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# General Equilibrium Modelling of the Insurance Industry: U.S. Crop Insurance

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*The U.S. farm policy has progressively changed in recent years, with greater reliance on subsidized crop insurance programs in the place of fixed direct payments. Despite the use of such insurance over a long period of time, quantitative macroeconomic assessments of insurance programs are lacking. We develop an original stochastic computable general equilibrium framework where we isolate the coverage effects provided by subsidized insurance programs. We find that their welfare effects are dramatically modified once we recognize their risk sharing properties. Our simulated market effects on the U.S. cereal markets are consistent with currently available microeconometric evidence.*

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## 1. Context and objectives

Production and price risks have always been significant in the farming sector and this has helped to motive many farm policies around the world (Gardner, 1992). This is particularly true in the U.S. where farm price supports and supply controls were the major instruments introduced after the Great Depression in the 1930s. Starting in the mid-1980s, a greater market orientation was adopted, culminating with the Federal Agricultural Improvement and Reform (FAIR) Act of 1996. This "decoupled" period with fixed direct payments did not last long, however. In the late 1990s, risk management programs were accentuated with countercyclical payments designed to cope with price risks and subsidized insurance programs to cope with production and price risks. The farm bills adopted in 2014 and 2018 confirm this trend by stopping the fixed direct payments and reinforcing the insurance programs. They are now the major source of subsidies for U.S. farmers (Smith et al., 2017).

This shift of policy instruments has motivated many micro-econometric analyses focused on the responses by U.S. farmers to subsidized insurance programs. On the other hand, the macroeconomic market and welfare impacts of these insurance programs are seldom assessed. To the best of our

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knowledge, Lusk (2017) is the unique and recent exception. He develops a Partial Equilibrium (PE) framework absent any market failures, with no risk aversion and assumes that crop insurance subsidies are similar to output subsidies. This study logically concludes that these programs are economically inefficient. The extent to which this finding is robust to more realistic assumptions is currently unknown. Accordingly, normative analyses of the crop insurance programs are mostly qualitative. Goodwin and Smith (2015, p.10) guess that "like many of its recent predecessors, and perhaps to an even greater degree, the 2014 farm bill …will almost certainly reduce the economic welfare of the average U.S. citizen". These authors believe that previous fixed direct payments are less distorting than the current risk management programs, in particular crop insurance programs.

In this context, the main objective of this paper is to develop a new Computable General Equilibrium (CGE) framework relevant for the macroeconomic analysis of crop insurance programs. By nature, CGE models are better tailored to normative analysis than PE models (Hertel, 2002). Even if our original CGE framework is designed to analyze crop insurance programs, we hope that our modelling strategy stimulates other CGE frameworks for the evaluation of other insurance programs. Indeed, there are quite few macroeconomic analyses of insurance programs for health care and other risks. According to Salanié (2017), data availability is the most critical limiting factor. Fortunately, U.S. federal crop insurance programs are fairly well documented and measured, allowing us to pursue our main objective.

Our framework starts from the standard GTAP framework which has a detailed coverage of farm products and policy instruments. Haque et al. (2018) is a recent application of this framework to the analysis of previous fixed direct payments of the U.S. farm bills. However, crop insurance programs purchased by farmers are treated as 'other productive inputs' in that static framework. The standard GTAP framework does not recognize that farmers pay premiums before the covered peril manifests and eventually receive ex post indemnities if the realized peril is greater than a critical threshold.

In order to realistically model the market and welfare impacts of crop insurance programs, we introduce three successive modifications to the standard GTAP framework. First, we specify the crop production uncertainty, leading us to model two periods (before and after the productivity shock). Second, we introduce a farm household, giving us the possibility to capture their risk attitudes. Third, we model the market of crop insurance programs, with explicit *ex ante* premiums paid by the farm household and *ex post* indemnities received in cases of significant losses. The three successive modifications capture the risk sharing properties of insurance programs wherein indemnities are paid when the farm household marginal utility of income is high. Our policy simulation with this original framework reveals the potential for subsidized crop insurance programs to contribute to improved economic efficiency.

This paper is organized as follows. Section 2 presents first the historical evolution of U.S. crop insurance programs and then provides a synthetic review of the microeconometric analyses focused on these programs. This review will later support the assumptions and calibration of our new modeling framework. Section 3 develops the theory of crop insurance in a general equilibrium setting. This will aid in interpreting the welfare results obtained with our framework. Section 4 details the specification of our CGE framework in order to properly capture the impacts of the crop insurance programs on farmers' decisions, markets and global welfare. Section 5 explains the empirical implementation of our original framework, in terms of economic data and calibrated behavioral parameters. Section 6 is devoted to policy simulations and robustness tests. Section 7 gathers and discusses the most critical assumptions of our framework. Section 8 concludes the paper.

## 2. Empirical evidence on US crop insurance programs

The US crop insurance programs have a long history that we briefly document below. More detailed presentations are available in Glauber (2004) and Smith et al. (2017). Programs are fully detailed on the website of the Risk Management Agency (RMA), a division of the U.S. Department of Agriculture (USDA).[1] Figures reported below are taken from these references.

The U.S. crop sectors have always been exposed to different perils (drought, freeze, disease, adverse weather preventing planting, …), potentially damaging crop quantity and quality. Major losses have long been covered by the federal government with *ex post* disaster payments. Following the dramatic consequences of the dust bowl, the federal government launched the first crop insurance programs in 1938 to favor *ex ante* management by farmers. These programs covered major crops in the main producing areas and were delivered by USDA county offices. However, during the ensuing 40 years, farmers' participation to the programs remained low with the insured acreage less than 20 percent of total cropped acreage. One major reason is that non-participating farmers still benefited from *ex post* disaster payments.

The 1980 Crop Insurance Act encouraged greater participation by eliminating standing disaster programs, subsidizing insurance premiums up to 30 percent, increasing the number of eligible crops and allowing private companies to deliver crop insurance programs. As expected, farmer participation increased but modestly (insured acreage reached 25 percent of cropped acreage). Major perils affected U.S. crops at the end of the 1980s and beginning of the 1990s (in particular a major drought in 1988), leading the Congress to provide *ex post* disaster payments to all affected farms, regardless of participation.

The 1994 and 2000 crop insurance reforms significantly increased the premium subsidies to approximately two-thirds of expected indemnities, further increased the number of eligible crops and covered perils; farmers can

[1] See https://www.rma.usda.gov/Policy-and-Procedure/Insurance-Plans.

now also insure per-acre revenues and thus protect from yield and price losses. Participation significantly increased, with insured acreage reaching 85 percent of cropped acreage. Revenue insurance rapidly became the predominant of crop insurance, with 70 percent of liability in revenue coverage. Another indicator of the success of these reforms is the absence of *ex post* disaster payments in 2012, despite a much more severe drought compared to 1988.

Currently the involvement of the federal government in the crop insurance programs mostly includes the premium subsidies perceived by farmers, the subsidy to the private insurance industry to cover their Administrative and Operation (A&O) expenditures of delivering federal crop insurance programs and finally part of underwriting losses. Premium subsidies perceived by the U.S. crop farmers represent the main budgetary outlay for the sector and have been the subject of many micro-econometric analyses.

The first main theme explored by these empirical analyses is the demand for insurance by U.S. crop farmers. Over the last 10 years, when farmers enroll in insurance programs, they can expect to receive, on average, twice the amount of their premium payments. Despite these economic incentives, some farmers still do not participate in insurance programs. One major explanation explored in the literature is that all farmers are not always offered fair insurance premiums for two reasons. First, the RMA defines the insurance products using individual and county level data. However, U.S. farmers face different production conditions and are not exposed to the same idiosyncratic risks (Claassen and Just, 2009). Accordingly, there is an informational challenge when accounting for yield heterogeneity. Secondly, the production risks that farmers face may change over time. If this is the case, a critical statistical challenge is knowing whether ongoing technical change affects all moments of the crop yield distribution (Tolhurst and Kert, 2014). These two informational challenges lead to the ex post observation of geographic miss-ratings (Woodard et al., 2012). Some cross subsidization thus arises among farmers, explaining the need for significant subsidies to reach the policy objective of increased participation. To save some public funds while still protecting farm income, new insurance products or new rating procedures have been proposed (Gerlt et al. 2015, Ramirez and Shonkwiller, 2017). These proposals balance the costs of collecting precise information and the benefits of a better targeting.

The second theme in these empirical studies addresses the production and risk management decisions of U.S. farmers. In particular, the land use and crop choice impacts of crop insurance programs have been the subject of many micro-econometric studies (recent references include Walters et al. 2012, Goodwin and Smith, 2013, Claassen et al., 2016, Weber et al., 2016, Yu et al., 2018). Results differ among studies because of different econometric models (for instance, with or without cross market effects), econometric procedures (for instance, tackling endogeneity issues of crop insurance decisions) and data (for instance, farm level or county data). In a general way, these studies find limited positive impacts on land use (less than 1 percent) and more significant impacts on crop choices (a 3–5 percent change in crop acreage for some regions is possible). They also find that the subsidized crop insurance programs affect crop acreage decisions via both a profit effect (i.e., increasing the expected return of insured crops) and a coverage effect (i.e., reducing the variance of returns). Insurance programs reduce the variability of net farm incomes by providing indemnities only in case of losses greater than the deductibles. The econometric studies find that U.S. farmers value this risk reduction property of insurance programs. Some econometric studies also examine farmers' other production decisions (input uses and yield objectives) and the environmental consequences. Cornaggia (2013) estimates positive impacts on crop yields (close to 1 percent for corn and soybeans) of the exogenous introduction of subsidized insurance programs. Weber et al. (2016) specify more explicitly the production technology by estimating the impacts of subsidized insurance programs on fertilizer and pesticide uses and production value per acre. These authors find small positive effects on input uses and larger effects on production values. Their interpretation is similar to that of Cornaggia: insurance programs may encourage farmers to invest more in productivity-enhancing capital goods. From these production decisions, some studies infer the environmental effects using biophysical models: they generally find limited negative impacts on several environmental indicators.

Overall, these micro-econometric studies reveal the presence of informational failures that prevent performing simple first-best assessment of crop insurance programs in the context of complete contingent markets. Furthermore, these studies find small but statistically significant positive impacts on production and input uses of subsidized insurance programs. These impacts come from both a transfer (or profit) effect and a coverage (or risk reduction) effect. Any normative macroeconomic analysis of U.S crop insurance programs must capture these two effects.

