less than a 30% subsidy while another 15% have over 65% of their AFP subsidized.

Table 3 contains analogous information for the case of the 85% coverage level.[5] As the coverage level increases, the premium estimates become relatively more accurate and, thus, there is a substantial decline in the required GSRs and PFGs as well as some reduction in the relative level of dispersion of the premium subsidies. At the 85% coverage level, 98% PPR, and the most optimistic scenario (SN6b), about 15% of the producers receive less than a 15% subsidy while another 15% have over 40% of their AFP subsidized. However, the GRP and PFG for this scenario (23% and 28.4%) are only about half of what are observed in practice, so this might not be a realistic case. In addition, the 3.8- to 4.4-year claim frequency associated with such a high coverage level (table 1) seems a bit excessive for a federally subsidized crop insurance product.

Analogous information for two select scenarios that assume left-skewed yield distributions is presented in table 4. Since its GSR and PFG values for 90% and 98% PPRs are similar to what is observed in practice, SS3 is considered to be the more realistic scenario. Alternatively, because of its low GSR and PFG statistics, SS6 is believed to be an overly optimistic scenario. Considering the information pertaining to these two, as well as the other four scenarios (available from the authors upon request), it is evident that left skewness decreases the accuracy of premium estimation, particularly at lower coverage levels, which results in somewhat higher GSRs and PFGs across the board.

As a consequence, farmers generally receive higher levels of subsidies in comparison to the normal yield case. The relative dispersion of the premium subsidies seems to widen as well. At the 65% coverage level, 98% PPR, and the most optimistic scenario (NF=200, SS=20, Range=N, and CC=0.25), for example, under normally distributed yields (SN6b in table 2), 15% of farmers pay 70% or more of their AFP and another 15% pay 35% or less, while under left-skewed yields (SS6b in table 4) about 12% pay 65% or more and over 10% pay 20% or less. The difference between the normal and the left-skewed results is less noticeable at the 85% coverage level: under normally distributed yields (SN6b in table 3), 15% of farmers pay 85% or more of their AFP and another 15% pay 60% or less, while under left-skewed yields (SS6b in table 4) over 10% pay 85% or more and about 12% pay 55% or less. However, both the normal and the left-skewed scenarios exhibit GSR and PFG levels that are much lower than what is observed in practice and are thus deemed unrealistic.

In fact, it can be argued that because of the assumption that the producer knows the AFP with certainty and is not willing to pay a risk protection premium (RPP), none of the previously discussed

[5] The same statistics for 75% coverage are available from the authors upon request.

Table 3. Government Subsidy Rate (GSR), Producer Participation Rate (PPR), Proportion of Indemnities Funded by the Government (PFG) and Percentiles of the Distribution of the RMA Premium Estimates under Normal Yields, 85% Coverage Level (CL), and Target PPRs of 90% (a) and 98% (b)

