Was Sandmo Right?
Experimental Evidence on Attitudes to Price Risk and Ambiguity

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Abstract

In his seminal 1971 article, Sandmo showed that when faced with an uncertain output price, a risk-averse firm manager would hedge by producing less than he would have when faced with a certain output price. We take Sandmo's prediction, among other things, to the lab. We study in turn the effects of price risk (i.e., uncertain prices whose distribution is known) and price ambiguity (i.e., uncertain prices whose distribution is not known, but whose range is known) while controlling for our subjects' income risk preferences. Our experimental protocol closely mimics Sandmo's theoretical model. For price risk, we use a two-stage randomization strategy aimed first at studying the effect of price uncertainty relative to price certainty, and then the effect of increases in price uncertainty conditional on there being price uncertainty. For price ambiguity, we use the same randomization strategy to study the effect of price ambiguity relative to price certainty while preventing our subjects from guessing the shape of the price distribution. For price risk, we find that, in stark contradiction to Sandmo's theoretical result, the presence of price uncertainty causes subjects to produce more than they do under price certainty, but that increases in price uncertainty makes them decrease their production monotonically. For price ambiguity, results are mixed and depend on whether the portion of the experiment aimed at eliciting our subjects' income risk aversion is played before or after the price uncertainty game. Lastly, we use our price risk data to study the problem structurally, in order to get at preference heterogeneity, and find that our structural results are consistent with our reduced-form results.

1 Introduction

How do producers adjust their production in response to output price uncertainty?[1] In his seminal article on producer behavior in the face of price uncertainty, Sandmo (1971) answered this question by showing that in order to hedge against output price risk, an income risk-averse producer will respond to the presence of output price uncertainty by producing less than he would under output price certainty.[2]

In this paper, we use experimental methods to study how individual producers behave in the face of output price uncertainty. Specifically, we study how individuals who are put in the role of firm managers make production decisions in the presence of two different kinds of output price uncertainty. The first is output price *risk*, or an uncertain output price whose distribution is known; the second is output price *ambiguity*, or an uncertain output price whose distribution is unknown but whose range is known.

In the output price risk treatment, we use a two-stage randomized design to first determine whether producers face a certain or an uncertain output price and then, conditional on facing an uncertain price, to determine how much uncertainty they face. This allows studying the effect of output price risk at the extensive and intensive margins, i.e., the effect of output price risk relative to output price certainty, and the effect of more relative to less output price risk. In this output price risk treatment, we show experimental

[1]We use "uncertainty" to refer to both risk and ambiguity. When referring specifically to either of those concepts, we will refer to "risk" or "uncertainty." In order to minimize confusion, we will not be referring to ambiguity as "Knightian uncertainty."

[2]We differentiate between income risk aversion, or risk aversion over income gambles, and price risk aversion, or risk aversion over price gambles.

subjects the distribution from which we draw the *ex post* output price, *ex ante* of which they must make their production decision. Thus, in cases where price is risky, experimental subjects have to choose how much to produce before the realization of output price uncertainty, knowing both the mean and the standard deviation of the price distribution from which the price will be drawn.

In the output price ambiguity treatment, we use the same two-stage randomized design to first determine whether producers face a certain or an uncertain output price and then, conditional on facing an uncertain output price, to determine how much uncertainty they face. The difference in this case relative to the price risk case is that we do not show experimental subjects the distribution from which we draw the price from, but only tell them the range of possible prices. This allows studying the effect of output price ambiguity while preventing experimental subjects from eventually guessing the shape of the (uncertain) distribution we draw each price from, Thus, in cases where price is ambiguous, experimental subjects have to choose how much to produce before the realization of output price uncertainty, knowing neither the mean nor the standard deviation of the price distribution from which we draw, but knowing the range of that distribution.

Our two-stage randomization in the output price risk treatment allows testing (i) whether the move from a certain to a risky output price causes producers to hedge by decreasing how much they produce, as Sandmo (1971) famously predicted, and (ii) conditional on facing a risky output price, whether increases in output price risk cause producers to decrease how much they produce even more. Likewise, our two-stage randomization in the ambiguity treatment allows testing whether the move from a certain to an ambiguous output price causes producers to hedge by decreasing how much they produce and, if so, whether their response to output price ambiguity differs from their response to output price risk. In order to make sure that we are studying how experimental subjects respond to price rather than income uncertainty, we control for their income risk preferences throughout by controlling for our subjects' response in the Holt-Laury (2002) lottery game. Lastly, in order to eliminate potential order effects, we run two versions of each of our output price risk and ambiguity treatments, viz. one in which subjects play the output price uncertainty game first and the Holt-Laury income risk lottery second, and one in which subjects played the Holt-Laury income risk lottery first and the output price uncertainty game second.