## 3. General equilibrium theory of crop insurance

The well-established theory of risk shows that if there were a complete set of risk markets, no externalities and fully competitive markets, the market equilibrium would be Pareto optimal. On the other hand, if some risk markets (like insurance markets) are missing due to informational failures for instance, the competitive market equilibrium is no longer Pareto optimal. This justifies public intervention. In a general equilibrium framework, Newbery and Stiglitz (1982) define the optimal output tax that supports a constrained Pareto optimum. Innes and Rausser (1989) and Innes (1990) mobilize the same general equilibrium framework to analyze price supports and production quotas. They find that the welfare benefits from these policy interventions can be large.

The market and welfare effects crop insurance programs have been theoretically analyzed in simpler partial equilibrium framework (among others, Ahsan et al., 1982; Myers, 1988) and in the context of an exchange economy (for instance, Eeckhoudt et al., 2005). Here we develop the general equilibrium theory of crop insurance in the context of a production economy. Similar to Newbery and Stiglitz (1982), we consider a simple production economy with risk in order to obtain analytical results. We first present the case without insurance and then introduce an ideal insurance program. We implicitly assume that informational failures prevent the existence of insurance in the first case. In the second case, we implicitly assume that these failures are solved due to the costless availability of information.

*3.1. Without crop insurance*

Our economy contains two goods (crop and numeraire) and two representative economic agents (farmer, consumer). The farmer decides the level of labor (noted by L) devoted to farming at the start of the season, before the state of nature is known (such as the full impact of the weather on crop production). At the end of the season, the state of nature is observed and the realized production of crops is sold to the consumer. We simplify the analysis by assuming multiplicative production risk and two states of nature (indexed by $s = 1,2$) : normal and bad weather with different probabilities of occurrence (noted by $\pi_s$ ). The farm production technology is an increasing and concave function of the farm labor. Observed production is thus given by: $Y_s = \alpha_s f(L)$ where $\alpha_s$ is the multiplicative production risk. We also assume that the farmer is a price taker and has rational expectations. This means that the farmer is able, at the start of the season, to compute the two market prices that will prevail at the end of the season when the crop is marketed. Finally, the farmer has preferences over the numeraire and leisure and maximizes expected utility. The consumption of the numeraire is given by the profit and thus depends on the market price that will prevail at the end of the season. Formally the program of the farmer is given by:

$$max_L E_s U(I_s, L) = \pi_1 U\big(P_1 \alpha_1 f(L)\big) + \pi_2 U\big(P_2 \alpha_2 f(L)\big) - Z(L)$$

With $E_s$ the expectation operator, $I_s$ the income of the farmer, $P_s$ the crop market price, $U$ the farmer utility function over the numeraire that is increasing and concave and $Z$ the disutility of effort which is also an increasing and concave function.

The consumer makes choices after the state of nature and hence the crop availability are known. The consumer has preferences over the crop and the numeraire. The consumer's budget is given by a fixed endowment of the numeraire (noted by R). The state invariant indirect utility function of the consumer is given by $V = V(P, R)$.

In this economy without a risk market, the competitive equilibrium is usually not a Pareto optimal equilibrium. The two equilibria coincide in only two restrictive cases: 1/ the farmer is risk neutral and the consumer marginal utility of income is constant, 2/ the crop demand of the consumer has a unitary price elasticity. We derive these theoretical results by first characterizing the competitive equilibrium.

First solve the program of the farmer. The optimal labor effort made by the farmer (noted $\hat{L}$) is determined implicitly by the following first-order condition:

$$f_L(\hat{L})\left(\pi_1 P_1 \alpha_1 U_I\left(I_1(\hat{L})\right) + \pi_2 P_2 \alpha_2 U_I\left(I_2(\hat{L})\right)\right) = Z_L(\hat{L}) \tag{1}$$

With $f_L$ (the first order derivative of the production function) measures the marginal productivity of farm labor, $U_I$ (the first order derivative of the utility function) measures the marginal utility of farmer income and $Z_L$ (the first order derivative of the utility function with respect to farm labor) measures the marginal disutility of effort. The optimal labor effort of the farmer depends on this risk attitude, captured by the evolution of the marginal utility of income. If this marginal utility is constant, then the farmer is risk neutral and this first order condition reduces to the standard (absent risk).

In our simplified production economy, crop production is fully consumed at the end of the season. The consumer demand function then implicitly determines the market price. Using Roy's identity, we get:

$$\alpha_s f_L(\hat{L}) = D(\widehat{P_s}, R) = -\frac{V_p(\widehat{P_s}, R)}{V_R(\widehat{P_s}, R)} \tag{2}$$

The competitive equilibrium given by equations (1) and (2) is not in general Pareto optimal. The Pareto optimal outcome is given by maximizing the total welfare, the weighted sum (by the parameter $\gamma$) of consumer and farmer welfare:

$$max_L E_s[V(P_s, R) + \gamma U(I_s, L)]$$

Subject to the feasibility condition that the crop demand is lower or equal to the availability in both states of nature:

$$D(P_s, R) \leq Y_s$$

The first order condition for an interior solution is given by:

$$\begin{aligned} &\pi_1 \frac{\partial \tilde{P}_1}{\partial L}\left(V_p[\tilde{P}_1, R] + \gamma U_I\left(I_1(\tilde{L})\right)\tilde{Y}_1\right) \\ &+ \pi_2 \frac{\partial \tilde{P}_2}{\partial L}\left(V_p[\tilde{P}_2, R] + \gamma U_I\left(I_2(\tilde{L})\right)\tilde{Y}_2\right) \\ &+ \gamma\left(f_L(\tilde{L})\left(\pi_1 \tilde{P}_1 \alpha_1 U_I\left(I_1(\tilde{L})\right)\right.\right. \\ &\left.\left. + \pi_2 \tilde{P}_2 \alpha_2 U_I\left(I_2(\tilde{L})\right)\right) - Z_L(\tilde{L})\right) = 0 \end{aligned} \tag{3}$$

The Pareto optimal equilibrium is implicitly determined by equations (3) and (2). If the first line of equation 3 equals zero, then the competitive and Pareto equilibria are characterized by the same equations. Using the Roy's identity, this condition on the first line of equation (3) can be rewritten as:

$$\pi_1 \frac{\partial \tilde{P}_1}{\partial L} V_R[\tilde{P}_1, R]\tilde{Y}_1 \left( \gamma \frac{U_I\left(I_1(\tilde{L})\right)}{V_R[\tilde{P}_1, R]} - 1 \right) + \pi_2 \frac{\partial \tilde{P}_2}{\partial L} V_R[\tilde{P}_2, R]\tilde{Y}_2 \left( \gamma \frac{U_I\left(I_2(\tilde{L})\right)}{V_R[\tilde{P}_2, R]} - 1 \right) = 0 \tag{4}$$

Additional effort made by the farmer will always increase production in both states of nature. Hence the derivatives of price with respect to farmer labor are always negative. This condition (4) is always satisfied when both parentheses equal zero. This leads to:

$$\frac{U_I\left(I_1(\tilde{L})\right)}{V_R[\tilde{P}_1, R]} = \frac{U_I\left(I_2(\tilde{L})\right)}{V_R[\tilde{P}_2, R]} = \frac{1}{\gamma} \tag{5}$$

This condition (5) implies that the ratio of marginal utilities of income does not vary with the state of nature. Newbery and Stiglitz (1982) show that this necessary and sufficient condition is satisfied in only two restrictive cases. The first is when the marginal utilities of income are constant for both the consumer and the farmer. In this case, the farmer is risk neutral. A second case arises when the consumer marginal utility of income is constant and additionally the crop demand elasticity is unity. In this second case, the income of the farmer is constant across the states of nature. In summary, in this simple production economy with multiplicative production risk and no risk contingent market, the decentralized competitive equilibrium is thus unlikely to be Pareto optimal.

### *3.2. With crop insurance*

In our general equilibrium setting, the multiplicative production risk induces price risk. Accordingly, we can contemplate yield insurance, price insurance or revenue insurance programs. We focus on the simplest case of revenue insurance, which is the one currently favored by the U.S. crop farmers (Smith et al., 2017). We assume an "ideal" revenue insurance program due to the absence of moral hazard, adverse selection and operating costs (when collecting insurance premiums or assessing crop loss). Furthermore, our ideal revenue insurance program covers all revenue loss per unit of insured crop production and insurance premium is assumed to be fair. The revenue insurance program works as follows. The farmer decides at the start of the season the level of labor and the level of insured crop (noted by YI). By choosing to insure the crop production, the farmer engages to pay premium at the end of the season to the insurance provider (in our setting, the consumer). At the end of the season, the production level, the market price and the unitary crop revenue are known. The revenue insurance program provides ex post indemnity to the farmer when the realized unit crop revenue is lower than the insured unit revenue. This indemnity decreases the consumer income. When the realized unit crop revenue is greater than the insured unit revenue, no indemnity is granted to the farmer and the consumer fully benefits from the premium paid by the farmer.

In the derivation below, we consider that the second state of nature leads to lower farm revenue that the first state of nature. The revenue insurance program provides full coverage of unitary revenue loss. That is, the indemnity paid in the second state of nature to the farmer is given by $(P_1\alpha_1 - P_2\alpha_2)YI$ while the fair premium paid by the farmer is given by $\pi_2(P_1\alpha_1 - P_2\alpha_2)YI$. In this case, the revenues of the farmer in the two states of nature are given by:

$$I_1(L, YI) = P_1\alpha_1 f(L) - \pi_2(P_1\alpha_1 - P_2\alpha_2)YI$$

$$I_2(L, YI) = P_2\alpha_2 f(L) + \pi_1(P_1\alpha_1 - P_2\alpha_2)YI$$

These two revenues are equal if the insured crop level equals the expected production. By insuring all expected production at the start of the season, the revenue of the farmer is no longer risky at the end of the season. This is indeed an optimal decision for the farmer. The program of the risk averse farmer is given now by:

$$max_{L,YI} E_s U(I_s, L, YI) \\ = \pi_1 U\big(I_1(L, YI)\big) + \pi_2 U\big(I_2(L, YI)\big) - Z(L)$$

The optimal insurance level for the farmer (noted by $\breve{YI}$) is solution to the first order condition:

$$-\pi_1\pi_2(P_1\alpha_1 - P_2\alpha_2)U_I\left(I_1\big(\breve{L}, \breve{YI}\big)\right) \\ + \pi_2\pi_1(P_1\alpha_1 - P_2\alpha_2)U_I\left(I_2\big(\breve{L}, \breve{YI}\big)\right) = 0$$