	SN1a	SN2a	SN3a	SN4a	SN5a	SN6a	SN1b	SN2b	SN3b	SN4b	SN5b	SN6b
NF	**50**	**50**	**200**	**50**	**50**	**200**	**50**	**50**	**200**	**50**	**50**	**200**
SS	**10**	**10**	**10**	**20**	**10**	**20**	**10**	**10**	**10**	**20**	**10**	**20**
Range	**W**	**W**	**W**	**W**	**N**	**N**	**W**	**W**	**W**	**W**	**N**	**N**
CC	**0.25**	**0.50**	**0.50**	**0.50**	**0.50**	**0.25**	**0.25**	**0.50**	**0.50**	**0.50**	**0.50**	**0.25**
GSR	0.260	0.350	0.330	0.280	0.280	0.130	0.380	0.500	0.490	0.410	0.420	0.230
PPR	0.901	0.905	0.902	0.905	0.903	0.902	0.980	0.982	0.980	0.980	0.982	0.981
PFG	0.317	0.401	0.395	0.346	0.361	0.205	0.412	0.522	0.519	0.449	0.456	0.284
Proportion of AFPs					**Percentiles of the RMA Premium Estimates**							
0.20	1.000	0.983	0.982	0.999	0.968	0.997	0.998	0.960	0.973	0.996	0.977	1.000
0.25	0.998	0.963	0.970	0.995	0.954	0.997	0.994	0.920	0.943	0.986	0.948	1.000
0.30	0.994	0.937	0.950	0.987	0.932	0.997	0.985	0.858	0.889	0.965	0.909	1.000
0.35	0.987	0.899	0.922	0.972	0.902	0.997	0.962	0.766	0.790	0.920	0.856	0.999
0.40	0.971	0.844	0.874	0.945	0.866	0.996	0.910	0.663	0.675	0.841	0.787	0.997
0.45	0.938	0.772	0.799	0.894	0.818	0.994	0.833	0.554	0.557	0.743	0.701	0.989
0.50	0.883	0.695	0.714	0.823	0.761	0.988	0.732	0.437	0.442	0.631	0.594	0.972
0.55	0.812	0.611	0.624	0.741	0.692	0.975	0.617	0.338	0.337	0.516	0.478	0.936
0.60	0.724	0.527	0.533	0.648	0.610	0.950	0.500	0.261	0.256	0.385	0.358	0.859
0.65	0.623	0.433	0.443	0.552	0.516	0.901	0.367	0.198	0.191	0.289	0.273	0.726
0.70	0.518	0.347	0.352	0.450	0.425	0.810	0.271	0.146	0.140	0.212	0.201	0.563
0.75	0.390	0.278	0.274	0.336	0.328	0.679	0.191	0.103	0.099	0.149	0.144	0.397
0.80	0.289	0.214	0.207	0.249	0.258	0.529	0.126	0.071	0.067	0.101	0.100	0.248
0.85	0.202	0.153	0.147	0.173	0.193	0.372	0.077	0.044	0.043	0.063	0.067	0.144
0.90	0.124	0.100	0.094	0.107	0.134	0.221	0.042	0.025	0.025	0.037	0.040	0.073
0.95	0.056	0.048	0.046	0.048	0.071	0.100	0.017	0.011	0.011	0.015	0.018	0.028
1.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Notes: NF=number of farms; SS=sample size; Range: W=wide range, N=narrow range; CC=correlation coefficient; AFPs=Actuarially Fair Premiums.

Table 4. Government Subsidy Rate (GSR), Producer Participation Rate (PPR), Proportion of Indemnities Funded by the Government (PFG) and Percentiles of the Distribution of the RMA Premium Estimates under Left-Skewed Yields, 65%, 75% and 85% Coverage Levels (CL), and the Most Realistic (SS3) and Optimistic (SS6) Scenarios (NF=200)

Scenario	SS3a	SS6a	SS3b	SS6b	SS3a	SS6a	SS3b	SS6b	SS3a	SS6a	SS3b	SS6b
CL	**65%**	**65%**	**65%**	**65%**	**75%**	**75%**	**75%**	**75%**	**85%**	**85%**	**85%**	**85%**
SS	**10**	**20**	**10**	**20**	**10**	**20**	**10**	**20**	**10**	**20**	**10**	**20**
Range	**W**	**N**	**W**	**N**	**W**	**N**	**W**	**N**	**W**	**N**	**W**	**N**
CC	**0.50**	**0.25**	**0.50**	**0.25**	**0.50**	**0.25**	**0.50**	**0.25**	**0.50**	**0.25**	**0.50**	**0.25**
GSR	0.570	0.430	0.770	0.600	0.450	0.250	0.650	0.410	0.350	0.140	0.520	0.260
PPR	0.903	0.897	0.979	0.979	0.901	0.897	0.981	0.979	0.902	0.899	0.981	0.981
PFG	0.663	0.534	0.804	0.654	0.539	0.354	0.688	0.475	0.426	0.221	0.554	0.317
Proportion of AFPs					**Percentiles of the RMA Premium Estimates**							
0.20	0.726	0.986	0.440	0.893	0.897	1.000	0.734	0.999	0.968	0.998	0.940	1.000
0.25	0.627	0.944	0.338	0.761	0.838	0.999	0.599	0.993	0.943	0.998	0.889	1.000
0.30	0.539	0.865	0.264	0.630	0.757	0.995	0.477	0.974	0.911	0.998	0.811	1.000
0.35	0.462	0.766	0.207	0.515	0.670	0.986	0.377	0.920	0.869	0.998	0.693	0.998
0.40	0.397	0.666	0.162	0.414	0.584	0.963	0.296	0.822	0.811	0.996	0.572	0.993
0.45	0.336	0.570	0.127	0.329	0.504	0.913	0.233	0.700	0.729	0.993	0.456	0.980
0.50	0.287	0.482	0.101	0.260	0.432	0.836	0.183	0.570	0.637	0.984	0.351	0.951
0.55	0.243	0.404	0.079	0.203	0.366	0.739	0.142	0.446	0.548	0.967	0.273	0.884
0.60	0.204	0.328	0.062	0.157	0.307	0.632	0.110	0.333	0.461	0.932	0.209	0.763
0.65	0.169	0.266	0.048	0.118	0.257	0.524	0.084	0.244	0.379	0.864	0.158	0.606
0.70	0.137	0.212	0.036	0.087	0.211	0.417	0.063	0.175	0.308	0.754	0.118	0.444
0.75	0.108	0.164	0.027	0.063	0.171	0.317	0.046	0.121	0.247	0.617	0.087	0.297
0.80	0.083	0.123	0.020	0.044	0.133	0.230	0.033	0.080	0.191	0.471	0.061	0.187
0.85	0.059	0.086	0.013	0.028	0.097	0.157	0.022	0.050	0.140	0.331	0.040	0.108
0.90	0.037	0.054	0.008	0.016	0.065	0.096	0.013	0.028	0.095	0.201	0.023	0.056
0.95	0.018	0.025	0.004	0.007	0.033	0.044	0.006	0.012	0.050	0.095	0.010	0.022
1.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Notes: NF=number of farms; SS=sample size; Range: W=wide range, N=narrow range; CC=correlation coefficient; AFPs=Actuarially Fair Premiums.