This condition is satisfied when the revenues in the two states are equal, hence:

$$\breve{YI} = f\big(\breve{L}\big) \quad (6)$$

The optimal labor effort made by the farmer is now determined implicitly by the following first order condition:

$$U_I\left(I\left(\breve{L}, f\big(\breve{L}\big)\right)\right) f_L\big(\breve{L}\big)(\pi_1 P_1\alpha_1 + \pi_2 P_2\alpha_2) = Z_L\big(\breve{L}\big) \quad (7)$$

This must be compared to condition (1) above when no insurance program is available. The evolution of the marginal utility of income of the farmer between the two states of nature (hence the farmer risk attitude) no longer appears. The effort is such that the marginal productivity evaluated at the average unitary revenue equals the marginal disutility of effort. The introduction of the revenue insurance program also changes the disposable income of the consumer, which is no longer fixed:

$$R_1 = R + \pi_2(P_1\alpha_1 - P_2\alpha_2)YI$$

$$R_2 = R - \pi_1(P_1\alpha_1 - P_2\alpha_2)YI$$

The market equilibrium condition becomes:

$$\alpha_s f_L(\breve{L}) = D(\breve{P_s}, \breve{R_s}) = -\frac{V_p(\breve{P_s}, \breve{R_s})}{V_R(\breve{P_s}, \breve{R_s})} \qquad (8)$$

The system of equations (6)-(7)-(8) characterizes the competitive equilibrium with a revenue insurance program. We now show that this system of equations is also the solution of a social planner's problem. We proceed as before. The global welfare to be maximized is now:

$$max_{L,YI} E_s[V(P_s, R_s) + \gamma U(I_s, L, YI)]$$

Subject to the same feasibility condition

$$D(P_s, R) \leq Y_s$$

The two first order conditions for interior solutions are given by:

$$\begin{aligned}
&\pi_1 \frac{\partial \bar{\bar{P}}_1}{\partial L}\left(V_p[\bar{\bar{P}}_1, \bar{\bar{R}}_1] + \gamma U_I\left(I_1(\bar{\bar{L}}, \overline{\overline{YI}})\right)\bar{\bar{Y}}_1\right) \\
&+ \pi_2 \frac{\partial \bar{\bar{P}}_2}{\partial L}\left(V_p[\bar{\bar{P}}_2, \bar{\bar{R}}_2] + \gamma U_I\left(I_2(\bar{\bar{L}}, \overline{\overline{YI}})\right)\bar{\bar{Y}}_2\right) \\
&+ \gamma\left(f_L(\bar{\bar{L}})\left(\pi_1 \bar{\bar{P}}_1 \alpha_1 U_I\left(I_1(\bar{\bar{L}}, \overline{\overline{YI}})\right)\right.\right. \\
&\left.\left.+ \pi_2 \bar{\bar{P}}_2 \alpha_2 U_I\left(I_2(\bar{\bar{L}}, \overline{\overline{YI}})\right)\right) - Z_L(\bar{\bar{L}})\right) \\
&+ \pi_1 \pi_2 \overline{\overline{YI}}\left(\frac{\partial \bar{\bar{P}}_1}{\partial L}\alpha_1 - \frac{\partial \bar{\bar{P}}_2}{\partial L}\alpha_2\right)\left(V_R[\bar{\bar{P}}_1, \bar{\bar{R}}_1]\right. \\
&- V_R[\bar{\bar{P}}_2, \bar{\bar{R}}_2] \\
&\left.+ \gamma\left(U_I\left(I_1(\bar{\bar{L}}, \overline{\overline{YI}})\right) - U_I\left(I_2(\bar{\bar{L}}, \overline{\overline{YI}})\right)\right)\right) = 0
\end{aligned} \qquad (9)$$

$$\begin{aligned}
&\pi_1 \frac{\partial \bar{\bar{P}}_1}{\partial YI}\left(V_p[\bar{\bar{P}}_1, \bar{\bar{R}}_1] + \gamma U_I\left(I_1(\bar{\bar{L}}, \overline{\overline{YI}})\right)\bar{\bar{Y}}_1\right) \\
&+ \pi_2 \frac{\partial \bar{\bar{P}}_2}{\partial YI}\left(V_p[\bar{\bar{P}}_2, \bar{\bar{R}}_2] + \gamma U_I\left(I_2(\bar{\bar{L}}, \overline{\overline{YI}})\right)\bar{\bar{Y}}_2\right) \\
&+ \pi_1 \pi_2 (\bar{\bar{P}}_1 \alpha_1 - \bar{\bar{P}}_2 \alpha_2)\left(V_p[\bar{\bar{P}}_1, \bar{\bar{R}}_1] - V_p[\bar{\bar{P}}_2, \bar{\bar{R}}_2]\right. \\
&\left.- \gamma\left(U_I\left(I_2(\bar{\bar{L}}, \overline{\overline{YI}})\right) - U_I\left(I_1(\bar{\bar{L}}, \overline{\overline{YI}})\right)\right)\right) \\
&+ \pi_1 \pi_2 \overline{\overline{YI}}\left(\frac{\partial \bar{\bar{P}}_1}{\partial YI}\alpha_1 - \frac{\partial \bar{\bar{P}}_2}{\partial YI}\alpha_2\right)\left(V_R[\bar{\bar{P}}_1, \bar{\bar{R}}_1]\right. \\
&- V_R[\bar{\bar{P}}_2, \bar{\bar{R}}_2] \\
&\left.+ \gamma\left(U_I\left(I_2(\bar{\bar{L}}, \overline{\overline{YI}})\right) - U_I\left(I_1(\bar{\bar{L}}, \overline{\overline{YI}})\right)\right)\right) = 0
\end{aligned} \qquad (10)$$

The condition (9) reduces to the former condition (3) when the crop insured level is null, i.e. when the last line of condition 9 is zero. This last line captures the effect of farm labor on the evolution of insurance premium and indemnity. The first order condition (10) differs from the first order condition (9) only with respect to their second lines: the insured level has direct effect on net indemnities but no direct physical effect on the crop production. Plugging the equations characterizing the competitive equilibrium ((6) and (7)) in these two first order conditions, using again Roy's identity and rearranging terms gives the following restrictions:

$$\left(\pi_1 \frac{\partial \bar{\bar{P}}_1}{\partial L} \bar{\bar{Y}}_1 + \pi_2 \frac{\partial \bar{\bar{P}}_2}{\partial L} \bar{\bar{Y}}_2\right)\Big(-\pi_1 V_R\big[\bar{\bar{P}}_1, \bar{\bar{R}}_1\big] - \pi_2 V_R\big[\bar{\bar{P}}_2, \bar{\bar{R}}_2\big] + \gamma U_I\left(I\big(\bar{\bar{L}}, \overline{\overline{YI}}\big)\right)\Big) = 0 \tag{11}$$

$$\begin{aligned}\pi_1 \frac{\partial \bar{\bar{P}}_1}{\partial YI} \bar{\bar{Y}}_1 &\left(-V_R\big[\bar{\bar{P}}_1, \bar{\bar{R}}_1\big] + \gamma U_I\left(I\big(\bar{\bar{L}}, \overline{\overline{YI}}\big)\right)\right) \\ &+ \pi_2 \frac{\partial \bar{\bar{P}}_2}{\partial YI} \bar{\bar{Y}}_2 \left(-V_R\big[\bar{\bar{P}}_2, \bar{\bar{R}}_2\big] + \gamma U_I\left(I\big(\bar{\bar{L}}, \overline{\overline{YI}}\big)\right)\right) \\ &+ \pi_1\pi_2 \left(\left(\frac{\partial \bar{\bar{P}}_1}{\partial YI}\overline{\overline{YI}} + \bar{\bar{P}}_1\right)\alpha_1 - \left(\frac{\partial \bar{\bar{P}}_2}{\partial YI}\overline{\overline{YI}} + \bar{\bar{P}}_2\right)\alpha_2\right)\left(V_p\big[\bar{\bar{P}}_1, \bar{\bar{R}}_1\big] - V_p\big[\bar{\bar{P}}_2, \bar{\bar{R}}_2\big]\right) \\ &= 0\end{aligned} \tag{12}$$

These two restrictions are always simultaneously satisfied when:

$$\frac{U_I\left(I\big(\bar{\bar{L}}, \overline{\overline{YI}}\big)\right)}{V_R\big[\bar{\bar{P}}_1, \bar{\bar{R}}_1\big]} = \frac{U_I\left(I\big(\bar{\bar{L}}, \overline{\overline{YI}}\big)\right)}{V_R\big[\bar{\bar{P}}_2, \bar{\bar{R}}_2\big]} = \frac{1}{\gamma} \tag{13}$$

Condition (13) must be compared to the previous condition (5). This new condition is less restrictive: it is always satisfied when the marginal utility of income of the consumer is constant (an assumption usually made with partial equilibrium analysis, Myers, 1988). Unlike the no-insurance case, it is no longer required that either the farmer is risk neutral or that the crop demand has a unitary price elasticity.

In our general equilibrium production economy, the introduction of a revenue insurance program is thus welfare improving when the farmer exhibit risk aversion and the crop demand own price elasticity is different from unity. We obtain this analytical result in a highly stylized economy suffering from only one missing risk market. Moving to more realistic cases with, for instance, insurance transaction costs, other market imperfections or policy distortions, requires empirical modelling, to which we turn now.

## 4. CGE modeling framework

Empirical macro-economic modelling of the insurance industry is lacking (Salanié, 2017). We develop a new stochastic general equilibrium framework in order to analyze the U.S crop insurance industry and policy. We choose to start from the standard GTAP model (Hertel, 1997), which is a global CGE model detailing many farm sectors and the pervasive farm policies. All activities are, by definition of general equilibrium, included in the model and database, in particular the insurance industry. However, the standard GTAP model is a static CGE model without explicit risk modelling, such as the explicit measurement of farmers' risk attitude, insurance premiums paid by the farmer and the eventual indemnities that they receive in case of losses. By starting with this widely used CGE model, we are also close to the only recent macroeconomic analysis focused on crop insurance by Lusk (2017) and can test its robustness. More importantly, this CGE model serves as a benchmark to a more elaborated version where the risk attitude of farmers and insurance programs are introduced.

We make three important changes in the model. We first introduce the crop production uncertainty and consider two periods, capturing the fact that a risky event is a future event. We then introduce a farm household that has many possibilities to manage risks and smooth consumption levels (Pope et al., 2011). The third modification involves explicitly modeling the agricultural insurance market, in particular, the demand by farmers of subsidized insurance products. In this way, we are able to introduce into the normative analysis the risk sharing properties of insurance programs.

We first give a general description of the benchmark CGE model. Then we explain the different modifications introduced to perform a more consistent welfare analysis of the U.S. farm crop insurance programs.

### *4.1. The CGE model*

In order to make the connection between the previous section and the GTAP framework used below, we provide below the critical CGE equations that we later modify. At this point, we retain the closed economy assumption, because we will not change the trade equations, so the multi-region character of the GTAP model will remain intact. In the equations below, endogenous variables are in upper case, exogenous variables in lower case.

$$F_{f,j} = F_{f,j}\left(Y_j, W_{.,j} + tf_{.,j}, P_{.} + ti_{.,j}\right) \quad (14)$$

$$IC_{i,j} = IC_{i,j}\left(Y_j, W_{.,j} + tf_{.,j}, P_{.} + ti_{.,j}\right) \quad (15)$$

$$\left(P_j + ty_j\right).Y_j = \sum_f \left(W_{f,j} + tf_{f,j}\right).F_{f,j} + \sum_i \left(P_i + ti_{i,j}\right).IC_{i,j} \quad (16)$$

$$F_{f,j} = F_{f,j}\left(ft_f, W_{f,.}\right) \quad (17)$$

$$INV_i = I_i(P_., INV) \quad (18)$$

$$D_i = D_i(P_., R - S) \quad (19)$$

$$S = S(R) \quad (20)$$

$$D_i + INV_i + \sum_j IC_{i,j} = Y_i \quad (21)$$

$$R = \sum_j \left( \sum_f W_{f,j}.F_{f,j} + \sum_f t_{f,j}.F_{f,j} + \sum_i ti_{i,j}.IC_{i,j} + ty_j.Y_j \right) \quad (22)$$

$$INV = S \quad (23)$$

With f the index of primary factors (labor, capital and land), i and j the index of commodities and sectors (due to the mono-product assumption), F the factor use, W the corresponding price, Y the production level of commodity, P the corresponding market price, t the tax on the corresponding economic flows, IC the intermediate consumption, ft the endowment of factors, INV the investment in commodity, D the final demand by the representative household, R the income, S the saving.

The first four equations (14-17) together represent the supply side of our closed economy. More precisely, equation (14) determines the derived demand of factor f by production sector j. It depends on the production level, the (net of tax) prices of factors and commodities. Equation (15) is similar, determining the input demand of commodity i by production sector j. These two dual equations result from the assumption of profit maximization under technological constraints, technically specified through nested Constant Elasticity of Substitution (CES) functions. Risk aversion is excluded for all producers. Equation (16) (the zero profit condition) implicitly determines the production level. Equation (17) determines the supply of factor f to production sector j. It depends on the factor endowment and the return provided by each production sector. Again, these dual supply functions are technically specified through nested Constant Elasticity of Transformation (CET) functions, capturing potentially imperfectly mobile factors. They derive from the assumption of revenue maximization by factor owners.

The next three equations together represent the demand side of our closed economy. More precisely, equation (18) determines the demand of investment commodity i as a function of price and total investment. Equation (19) determines the final demand of commodity i by the representative household as a function of commodity prices (for simplification we omit consumption taxes) and expenditures. The household saving is supposed to a (usually fixed) fraction of its income (equation 20).

The last three equations are macroeconomic equilibrium conditions: equation 21 implicitly determines the commodity market price; equation 22 defines the household income and finally equation 23 is the macroeconomic closure rule (investment is saving driven). Due to Walras Law and the homogeneity of supply and demand functions, one equation is omitted and a price is fixed when the model is solved.

The calibrated elasticities of the supply and demand functions can reflect the main feature of agricultural markets. However, it should be underlined that, at the farm supply side, the modeled agent is not one farmer who may own different primary factors (capital and land in addition to the own human capital and labor force) and decides production variables. Rather, the approach is activity-based with a distinction made according the different primary factor owners. More precisely, it is assumed in the standard GTAP framework that there is a representative landowner in each region who allocates the land asset over different farm and non-farm activities each year. This allocation depends on the land return provided by each activity and is technically implemented by (nested) CET mobility functions. This approach captures the heterogeneity of the land asset and land market regulations (a discussion of this approach is available in Zhao et al., 2019). In the same vein, there is a representative labor supplier (both skilled and unskilled) in each region, allocating the labor force and human capital to different activities in response to their labor returns each year. The logic is the same for the representative physical capital owner, which can be a domestic or a foreign household. The primary factor returns generated by the different activities are constrained by the market and policy environment and the technological relationships that link outputs to inputs and primary factors of production.

This activity-based agricultural supply modeling exhibits desirable features, such as the use of activity-based input–output matrices that are compiled by national statistical institutions. However, this CGE model also exhibits some weaknesses for risk analysis. First, this approach assumes that the regional households (more precisely primary factor owners) know the true market prices of commodities and the true primary factor returns when they determine their factor allocation. The lag between production decisions and commodity selling on the market is not recognized, preventing the real modeling of the crop production uncertainty. Second, this activity-based supply modeling does not allow for the explicit modeling of farmers' attitude towards risk. Farmers and other producers are not explicitly identified, but they are aggregated with other households, and only regional welfare effects are computed. Third, the insurance products purchased by farmers play the same role in the production technology as inputs such as fertilizers, seeds or chemicals. It does not recognize that farmers pay insurance premiums because they expect production indemnities in case of economic losses. Finally, it supposes that we are able to measure all (gross and net of taxes) commodity uses, primary factor returns and net taxes paid by all farming activities. This is far from obvious because many farms have multiple outputs (MacDonald et al., 2013) and because some net taxes (fixed direct payments for instance) are given independently of activities.

In order to analyse crop insurance programs, we introduce three main changes to the previous CGE model: crop production uncertainty following previous efforts by Boussard et al. (2006), the farm household following previous efforts by Hanson and Somwaru (2003) and finally insurance demand by farmers following the OECD (2005). We present them sequentially.

*4.2. The introduction of crop production uncertainty*

The production of an annual crop is performed by farmers who decide at the beginning of the production campaign the land devoted to crops and the crop practices. Then they apply some intermediate inputs such as fertilizers and pesticides during the season that may depend on external shocks such as climate events (Bontems and Thomas, 2000). Finally, they harvest their crops and sell them on the market at the end of the season. The realized production may differ from the expected production at the start of the season.

In order to model this crop production uncertainty, we first need to identify farmers. As underlined above, the GTAP approach supposes that economic agents automatically adjust to economic incentives, for instance with workers and capital goods departing from less profitable activities. This makes sense in a steady state perspective. In reality, factors may take time to move following shocks. This can be captured by restraining factor movements technically by fixing at the limit a zero elasticity in the CET mobility function (Keeney and Hertel, 2009). In such a case, we obtain short-run (yearly) impacts compared to medium or long-run effects. We do so for an aggregate factor composed of physical capital and human capital that we assume to be fixed in the short run per activity. By creating a fixed factor, we can later identify a farm household who owns this aggregate factor and makes the crop production decisions. The return for managing the farm is the residual income defined as market receipts plus subsidies less input and factor expenditures. For the moment, we assume that the farmer’s objective is to maximize the expected income.

In order to model this crop production uncertainty, we also need to consider that inputs and primary factors of production are engaged before the stochastic events and production are realized. This time lag between production decisions and production marketing implies that farmers must base their decisions on expected prices and productivity shocks. This time lag has already been implemented in PE models such the Aglink Cosimo (OECD, 2015) or CGE models (Boussard et al., 2006). We follow these examples and assume that one year or campaign can be divided in two periods. In the first period that can be labeled the production period, crop farmers equipped with their physical capital determine their production, input and primary factor levels given their expectations of state-contingent productivity shocks and commodity and labor prices (labor is used all along the production campaign, such as during harvesting). However, we assume that the land use and rental rate are negotiated with the landowner at the beginning of the production campaign. Indeed most rented land in the U.S. is under fixed contract. Hence, in the first period of a given year, we determine the expected output level, the true input

use, primary factor use (land and labor) by the crop farmers, parts of the land allocation by the landowner and the corresponding land return.
Formally, the program of the crop farmer in this first period is given by:

$$max_{IC_{i,j},F_{f\neq K,j}} E_{j,s}(I_{j,s}) = E_{s,j}\left( (P_{j,s} + ty_j).Y_{j,s} - \sum_{f\neq K}(W_{f,j,s} + tf_{f,j}).F_{f,j} - \sum_{i}(P_{i,s} + ti_{i,j}).IC_{i,j} \right)$$

Subject to:

$$Y_{j,s} = \alpha_s Y_j = \alpha_s f(IC_{i,j}, F_{f\neq K,j}, K_j)$$

The s index stands for the state of nature, $E_{s,j}$ the expectation made by the economic agent h over the states of nature, $K_j$ is the fixed factor. In this program, we assume that the unitary net taxes are perfectly known by the crop farmers at the beginning of the season. We first solve this program to obtain:

$$F_{f\neq K,j} = F_{f\neq K,j}(Y_j, E_{j,s}(W_{.,j,s} + tf_{.,j}; P_{.,s} + ti_{.,j}), K_j)\ ;\ F_{f=K,j} = K_j \tag{24}$$

$$IC_{i,j} = IC_{i,j}(Y_j, E_{j,s}(W_{.,j,s} + tf_{.,j}; P_{.,s} + ti_{.,j}), K_j) \tag{25}$$

$$Y_j = f(IC_{i,j}, F_{f\neq K,j}, K_j) \tag{26}$$

The equations (24) and (25) are very similar to equations (14) and (15). The two modifications are the specifications of expected prices by the farmers rather than the true prices and the capital stock is fixed. The equation (26) is simply the production technology.

At the start of the season the crop farmers interact with the landowner who still maximizes revenue subject to the land mobility constraint. Like the farmers, the landowner formulates return expectations for the land allocated to other activities. The land supply function to the crop farmers is of the form:

$$F_{f=land,j=crop} = F_{f,j}\left(ft_f, E_{f,s}(W_{f,.})\right) \tag{27}$$

Again, this equation is very similar to equation (17), with the true prices replaced by expected returns by the landowner. These expected returns may be different from the farmers' expected returns if both agents have not rational expectations.

In the first period we solve a simple partial equilibrium model made of equations (24) to (27). This gives the true intermediate input and factor uses by the crop farmers, the true land return for this activity and the expected crop production. In the second period of the given year, which can be labeled the marketing period, these variables become predetermined in the former CGE model. The corresponding equations (14) to (17) are removed. The CGE model is then solved $S$ times for a set of random draws of productivity shocks. We obtain in $S$ crop market prices. They may differ from expected prices by the crop farmers if they do not have rational expectations. Our division of one year or campaign into two periods is obviously a simplification, as farmers may learn about stochastic events during the campaign and adjust their production decisions accordingly. This simplification prevents us from considering the potential moral hazard issue when insurance programs will be introduced (Yu and Wu, 2016).