scenarios are truly realistic. More sophisticated scenarios dealing with producer uncertainty and risk aversion have to be developed in order to investigate the effect of these two factors.

Scenarios with Producer Uncertainty and Risk Aversion

The difficulty with developing these scenarios is that, unlike in the case of the insurer, no one knows how producers develop an estimate or perception of the maximum crop insurance premium that they are willing to pay. Thus, the only alternative is to devise a process to simulate their premium estimates that makes economic and logical sense and produces results (i.e., GSR and PFG values) consistent with those observed in practice.

Specifically one would assume that since, as the RMA, the farmer weighs his or her recent yield history when deciding how much he or she is willing to pay and would perhaps give some credence to the quote provided by the insurer, there should be a certain level of correlation between the producer and the RMA premium estimates (PPE_i and IPE_i). One would also assume that the farmer's estimate is at least as accurate as the RMA's. Finally, while it is reasonable to think that the producers are willing to pay some risk protection premium for crop insurance, it is also possible that they tend to underestimate their AFP (i.e., believe that they should pay less than what is actuarially called for). If this were the case, their estimate would exhibit a downward bias that might offset any RPP they are willing to pay.

Therefore, in these scenarios, the producer premium estimates are constructed as simple linear functions of the true premium (AFP_i) and the RMA estimate (IPE_i), calibrated to exhibit no bias and the desired risk protection premium, level of accuracy, and correlation with AFP_i and IPE_i. Specifically:

$$PPE_i = \{1 + RPP\}\{AFP_i + CF(IPE_i - EB_i)\}, \tag{18}$$

where EB_i is the expected bias in IPE_i and CF is a calibration factor. EB_i is computed endogenously as the average bias exhibited by the insurer premium estimates for producer i across the NR=1,000 runs; its presence ensures that PPE_i is an unbiased estimate for AFP_i. Note that if $CF = 0$ and $RPP = 0$, then $PPE_i = AFP_i$, as assumed in the previously discussed scenarios.

The first scenario in table 5 assumes 65% coverage, a target PPR of 90%, a low level of producer uncertainty (LPU), no risk protection premium (RPP), and the most optimistic NF (200), SS (20), range (N), and CC (0.25) conditions. To simulate low producer uncertainty, equation (18) is calibrated (CF=0.75) so that the RMSE of the resulting PPE_i relative to AFP_i is about half of that of IPE_i (i.e., the producer error is half of the insurer error). Compared with what has been observed in practice, the GSR (40%) and PFG (50.2%) corresponding to this scenario are somewhat low, even for a PPR of 90%. Notably, about 18% of farmers receive at least a 75% subsidy,[6] while nearly 12% enjoy no effective subsidy at all (i.e., they end up paying more than their AFPs). Clearly, even low levels of producer uncertainty can markedly exacerbate the dispersion in the distribution of the crop insurance subsidies.