*4.3. The introduction of the farm household and the risk aversion*

We now introduce the farm household in order to be able to reflect their eventual risk aversion. Of the three possible approaches explained by Keeney and Hertel (2005), we favor the most complete one as already implemented by Hanson and Somwaru (2003). That is, we depart from the representative regional household assumption and assume there are two types of households: farm and non-farm. Each household optimizes separately, and they interact through factor and product markets. This distinction allows specifying the risk attitudes of the farm household (eventually their risk aversion) that may differ from the risk attitudes of other households. Moreover, this approach potentially allows for the capturing of different risk management strategies that farm households may mobilize to smooth their consumption levels (Pope et al., 2011). These strategies include short-term production decisions, long-term investment and saving decisions, off-farm labor decisions, contracting with intermediaries (Du et al., 2015) or input suppliers (Kuethe and Paulson, 2014), and insurance contracts. If one wants to consistently compare the efficiencies of these strategies, the distinction between farm and non-farm households is recommended. The implementation of this differentiated household approach requires a large amount of additional data. Some of them are not easily accessible, we discuss this issue in the next section. The implementation of this approach also requires a large number of additional parameters, notably on the risk preferences and perceptions by farmers. Risk (and time) preferences have been extensively investigated with different methods. It seems well accepted that farm household preferences are concave and thus exhibit risk aversion. We follow many simulation studies (for instance Miao et al., 2016) by specifying farmers to be expected utility maximizers. This specification is also supported by the econometric results obtained by Pope et al. (2011) who also assume that utility depends on consumption levels (and not wealth or profits).

Concretely, we assume that the farm household maximizes its expected utility at the start of the season by an optimal choice of input and factor uses, state contingent commodity consumptions and participation in insurance programs (see below). We will vary the exogenous risk aversion parameter characterizing the risk attitude. We assume that the investment, off-farm labor and marketing contracts decisions are fixed. In particular, we assume that their investment level equals an exogenous depreciation of the capital stock.

Formally, we introduce a new index h for the two households (farm and non-farm). The program of the farm household at the start of the season is now given by:

$$max_{IC_{i,j},F_{f\neq K,j},D_{i,h,s}} E_{h,s}U\left(D_{.,h,s}\right) = \sum_{s} \pi_s U\left(D_{.,h,s}\right)$$

Subject to:

$$\sum_{i} P_{i,s}\left(D_{i,h,s} + inv_{i,h}\right) \leq \left( \left(P_{j,s} + ty_j\right).Y_{j,s} - \sum_{f\neq K}\left(W_{f,j,s} + tf_{f,j}\right).F_{f,j} - \sum_{i}\left(P_{i,s} + ti_{i,j}\right).IC_{i,j} \right)$$

$$Y_{j,s} = \alpha_s Y_j = \alpha_s f\left(IC_{i,j}, F_{f\neq K,j}, K_j\right)$$

$$inv_{i,h} = \delta_{i,j} K_j$$

Where $D_{i,h,s}$ is the final consumption of good i by the farm household in the state s, $inv_{i,h}$ is the investment made by the farm household in good i to maintain the capital stock, $\delta_{i,j}$ is the capital depreciation rate. The optimal decisions of the farm household now depend on the risk attitude captured by the parameters of the utility function (with $\rho_h$ the exogenous risk aversion parameter). Formally they are given by:

$$F_{f\neq K,j} = F_{f\neq K,j}\left(Y_j, E_{j,s}\left(W_{.,j,s} + tf_{.,j}; P_{.,s} + ti_{.,j}\right), K_j, inv_{i,j}, \rho_h\right);\ F_{f=K,j} = K_j \tag{28}$$

$$IC_{i,j} = IC_{i,j}\left(Y_j, E_{j,s}\left(W_{.,j,s} + tf_{.,j}; P_{.,s} + ti_{.,j}\right), K_j, inv_{i,j}, \rho_h\right) \tag{29}$$

$$Y_j = f\left(IC_{i,j}, F_{f\neq K,j}, K_j\right) \tag{30}$$

$$D_{i,h,s} = D_{i,h,s}\left(Y_{j,s}, E_{j,s}\left(W_{.,j,s} + tf_{.,j}; P_{.,s} + ti_{.,j}\right), K_j, inv_{i,j}, \rho_h\right) \tag{31}$$

Equations (28) to (30) are similar to equations (24) to (26), the two modifications concerning the fixed level of investment made by the farm household and the introduction of the risk attitude. Equation (31) is a new equation introduced in the first period partial equilibrium. It determines the expected final consumptions by the farm household in the different states of nature. These consumption depend on the income of the farm household (hence the expected factor prices for instance) and expected prices of final goods. In the first period, we solve a partial equilibrium framework made of equations (28) to (31) and the previous land supply function (equation 27).

Again, the production variables are then introduced as predetermined variables in the CGE model (not the state contingent commodity consumption of the farm household). This CGE model needs to be slightly modified to account for the presence of two households. The ex post income of the farm household is given by:

$$\begin{aligned} R_{farm,s} &= \left(P_{j,s} + ty_j\right).\alpha_s.Y\left(IC_{i,j}, F_{f,j}\right) \\ &- \sum_{i \neq "ins"} \left(P_{i,s} + ti_{i,j}\right).IC_{i,j} \\ &- \sum_{f \neq "K"} \left(W_{f,j,s} + tf_{f,j}\right).F_{f,j}, j = cereals \end{aligned} \tag{32}$$

and the income of the non-farm household in the contingent state $s$ by:

$$\begin{aligned} R_{nonfarm,s} = \sum_j \Bigg( &\sum_f W_{f,j,s}.F_{f,j,s} + \sum_f t_{f,j}.F_{f,j,s} \\ &+ \sum_i ti_{i,j}.IC_{i,j,s} + ty_j.Y_{j,s} \Bigg) - R_{farm,s} \end{aligned} \tag{33}$$

The true final demands by the two households are expressed as:

$$D_{i,h,s} = D_{i,h,s}\left(P_{.,s}, R_{h,s} - S\left(R_{h,s}\right)\right) \tag{34}$$

Finally the market equilibrium conditions for the different product are:

$$\sum_h D_{i,h,s} + INV_{i,h,s} + \sum_j IC_{i,j,s} = Y_{i,s} \tag{35}$$

The new CGE model is again solved $S$ times with the different state contingent productivity shocks and distinguishes two households. It again determines contingent market prices, residual capital return for the farm household and the final consumption of commodities.

*4.4. The introduction of the crop insurance programs*

The last main change relates to the crop insurance. Crop insurance used by farmers does not directly influence the biological process of arable crops. It is a financial decision. Farmers determine the optimal use of insurance products in terms of insured acreage and coverage levels before the realization of stochastic events. They engage themselves to pay premiums (net of subsidies) to the insurance industry. They receive indemnities in case of observed losses greater than deductibles. In the United States, arable crop farmers are currently offered a variety of insurance products that differ in many aspects.[2] They can cover yield versus revenue losses (with or without harvest price exclusion) with different levels of coverage (from 50 to 90 percent) at different unit levels (enterprise vs basic vs optional). The subsidy levels also differ across these products (from 100 percent for catastrophic level to 35 percent). There is great heterogeneity across the U.S. cropping conditions, leading to the observation of varying participation in these insurance products. Because we start from a macroeconomic CGE approach with representative aggregate agents, it is impossible to fully reflect this heterogeneity. We focus on the insurance product that has been most purchased by the U.S. farmers in recent years: revenue insurance at the 85 percent coverage level (Du et al., 2017).

In limiting the insurance products, we follow the OECD (2005) by modeling the insured acreage decision only. This decision obviously interacts with other decisions of the farm household. In particular, we assume that the farm household cannot speculate on insurance in the sense that he cannot insure more than the cropped area. Their optimal insured acreage depends on the risk aversion: if the farm household is risk neutral, it does not value the risk reduction properties of insurance and fully insures the cropped acreage only if it is profitable (positive net expected indemnities). In this instance, insurance becomes similar to a land subsidy. If the farm household is risk averse, he can insure part of the cropped acreage, even if the insurance products are not subsidized. We introduce the insured acreage demand in the farm household program defined in the production period. We assume that the supply of insurance products is perfectly elastic. This is indeed the logic of current legislation: the insurance industry cannot refuse the distribution of RMA-defined insurance products to farmers. The farm household model solved in the first period now defines the expected output, the true input and factor uses, the insured acreage and the premiums to be paid to the insurance industry. Formally the program of the farm household is now defined by:

$$max_{IC_{i,j},F_{f\neq K,j},D_{i,h,s}} E_{h,s} U\left(D_{.,h,s}\right) = \sum_{s} \pi_s U\left(D_{.,h,s}\right)$$

Subject to:

[2] Full description is available on the RMA website: https://www.rma.usda.gov/Policy-and-Procedure/Insurance-Plans

$$\sum_{i} P_{i,s}\left(D_{i,h,s}+inv_{i,h}\right) \leq \left(\left(P_{j,s}+ty_j\right).Y_{j,s}-\sum_{f\neq K}\left(W_{f,j,s}+tf_{f,j}\right).F_{f,j} - \sum_{i\neq ins}\left(P_{i,s}+ti_{i,j}\right).IC_{i,j}\right)-LI_j NI_{j,n}$$

$$Y_{j,s}=\alpha_s Y_j=\alpha_s f\left(IC_{i\neq ins,j},F_{f\neq K,j},K_j\right)$$

$$inv_{i,h}=\delta_{i,j}K_j$$

$$LI_j \leq F_{land,j}$$

$$NI_{j,s}=inscap.\left(max\left(0;\beta-P_{j,s}.\alpha_s\right)-(1+\gamma).\left(1+ti_{"ins",j}\right).E_s max\left(0;\beta-P_{j,s}.\alpha_{j,s}\right)\right)$$

Where $LI_j$ the insured acreage, $NI_{j,s}$ the net indemnity in state s, $inscap$ the value of insured capital, $\beta$ the coverage provided by the revenue insurance product, $\gamma$ the loading factor. The pure insurance premium is given by $inscap.\mathrm{E}_s\max\left(0;\beta-P_{j,s}.\alpha_s\right)$. The farm household pays this pure premium plus loading costs minus insurance subsidies ($ti_{"ins",j}$ is negative). It should be noted that the prices entering this program are the expected ones by the farm household (the true ex post ones are computed with the CGE model).

It is possible to directly solve this program (as in OECD 2005) or solve the system of first order conditions. We provide them because they interact with the land supply function in the first period PE model. The first order conditions when the constraint on insured acreage is binding (this is not always the case in the scenarios that we simulate) are:

$$\pi_s.\frac{\partial U\left(D_{i,h,s}\right)}{\partial D_{i,h,s}}=\lambda_s.E_s\left(P_{i,s}\right) \tag{36}$$

$$\sum_s \lambda_s.\left(\left(E_s\left(P_{j,s}\right)+ty_j\right).\alpha_s.\frac{\partial Y(.)}{\partial F_{f,j}}-E_s\left(W_{f,j,s}\right)-tf_{f,j}\right)+\lambda l_{f="land"}=0 \tag{37}$$

$$\sum_s \lambda_s.\left(\left(E_s\left(P_{j,s}\right)+ty_j\right).\alpha_s.\frac{\partial Y(.)}{\partial IC_{i,j}}-E_s\left(P_{i,s}\right)-ti_{i,j}\right)=0, i\neq "ins" \tag{38}$$

$$\sum_{s} \lambda_s NI_{j,s} - \lambda l_{f="land"} = 0 \quad (39)$$

Where $\lambda_s$ is the Lagrangian multiplier associated with the budget constraint in the contingent state $s$ (it is also the marginal utility of income and depends on the risk attitude), $\lambda l_{f="land"}$ the Lagrangian multiplier associated with the constraint on insured acreage.

Equation (36) determines the *ex ante*, contingent final consumption. Equation (37) determines the optimal true factor uses and equation (38) the optimal intermediate consumption of commodity. The exception is the demand of insurance service. It is defined by the level of insured acreage times the premium (net of the loading factor and the premium subsidy). By using the production function, we then obtain the expected production level (it may differ from the true one due to productivity shock). Equation (39) determines the Lagrangian multiplier on insured acreage.

The resolution of these first order conditions, together with the land supply function (27) gives the true (i.e. observed) factor and intermediate input uses, the true insured acreage decided by the farm household and the corresponding land return. It also give the expected production.

Again, we introduce the levels of the production variables in the CGE model that needs to be slightly modified to account for ex post insurance indemnities as such:

$$\begin{aligned} R_{h,s} &= \left(P_{j,s} + ty_j\right).\alpha_s.Y\left(IC_{i,j}, F_{f,j}\right) \\ &- \sum_{i \neq "ins"} \left(P_{i,s} + ti_{i,j}\right).IC_{i,j} \\ &- \sum_{f \neq "K"} \left(W_{f,j,s} + tf_{f,j}\right).F_{f,j} - LI_j NI_{j,s}, h \\ &= farmer, j = cereals \end{aligned}$$

We again modify the income of U.S nonfarm household by subtracting this farm household income. This modified CGE model is solved S times with different state contingent productivity shocks. We hence obtain contingent market prices, residual capital return and farm household final consumptions and net indemnities paid by the insurance industry to the farm household. For instance, if a severe negative productivity shock materializes, the insurance industry pays ex post indemnities to the farm household that can be larger than the collected premiums. In that case, the return to the insurance industry is lower. By assuming only two types of household, then the non-farm household income is also lower. In contrast, if there is no negative productivity shock, the insurance industry benefits from underwriting gains that are transmitted to non-farm households in our modeling framework.

### *4.5. Implementation in the GTAP model*

The three main changes presented above are introduced into the multi-regional GTAP CGE model, fully detailed in Hertel and Tsigas (1997). These changes deliver new state contingent market results. They will depend in particular on the calibrated risk aversion parameter. To assess the normative efficiency of public policies, it remains to compute the welfare effects. In a static CGE model, this is usually done with the equivalent variation for the regional household that is straightforward to compute (a difference of closed-form expenditure functions). With our stochastic approach with two types of households, a distinction must be made between ex ante and ex post welfare effects (Just et al., 2005). We compute the *ex ante* equivalent variation for the farm and non-farm households. This is slightly less trivial when one assumes risk aversion because there is no closed-form solution. We solve a nonlinear equation involving indirect utility functions defined over contingent states for the farm household.

## 5. Economic data and behavioral parameters

We rely on the GTAP database measuring the economic flows for the year 2011 (Aguiar et al., 2019). As regards the U.S. crop insurance market, this year is not exceptional. The loss ratio (defined as indemnities divided by premiums) over all commodities (including cotton) is approximately 0.9, which is the average loss ratio over the period 2001–2015.

This database covers 140 countries and 57 commodities. The usual practice is to aggregate them to ease the mathematical resolution. We retain 3 countries, namely, the U.S., the European Union and the Rest of the World. The purpose of the two other countries is simply to check that we do not make computational mistakes (the Walras law). We retain 9 commodities or activities, namely, cereals (an aggregate of rice, wheat and coarse grains), oilseeds, other crops, live animals, food, manufacture, insurance, trade and transport and other services. We concentrate on cereals.

The construction of the GTAP database requires many assumptions, partly because input-output tables are not regularly updated; products are not highly disaggregated, and value added is not split between all primary factors. We make two data corrections to the U.S. data. The U.S. data in our GTAP database are updates from the 1992 input–output tables. That is, input output coefficients measured in 1992 by the Bureau of Economic Analysis are applied to 2011 production values. Without surprise, the insurance expenditures by the cereal sector do not fit with the RMA data. In fact, the input–output table reports the premium expenditures net of ex post indemnities. In other words, the input–output table reports the ex post observed contingent state. With this accounting rule, for some years (such as 2012 with a severe drought), the insurance expenditures by some sectors can be negative (insurance expenditures cover crop insurance but also activity based insurance on building, machines or stocks). According to the RMA, the premiums paid on the insured cereal acreage amounted to $6904 million in 2011[3]. Farm households received $4252 million of premium subsidies. Ex post indemnities

[3] We aggregate barley, corn, rice and wheat values from https://www3.rma.usda.gov/apps/sob/current_week/crop2011.pdf.

amounted to \$5525 million. The net gain for farmers is thus \$2873 million ex post. Before the subsidies, the cost of participating in the insurance programs is \$1379 million. This corresponds to underwriting gains captured by the insurance industry. Because the year 2011 was not exceptional, we make the simplifying assumption that these ex post gains just cover the expected expenditures of the insurance industry for delivering insurance programs. These gains represent 20 percent of premiums, which is close to the proportion for determining A&O values. One may object that the intention of the RMA when rating insurance products is that premiums should be fair and farmers should not pay these A&O expenditures. However, from 2001 to 2010, the average loss ratio was 0.8. We cannot exclude the possibility that farmers, when paying their premiums, believe that part of the premium is used to cover A&O expenditures. They are ready to pay these additional expenditures because they receive some subsidies. In other words, we assume a loading factor of 20 percent.

The second data correction concerns the distribution of U.S. cereal value added across the primary factors. This distribution determines in particular the return to farm labor and is directly related to the long-lasting debate on the "farm problem" (Gardner, 1992; Key et al., 2017). In the GTAP database, these returns are derived from econometric estimates of medium-run U.S. price supply responses where risk attitudes are ignored. Furthermore, the farm capital is assumed to be mobile, and the only fixed factor is family labor (Ball, 1988). The returns to land, labor and capital are all close to 15 percent of production values. If we keep this distribution and assume that the capital is the only fixed factor, we end up with negative consumption levels when the revenue shock is larger than 15 percent. According to the USDA data, the net U.S. farm income over the period 2002–2011 is approximately 24 percent of production values. We increase the capital return in the U.S. cereal sector to this percentage to the detriment of the labor return. The capital factor in this sector now comprises both capital and farm household labor that are both considered fixed in the short run. It is then possible to simulate a revenue shock of up to 24 percent without getting negative consumption levels.

To implement the stochastic CGE model with insurance and the farm household, additional data are needed. Key et al. (2017) report that off-farm income can be very significant for some farm households, contributing to 85 percent of the household income. However, for commercial farms, this share is much lower (approximately 25 percent). We introduce this additional income to the farm household composition. However, farm households spend part of their income for farm investment. This should be deduced from the income that remains for household consumption. These investment expenditures are quite volatile, suggesting that farmers can use this strategy to smooth consumption levels. We do not explore this issue. Thus, we rely on the smoother depreciation values of approximately 30 percent of net farm income. By default, we assume that off-farm income and investment expenditures are fixed and are initially equal. A sensitivity analysis will be performed on these data assumptions.

Having determined the total final expenditures, we assume that the consumption pattern of final goods by the farm household is identical to the consumption pattern by the non-farm household.

To implement the stochastic CGE model, we also need to specify the risk preferences of the farm household, the distribution of expected price and productivity shocks as perceived by the farm household. We first calibrate the productivity shocks as follows. Like Ramirez and Shonkwiller (2017), we assume that economic agents rely on 10 contingent states and first specify normal distribution (we will adopt a lognormal in a sensitivity analysis). We assume that the standard error of this normal distribution is 0.25. The mean of this normal distribution is calibrated to reproduce observed indemnities. That is, we solve our second period CGE model 10 times with productivity shocks and predetermined U.S. cereal productions. We compute ex post the net indemnities paid by the insurance industry to the farmers. Because we consider revenue insurance, these indemnities depend on the simulated prices. These indemnities also depend on the insured acreages and total liabilities. There is a great heterogeneity of production risks across U.S. farmers that cannot be perfectly captured in a macroeconomic model. We assume that up to 85 percent of cropped acreage can be insured at the 85 coverage level and that initially this constraint is binding.

We use these simulated prices to determine the initial price and productivity shocks expected by farmers. We simplify the analysis by ignoring productivity shocks in the rest of the world or on other markets. By using these values, we implicitly assume that farmers have initially rational expectations, which are the same as those delivered by the CGE model. Plugging the expected values in the first period PE model ensures that it reproduces the observed input decisions made by the U.S. cereal farmers in 2011. When we will simulate policy scenarios, we will have the possibility to vary these assumptions.