As expected, increasing the risk protection premium to 15% (scenario LPU/RPP) causes a significant reduction in the GSR (31.0%) and PFG (41.4%) required to achieve 90% participation and has a notable impact on the distribution of the subsidies. In this case, only 12% of farmers receive at least a 75% subsidy, but nearly 17% end up paying more than their AFPs. When a higher level of producer uncertainty (scenario HPU/RPP) is assumed by setting CF to 1.25, a much larger GSR (53.0%) and PFG (59.0%) are necessary for 90% participation. Because of the loftier government support, a lower share of the producers (8.4%) pay more than their AFPs but a higher percentage (29%) receive more than a 75% effective subsidy.

The next three columns on table 5 correspond to the same scenarios (LPU/NRP, LPU/RP, and HPU/RP) but a higher target PPR of 98%. As expected, much larger GSRs (66.0%, 60.0%,

[6] Technically, these producers are receiving both a government subsidy as well as an income transfer from those who pay more than their AFPs.

Table 5. Government Subsidy Rate (GSR), Producer Participation Rate (PPR), Proportion of Indemnities Funded by the Government (PFG) and Percentiles of the Distribution of the RMA Premium Estimates under Left-Skewed Yields, 65% and 85% Coverage Levels (CL)

CL/SS	**65%/20**	**65%/20**	**65%/20**	**65%/20**	**65%/20**	**65%/20**	**85%/10**	**85%/10**	**85%/10**	**85%/10**	**85%/10**	**85%/10**
Scenario	**LPU/NRP**	**LPU/RP**	**HPU/RP**	**LPU/NRP**	**LPU/RP**	**HPU/RP**	**LPU/NRP**	**LPU/RP**	**HPU/RP**	**LPU/NRP**	**LPU/RP**	**HPU/RP**
Range/CC	**N/0.25**	**N/0.25**	**N/0.25**	**N/0.25**	**N/0.25**	**N/0.25**	**W/0.50**	**W/0.50**	**W/0.50**	**W/0.50**	**W/0.50**	**W/0.50**
GSR	0.400	0.310	0.530	0.660	0.600	0.990	0.180	0.050	0.170	0.290	0.190	0.550
PPR	0.900	0.902	0.900	0.980	0.980	0.963	0.906	0.899	0.903	0.980	0.984	0.980
PFG	0.502	0.414	0.590	0.706	0.647	0.991	0.257	0.144	0.228	0.339	0.247	0.576
Proportion of AFPs						**Percentiles of the RMA Premium Estimates**						
0.20	0.899	0.931	0.808	0.684	0.773	0.000	0.988	0.995	0.990	0.980	0.989	0.932
0.25	0.823	0.879	0.710	0.564	0.663	0.000	0.973	0.985	0.976	0.960	0.974	0.869
0.30	0.739	0.815	0.618	0.457	0.563	0.000	0.955	0.971	0.957	0.933	0.952	0.771
0.35	0.659	0.745	0.536	0.364	0.473	0.000	0.930	0.951	0.933	0.900	0.925	0.646
0.40	0.584	0.675	0.460	0.293	0.394	0.000	0.899	0.928	0.903	0.857	0.892	0.517
0.45	0.513	0.609	0.396	0.236	0.326	0.000	0.863	0.900	0.866	0.799	0.852	0.398
0.55	0.390	0.489	0.291	0.156	0.227	0.000	0.755	0.827	0.758	0.644	0.741	0.228
0.60	0.338	0.435	0.251	0.126	0.191	0.000	0.684	0.779	0.689	0.560	0.673	0.170
0.65	0.292	0.387	0.218	0.103	0.161	0.000	0.606	0.724	0.618	0.483	0.602	0.125
0.70	0.254	0.340	0.190	0.084	0.135	0.000	0.531	0.662	0.546	0.411	0.534	0.091
0.75	0.222	0.302	0.165	0.069	0.114	0.000	0.461	0.599	0.478	0.341	0.467	0.066
0.80	0.195	0.267	0.144	0.056	0.096	0.000	0.396	0.537	0.416	0.283	0.404	0.048
0.85	0.171	0.237	0.126	0.045	0.081	0.000	0.333	0.477	0.357	0.234	0.343	0.034
0.90	0.150	0.211	0.110	0.037	0.068	0.000	0.279	0.419	0.309	0.194	0.293	0.023
0.95	0.133	0.189	0.096	0.030	0.058	0.000	0.232	0.362	0.267	0.159	0.250	0.016
1.00	0.117	0.169	0.084	0.024	0.049	0.000	0.193	0.312	0.230	0.130	0.213	0.011
1.05	0.103	0.152	0.073	0.020	0.041	0.000	0.161	0.268	0.198	0.106	0.180	0.007
1.10	0.091	0.136	0.064	0.016	0.035	0.000	0.133	0.229	0.170	0.086	0.152	0.005
1.15	0.081	0.122	0.056	0.013	0.029	0.000	0.108	0.196	0.145	0.069	0.128	0.003
1.20	0.071	0.110	0.048	0.010	0.025	0.000	0.087	0.166	0.124	0.055	0.107	0.002