We finally need to specify the risk attitude of our U.S. farm household. We consider two values. First, this farm household is not risk averse at all. It buys the insurance product only because of the subsidy effect. The preferences over all final goods are governed by a simple Cobb–Douglas utility function. A linear expenditure system with commitments was also tested without significantly changing the results. Second, this farm household still exhibits risk aversion in the initial year despite the existence of subsidized risk products. That is, he is ready to pay a remaining risk premium to face less residual economic risk. The calibration of this initial risk premium and its evolution are critical. We simplify the analysis by assuming a power utility function (compared to the less parsimonious prospect theory) and thus specify only one parameter. Miao et al. (2016) suggest calibrating the risk aversion parameter following the device of Babcock et al (1993) on the "gamble size". That is, the risk premium is initially fixed at 10 percent of the standard deviation of farm income. We take a more conservative value of 5 percent because we capture more risk management decisions in our framework. This risk premium is initially counted in the residual capital return. We separate the two components in the calibration phase using the constant return to scale assumption (Femenia et al., 2010).

## 6. Results

We first simulate below the market and welfare effects of the removal of the crop insurance programs with both the standard GTAP CGE model and our original stochastic CGE model. We ignore potential interactions with other farm policy instruments, that may become active when market outcomes reach policy triggers (for instance when market prices reach loan rates). When we use the standard CGE model, we make our analysis comparable to the simulation study of Lusk by assuming that the premium subsidies are coupled to production. We also assume with this model that the U.S. farm household will no longer purchase insurance if not subsidized. When we use our preferred stochastic CGE model, premium subsidies are logically linked to the insurance expenditures. This model must be solved for different random draws of a series of 10 productivity shocks. The results are averaged afterwards. Below we report results for one random draw to simplify the analysis of results. To prove the robustness of the analysis, we will report the results with a different random distribution in the sensitivity analysis.

### *6.1. Impacts of removing crop insurance subsidies*

The upper part of Table 1 reports the market effects of this scenario on selected variables. The lower part reports the welfare effects. The first column gives the result when using the CGE model. The results are standard: the removal of coupled subsidies leads to a decrease of U.S. cereal production. This creates a deficit on the world market. The U.S. market price increases, dampening the initial decrease of the U.S. production. At the new equilibrium, the US market price is 0.4 percent higher, and the U.S. cereal production 1.7 percent lower. The U.S. cereal cropped acreage decreases by 1 percent, which favors other crop production (the U.S. oilseed production increases by 0.2 percent). The removal of crop insurance subsidies is partly shared by landowners: the rental rate of cereal land decreases by 5.7 percent. The value added generated by the U.S. cereal sector decreases. However, the U.S. economy saves insurance subsidies and insurance loading costs. Overall, the U.S. welfare increases by $1.4 billion. This scenario leads to a decrease of U.S. exports of cereals. Consequently, the economies in the RoW suffer from the price increases: their welfare decreases by nearly $0.3 billion. The world welfare increases by $1.1 billion. Our market results are qualitatively similar to those obtained by Lusk. Our welfare results also look like those obtained by Lusk but are slightly different. We obtain global welfare gains only because we remove insurance loading costs. The sole removal of insurance subsidies, while incorrectly assuming that the farm household continues to pay useless insurance services, leads to a global welfare loss of $0.8 billion (and a 3.6 percent decrease of the U.S. cereal production). This is mostly explained by the increased policy distortions (ad valorem tariffs) that prevail in the RoW. These first results already signal that defining a welfare increasing policy reform is not trivial.

The second column of Table 1 reports the results of the same policy experiment when we use the stochastic CGE model with a risk neutral farm household. The expected production now decreases by 4 percent. This impact is higher than it was previously, partly because we assume here that the U.S. farm household does not anticipate the price increase (this will be taken into account in the sensitivity analysis). The average (ex post) U.S. market price now increases by 1.4 percent. The U.S. cereal acreage decreases by 1.6 percent and the U.S. cereal yield by 2.4 percent. This is partly explained by the less expensive land input (the rental rate decreases by 8.4 percent) compared to other inputs (the changes of price of manufactured goods, including fertilizers and chemicals, are not discernible). Unsurprisingly, we find that the U.S. farm household no longer insures its cropped acreage. The initial insurance demand was only motivated by a profit effect. This effect disappears with the removal of these insurance subsidies and maintained insurance loading costs. In terms of welfare, we report the *ex ante* equivalent variation measures. We find that the U.S. farm household loses from this scenario ($0.6 billion). However, we still find that the U.S. economy enjoys welfare gains thanks to reduced subsidies and now useless insurance loading costs. The global ex ante welfare increases by $0.7 billion. This is consistent with the theoretical results: when farmers are risk neutral, the competitive equilibrium is likely Pareto optimal.

**Table 1.** Market and welfare impacts of the removal of premium subsidies (in deviation from the baseline)

| Model | Standard CGE | Stochastic CGE No risk aversion | Stochastic CGE risk aversion |
|---|---|---|---|
| Cereal Market effects (%) | | | |
| Expected U.S production | -1.7 | -4.0 | -7.4 |
| Average U.S. price | 0.4 | 1.4 | 2.6 |
| U.S. acreage | -1.0 | -1.6 | -3.0 |
| Rental rate of land | -5.7 | -8.4 | -15.0 |
| Share of insured acreage | -- | 0 | 73.2 |
| Welfare Effects ($million) | | | |
| Farm household | -- | -554 | -586 |
| Total U.S. economy | 1399 | 1190 | -876 |
| Row economies | -287 | -436 | -786 |
| Total | 1112 | 754 | -1662 |

*Source: Author calculation's*

The third column reports the results when we use our stochastic CGE model with a risk-averse farm household. The expected production now decreases by 7.4 percent, with cereal acreage decreasing by 3 percent and yield by 4.4 percent. The production decrease is 3.4 percent greater than the previous result. Our simulated coverage (or risk sharing) effect on production provided by the subsidized insurance programs is hence close to the profit effect. This is similar to the OECD simulation results (OECD, 2005) and in line with recent econometric evidence supporting the important coverage effect (Yu et al., 2018). More debatable is the yield effect. We find that it decreases by 4.4 percent compared to a 2.4 percent decrease when we exclude risk aversion. This larger yield effect is partly explained by the evolution of the land rental rate: it now decreases by 15 percent (compared to 8.4 percent). Quite debatable is the impact on insured acreage. We find that the farm household insures 73.2 percent of insurable acreage (hence 62 percent of cropped acreage). This is much higher than the insured acreage observed in the 1980s. However, the situations are not fully comparable. We focus here on revenue insurance, not on yield insurance. Furthermore, we make the simplifying assumption that economic agents cannot manage price risks on futures markets. The results can be different if other risk management strategies (and their respective costs) are introduced in the analysis (see OECD, 2005).

In terms of ex ante welfare effects, we again find that the U.S. farm household loses from this policy scenario. Even if the ex post prices increase, the farm household produces less and generates less value added. Now we find that the U.S. economy no longer gains: the U.S. *ex ante* welfare decreases by as much as $0.9 billion. This is explained by the reduced U.S. production of cereals and the fact that insurance products are still used by the farm household. Hence, some insurance production costs remain. The economies in the RoW suffer more ($0.8 billion). We finally find that the global economy suffers a welfare loss following the removal of premium subsidies (by $1.7 billion). Again, this empirical result is consistent with the theoretical results derived in section two. Without the crop insurance subsidies, the expected incomes by the farm household are more different across states of nature, hence the theoretical condition (3) on marginal utility of income is less likely to hold.

*6.2. Impacts of removing fixed direct payments*

The previous simulation shows that our modeling contribution critically changes the efficiency of crop insurance programs. We now explore if it also changes the efficiency of fixed direct payments. In a theoretical first best world with complete contingent markets, no frictions and policy distortions, a direct payment to a fixed factor is decoupled from production decisions (Chambers and Voica, 2016). We simulate the removal of fixed direct payments provided to cereal producers with our two CGE models.

The modeling of market and welfare effects of fixed direct payments provided to farmers remains debated (Haque et al., 2018). In the standard GTAP approach, these fixed direct payments are split arbitrarily into farm activities and primary factor returns. The modeler has the choice to modify this allocation. For instance, if we assume that all fixed direct payments are allocated to the fixed factor (capital in our case), then their removal has no market impacts. We only get a transfer between the non-farm and farm households. However, if we assume that part of these payments is diluted in mobile factors, then we can expect production effects. We do not model these frictions. Rather, we test whether the market and welfare impacts of fixed direct payments are similar across our two CGE models, conditional on their initial modeling. Table 2 reports the results of this policy experiment.

Let us start again with the standard CGE model (first column). The removal of the U.S. fixed direct payments (precisely those payments attached to land and labor used in the cereal sector) induces a decrease of the U.S. cereal production because of a reduction of both cropped acreage and expected yield. We again find a small increase of the U.S. cereal market price and a decrease of the land rental rate. The welfare effects are negative because of policy distortions in other activities.

When we use our new CGE model, the market results of this policy experiment are rather similar. Precisely, the U.S. expected production of cereals decreases by 1.27 percent without risk aversion and by 1.34 percent with risk aversion. The difference corresponds to a so-called wealth effect. Compared to the standard CGE model, we obtain slightly larger production and price effects because we assume that the U.S. farm household makes price expectation errors in the short run. We also find that the U.S. farm household fully insures insurable acreage. Interestingly, we find that the risk attitude of U.S. famers does not matter much when assessing the welfare effects of fixed direct payments: the global welfare losses are quite similar ($0.3 billion). Conditional on the initial modeling of U.S. fixed direct payments in the GTAP framework, we find that these payments mostly generate profit effects, limited wealth effects and no coverage effects. Hence their normative effects do not depend on the risk attitude of the farm household, again this is consistent with the theoretical results (no significant change in marginal utilities of income).

**Table 2.** Market and welfare impacts of the removal of direct payments (in deviation from the baseline)

| Model | Standard CGE | Stochastic CGE No risk aversion | Stochastic CGE risk aversion |
|---|---|---|---|
| Cereal Market effects (%) | | | |
| Expected U.S production | -0.7 | -1.3 | -1.3 |
| Average U.S. price | 0.2 | 0.4 | 0.4 |
| U.S. acreage | -0.4 | -0.7 | -0.7 |
| Rental rate of land | -2.9 | -3.7 | -3.8 |
| | | | |
| Share of insured acreage | -- | 100 | 100 |
| Welfare Effects ($million) | | | |
| Farm household | -- | -442 | -397 |
| Total U.S. economy | -45 | -207 | -198 |
| Row economies | -100 | -104 | -111 |
| Total | -145 | -311 | -309 |

*Source: Author calculation's*

### *6.3. Sensitivity analysis*

We recognize that our stochastic CGE with the farm households is based on many simplifying assumptions, in addition to those of the standard CGE model. We found previously that the market and welfare impacts of insurance subsidies depend on the modeling choice. We now test whether these differences are sensitive to three modeling assumptions.