Notes: NRP means Risk Protection Premium=0, RP means Risk Protection Premium=15%, LPU and HPU stand for Low and High Producer Uncertainty, NF=200 in all scenarios. NF=number of farms; SS=sample size; Range: W=wide range, N=narrow range; CC=correlation coefficient; AFPs=Actuarially Fair Premiums.

and 99.0%) and PFGs (70.6%, 64.7%, and 99.1%) are required, which dramatically reduces the number of producers paying more than their AFPs. The cost, however, is that 31.6%, 22.7%, and 100% of farmers receive an effective subsidy of at least 80%. Obviously, the third of these scenarios (HPU/RPP) is wholly unrealistic since it implies that—even at a 99% GSR—the maximum achievable participation is 96.3% (i.e., the target 98% PPR cannot be reached). In other words, 3.7% of farmers believe that they will never receive an indemnity at 65% coverage and are thus not willing to purchase insurance at any price.

Analogous scenarios were developed for the 85% coverage level. However, while the observed dispersion of the subsidy distribution remained high (data available from the authors upon request), high levels of participation (98%) were achieved at very low GSRs (14%) due to the optimistic assumptions about NF (200), SS (20), Range (N), and CC (0.25). Thus, scenarios with what are considered more realistic assumptions (NF=200, SS=10, Range=W, and CC=0.50) are presented for 85% coverage in the last six columns of table 5.

As in the case of 65% coverage, a 15% RPP substantially reduces the levels of subsidy required for 90% and 98% participation and noticeably shifts the distribution of those subsidies. A higher level of producer error demands larger subsidies to reach the pre-specified PPR. Notably, at this higher 85% coverage level, 90% participation can be reached with relatively low subsidies (PFGs of 26% or less), but their distribution remains very disperse. Specifically, 19.3% (LPU/NRP), 31.2% (LPU/RP), and 23.0% (HPU/RP) of the producers end up paying more than their AFPs while 18.6%, 13.3%, and 18.3% of them receive in excess of a 50% subsidy. In the LPU scenarios, 98% participation can be achieved with moderate (10% or less) subsidy increases, and the relative distributions of the subsidies are not substantially affected.

In the HPU/RP scenario, however, the government has to subsidize nearly 60% of the program expenses (PFG=57.6%) in order to achieve 98% participation. As a result, the subsidy distribution is shifted and compressed to where about 13% of farmers receive less than a 35% subsidy while another 13% enjoy more than a 75% subsidy. It can thus be argued that this is an unavoidable disadvantage of crop insurance. Using substantial external subsidies, it is possible to avoid a situation where too many farmers end up paying more than their AFPs, but it appears that the relative distribution of those subsidies across participating farmers will always be highly and randomly uneven. Just by chance, some producers will receive a very large share of the subsidy while others will get much less or possibly none at all.

A final important issue that can be analyzed using the data underlying the previously discussed scenarios is whether there is any correlation between the level of risk (i.e., downside yield volatility) associated with a particular operation and the percentage subsidy it receives. The relationship between these two variables under one of the more realistic scenarios is plotted in figure 2. Note that all high-volatility operations (with AFPs between $15 and $18 per acre) receive percentage subsidies ranging from 58% to 65%, which means that these producers end up paying premiums of $6 to $7 per acre.

In contrast, low-risk operations (with AFPs between $6 and $7 per acre) receive little or no subsidy and thus end up paying nearly the same premiums as the high-risk operations. In hindsight, this is an expected result of the "shrinkage" nature of the RMA method to estimate the farm-level premiums. In this particular case, for example, the AFPs range from $5.5 to $18.5 per acre while the RMA premium estimates range from $10 to $12 per acre. Because of this reason, APH crop insurance channels most of the government subsidies to high-risk producers who are not as adept in managing their downside yield volatility, and there is no reason to expect differently in the case of crop revenue (CRC) insurance.

Concluding Remarks

The first contribution of this study is to ascertain some key characteristics of the RMA's crop insurance premium estimates. Under fairly realistic conditions, we conclude that the estimates are

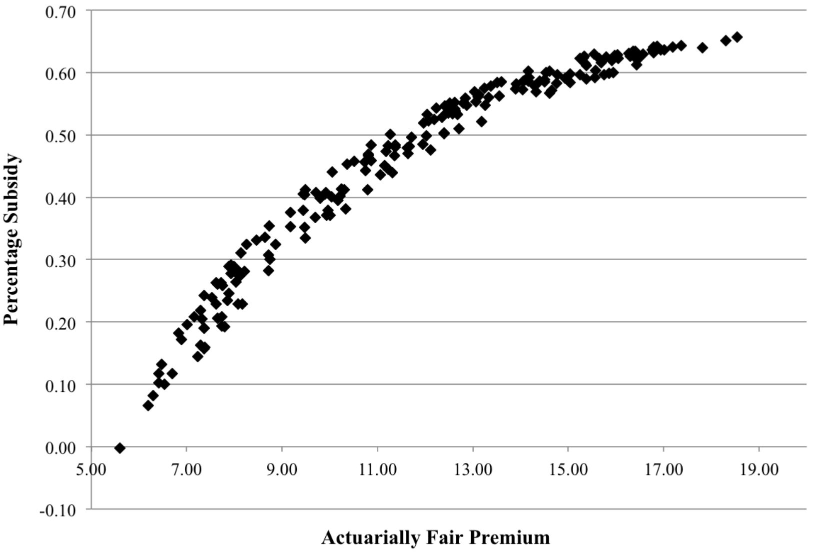

Figure 2. Average Percentage Subsidy vs. Actuarially Fair Premium

Notes: PPR=95%, CL=75%, CF=0.75, RPP=15%, NF=200, SS=10, R=W, CC=0.50.

biased both at the individual (farm) and aggregate (county) level. We also demonstrate that the farm-level premium estimates are tightly compressed toward the county average. Thus, unless the actuarially fair premiums (AFP) are highly homogeneous within the county, those producers whose AFPs are close to the lower or upper bounds of the county range would inevitably pay quite a bit more or less than what is actuarially fair if no subsidies are provided.

Our main contribution is the exploration of the potential impact of RMA premium estimation inaccuracy on the distribution of crop insurance subsidies across the producers participating in the program. Through the analyses, we determined that a variety of factors can negatively impact (i.e., broaden the range of) that distribution, namely a wider mean and variance dispersion across farms, a higher cross-yield correlation, a smaller sample size or number of farms in the county, a lower coverage level, producer uncertainty about his or her AFP, and yield left skewness.

Under all realistic scenarios comprising feasible combinations of those factors, the distribution of the subsidies is found to exhibit a relatively high level of dispersion, to the point where it seems likely that some farmers will receive little or no subsidies while others have more than 50% of their actuarially fair premium subsidized. In addition, the analyses suggest that APH crop insurance channels the vast majority of government subsidies to high-risk producers who are not as adept at managing their yield risks. There is no reason to expect differently in the case of revenue insurance. These findings raise the question of whether crop insurance is a sensible, efficient, and equitable mechanism for dispensing agricultural subsidies.

Finally, we hope that the analytical framework developed in this study can be used by policy makers and the RMA to better understand how the previously discussed factors affect the various aspects of program performance (i.e., the percentage premium subsidy required to achieve a certain producer participation rate at a given coverage level, the percentage of future indemnities that will then have to be paid by the government, and the relative distribution of the government subsidies across participating producers) and use that information to improve the actuarial and equity/welfare characteristics of the crop insurance program.

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