The first test focuses on the price expectations by the U.S. farm household. Thus far, we assume that the U.S. farm household does not anticipate that the decrease of its expected production level will induce a market price increase. This is a short-run view that is less likely in the medium or long run. We now assume that the U.S. farm household is able to partly anticipate this price increase: by 1 percent without risk aversion, by 2 percent with the risk aversion. Selected results are reported in Table 3 (that must be compared to Table 1). As expected, we find different market effects. For instance, assuming a risk-averse farm household, the expected U.S. cereal production decreases by 5.3 percent following the removal of premium subsidies (compared to 7.4 percent in the central case). The magnitude of welfare effects also differs. The U.S. farm households lose more in that case ($1.6 billion compared to $0.6 billion) because the simulated market prices increase less (on average 1.8 percent compared to 2.6 percent). Above all, the global welfare results remain highly sensitive to the risk aversion assumption. Removing the premium subsidies is welfare improving (decreasing) when the U.S. farm household is risk neutral (averse).

**Table 3.** Sensitivity of impacts following the removal of premium subsidies to price expectations by the farm household (in deviation from the baseline)

| Model | Stochastic CGE No risk aversion | Stochastic CGE risk aversion |
|---|---|---|
| Cereal Market effects (%) | | |
| Expected U.S production | -3.0 | -5.3 |
| Average U.S. price | 1.0 | 1.8 |
| Share of insured acreage | 0 | 73.6 |
| Welfare Effects ($million) | | |
| Farm household | -1137 | -1577 |
| Total welfare | 927 | -1103 |

*Source: Author calculation's*

The second sensitivity test focuses on the composition of the farm household income. Thus far, we assume that the initial off-farm income receipts equal the initial capital replacement expenditures. We now assume that the initial capital replacement expenditures are null, that the initial off-farm income receipts represent 25 percent of the farm household income. We assume that this "exogenous" income is fixed (to be precise, in a CGE model, prices are endogenous; we just fix the quantity of off-farm labor). With this exogenous income, the farm household risk premium is initially different. We recalibrate the risk aversion parameter such that this risk premium represents 5 percent of the standard deviation of the farm household income. Selected results of the premium subsidy scenarios are reported in Table 4. If the farm household is risk neutral, the market and welfare effects are exactly equal to those obtained earlier. This is expected because the decisions of the U.S. farm household do not depend on the wealth. When we assume risk aversion, the market impacts are again similar to the previous ones. However, the welfare effects are slightly different. The loss of the U.S. farm household is less important ($0.05 billion compared to $0.6 billion in the central case). The reason is the insurance decision. We find a significant decrease of insured acreage to 35 percent of cropped acreage. In other words, we find that the price sensitivity of the demand for insurance products depends on the extent of total economic risks faced by farmers. We also find that the global welfare losses are less important ($1.2 billion compared to $1.7 billion).

**Table 4.** Sensitivity of impacts following the removal of premium subsidies to off farm income (in deviation from the baseline)

| Model | Stochastic CGE No risk aversion | Stochastic CGE risk aversion |
|---|---|---|
| Cereal Market effects (%) | | |
| Expected U.S production | -4.0 | -7.4 |
| Average U.S. price | 1.4 | 2.6 |
| Share of insured acreage | 0 | 40 |
| Welfare Effects ($million) | | |
| Farm household | -553 | -51 |
| Total welfare | 754 | -1161 |

*Source: Author calculation's*

The third sensitivity test focuses on the distribution of productivity shocks. Thus far, we assume a normal distribution for the productivity shocks and then simulate the CGE model to get the initial price distribution, supposing that the U.S. economic agents (the farm household, the insurance industry, and the RMA) perfectly know the initial distribution. In the crop insurance literature, many efforts have been devoted to identifying the true distribution of crop yields and in particular to improving the efficiency of rating procedures (for instance, Classeen and Just, 2009). Of the numerous alternative distributions, we adopt a log normal distribution in this sensitivity analysis. We adopt the same calibration procedure (we adjust the mean to replicate ex post indemnities from revenue insurance), maintaining 10 contingent states. The adoption of this lognormal distribution leads to less dispersed indemnities, compared to the normal distribution: 7 contingent states lead to indemnities (compared to 6 with the normal distribution). The coefficient of variation of net indemnities perceived by the U.S. farm households is 1.6 (compared to 2.0). Maximum indemnities remain large ($12.6 billion) but less than those with the normal distribution ($15.5 billion). The effects of the removal of premium subsidies are reported in Table 5. Market results do not differ much compared to the central case results. The impacts on expected production are slightly lower because there are few extremely negative contingent states that the risk-averse farm household wants to avoid. Interestingly, we find that the risk-averse U.S. farm household no longer loses from the policy shock. This is partly explained by the reduction of insured acreages to 48 percent of insurable acreage (hence 41 percent of cropped acreage). However, the global welfare effects remain quite robust: from positive without risk aversion to negative with risk aversion.

**Table 5.** Sensitivity of impacts following the removal of premium subsidies to the distribution of TFP shocks (in deviation from the baseline)

| Model | Stochastic CGE<br>No risk aversion | Stochastic CGE<br>risk aversion |
|---|---|---|
| Cereal Market effects (%) | | |
| Expected U.S production | -2.9 | -6.8 |
| Average U.S. price | 0.9 | 2.3 |
| Share of insured acreage | 0 | 48 |
| Welfare Effects ($million) | | |
| Farm household | -939 | 62 |
| Total welfare | 1099 | -769 |

*Source: Author calculation's*

## 7. Discussion

The development of this novel CGE framework involves many data and modeling assumptions that deserve discussion at this point. We aggregate them in three themes: heterogeneity, the demand side and the supply side.

One major challenge of all macroeconomic analysis is the aggregation from individuals or the treatment of heterogeneity. The general equilibrium modelling of crop insurance is no exception. The U.S. crop farmers face production conditions and perils that vary across space and time. This great heterogeneity explains part of the federal subsidies to crop insurance programs in order to overcome informational issues (moral hazard, adverse selection, fair pricing). The numbers of covered perils and eligible crops in insurance programs have considerably expanded in the last decades. Our framework can be improved to better capture these heterogeneities, by incorporating more data (for instance, with state data or different crop insurance products). However, this is unlikely to be parsimonious. Recently CGE models have been extended to incorporate firm heterogeneity with some parsimonious approaches (Bekkers and Francois, 2019). Research can examine if these approaches are relevant for analyzing production risks and insurance programs.

Demand by farmers for crop insurance programs can also be refined or tested in at least two main directions. First, we rely on the traditional expected utility approach to model the risk preferences of farmers and ignore wealth effects by specifying CARA preferences. Many micro-econometric papers look for the identification of these preferences (for instance, Roe, 2015). They test if farmer preferences are better captured by the cumulative prospect theory (for instance, Babcock, 2015, Du et al., 2017). Results tend to favor this theory which is more flexible but less parsimonious. Second, we assume that U.S. farmers manage their risk with only production and insurance decisions. We ignore many other risk management solutions, such diversification in other activities, storage, borrowing or saving decisions as well dynamic investment decisions.

Introducing these strategies to cope with short-term volatilities require the development of a stochastic dynamic programming model that may be fruitfully benefit from the dynamic version of the GTAP model. Moreover, we do not distinguish risk increasing versus risk-decreasing inputs, such as fertilizers, pesticides or irrigation. This might imply departure from homothetic CES production functions.

Finally, our modelling of the supply of crop insurance programs does not fully reflect the current federal involvement. Before 1980, crop insurance programs were only supplied by federal offices. Then a private-public partnership has been implemented in order to foster distribution of crop insurance programs. The leakage of federal subsidies to the insurance industry, composed of insurance agents, insurance companies and reinsurers, has always been a major concern for policy makers. Indeed, the delivery of insurance products is not competitive, as the insurance suppliers cannot define their own insurance products, nor they can price it. The price of insurance services is fixed by the RMA as a proportion of premiums. With increasing crop prices in the mid-2000s, the A&O values were highest in 2008 (more than 2 billion US$; Glauber, 2016). They were not determined by the production cost of insurance services and were likely to generate rents. The policy makers accounted for this possibility (in the 2008 farm bill and the Standard Reinsurance Agreement-SRA negotiated in 2010) by lowering and capping the proportion of premiums going to cover A&O expenses. Since 2010, the A&O receipts have decreased, and the U.S. has experienced loss ratios greater than one. Hence, the recent leakage to the insurance industry is much lower than it was previously. According to the U.S. Government Accountability Office (GAO, 2009), the purpose of the insurance regulators with the SRA was to prevent industry consolidation that may have reduced competition in the long run to the detriment of farmers. There are indeed few insurance companies but many independent insurance agents delivering insurance products to farmers. It seems quite difficult to identify the production costs of the insurance industry, for instance if some scale economies exist when collecting and processing information on production risks. Moreover, agents may provide rebates by cross-subsidizing other insurance products purchased by farmers (such as property and casualty insurances). More data and researches on these supply features are needed to improve both microeconomic and macroeconomic analysis of crop insurance programs.

## 8. Concluding comments

The U.S. farm policy has progressively changed in recent years, with greater reliance on crop insurance programs in the place of direct payments. While there are many microeconometric studies identifying the production and management responses of farmers to crop insurance programs, few efforts assess their macroeconomic and efficiency impacts. More generally, the macroeconomic effects of the insurance industries and policies are seldom performed. In this paper, we partially fill this gap, recognizing that any macroeconomic evaluation tool requires many simplifying assumptions. We develop two CGE models focused on the U.S. crop sector, with and without risk-averse farm household and crop production uncertainty. This allows us an explicit capture of the coverage effects provided by subsidized insurance programs in addition to the profit effects. We find that the welfare effects of subsidized insurance programs are dramatically modified once we recognize the risk sharing properties of these programs. These findings are robust to many methodological assumptions. By contrast, the welfare effects of previous fixed direct payments remain independent of the risk attitude of farm households.

Our analysis relies on many data and modelling assumptions that prevent us from being definitive on the absolute efficiency of subsidized insurance programs. In particular, we do not include the various risk management strategies that the farm households can develop with other economic agents (futures or marketing contracts), on the farm (crop diversification) or off of the farm (off-farm employment), or over time (investment and saving decisions) or that the farm households can expect (disaster payments). Doing so requires the measurement of their relative costs and benefits in terms of risk sharing. We also do not include other potential market failures, such as informational issues or non-market environmental effects. In this paper, we focus on the prominent subsidized insurance programs that are extensively debated and relatively well documented. We emphasize that general equilibrium analyses of crop insurance programs and other risk management policy must always recognize their risk sharing property.

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