This paper is most closely related to recent work by Bellemare, Barrett, and Just (2013), who build on theoretical studies by Sandmo (1971), Turnovsky et al. (1980), and Finkelshtain and Chalfant (1991), who respectively studied the behavior of producers, consumers, and agricultural households in the face of price uncertainty,[3] to study empirically the impacts of price risk on the welfare of Ethiopian agriculutral households, who can both produce and consume a number of commodities. In their study, Bellemare, Barrett, and Just conclude that the average rural Ethiopian household is price risk-averse, and would be willing to pay about 20 percent of its income to stabilize the prices of the seven most important commodities in rural Ethiopia—i.e., to set the levels of those commodities' prices equal to their

[3]Agricultural households are distinct from producers and consumers in that they can both produce and consume the same commodities. See Singh, Squire, and Strauss (1986) or Bardhan and Udry (1999) for introductory treatments.

mean, and set their variances equal to zero.

The problem with Bellemare, Barrett, and Just's study, however, is that it relied on observational data, which are noisy and do not lend themselves to the credible causal identification, as well as on a structural approach that requires a number of strong assumptions.[4]

The contribution of this paper is threefold. First and foremost, we conduct the first experimental test of Sandmo's (1971) prediction that the presence of output price risk causes producers to hedge by decreasing the quantity they produce, i.e., we test the effect of output price risk at the extensive margin. Second, conditional on there being output price risk, we study how producers respond to increases in output price risk by studying the effect of mean-preserving spreads of the price risk distribution, i.e., how they respond to output price risk at the intensive margin, something on which Sandmo remained agnostic. Finally, we study the behavior of producers in the face of output price ambiguity. To our knowledge, this is the first study of output price ambiguity, experimental or otherwise.

Our experimental findings are striking. First, we reject Sandmo's theoretical prediction that, relative to situations of output price certainty, situations of output price risk will cause producers to reduce how much they produce in order to hedge against price risk. In fact, we find the contrary: When going from a situation where output price is known with certainty to

[4]McBride (2015) shows that when one of those assumptions is changed, Bellemare, Barrett, and Just's (2013) qualitative finding that household willingness to pay to stabilize prices is increasing in household income is overturned. Bellemare, Barrett, and Just (2015) identify a number of other cases where changing one of their assumptions might change their findings. In the second half of this article, we apply our experimental data to Bellemare, Barrett, and Just's (2013) approach, finding that it generates predictions consistent with our reduced-form results.

a situation where that same output price is uncertain but whose distribution is known, experimental subjects respond by *in*creasing how much they produce. Second, we find that conditional on output price being risky, increases in output price risk cause experimental subjects to decrease how much they produce. Finally, we find that the presence of output price ambiguity—i.e., an uncertain price whose distribution is unknown—causes experimental subjects to respond by either decreasing or increasing their quantity produced depending on whether the Holt-Laury lottery aimed at eliciting their income risk preferences is played before or after our price risk game, or perhaps as a result of overconfidence.

The remainder of this paper is organized as follows. Section 2 lays out the theoretical framework we use to guide our experiments. In section 3, we present the experimental protocol we developed to mirror the theoretical framework in section 2 and to elicit producer price risk and ambiguity preferences in the laboratory. Section 4 discusses our experimental subjects and presents the relevant descriptive statistics. In section 5, we discuss our empirical framework. Section 6 presents and discusses our experimental results, along with their limitations. We conclude in section 7 by discussing the potential policy implications of our work and directions for future research.

2 Theoretical Framework

Because we focus on testing Sandmo's (1971) original claim that the presence of (output) price uncertainty causes firm managers to hedge by producing a smaller quantity of output than they would in the case where output price is certain, we reproduce here Sandmo's original theoretical framework.

Suppose that a firm manager's utility $u(\cdot)$ is defined over profit π, such that $u(\pi)$. Profit is such that $\pi = px - c(x) - F$, where output price $p > 0$ is uncertain, such that $E(p) = \mu$, and $\mathrm{Var}(p) > 0$, and where $x > 0$ is the firm manager's choice of output, $c(x)$ is an increasing and convex function representing the firm's variable costs (i.e., $c'(x) > 0$ and $c''(x) > 0$), and F is a constant representing the firm's fixed costs.

The firm manager's objective is to maximize the utility he derives from his firm's profit by choosing how much to produce *ex ante* of the realization of the uncertain output price p. That is, the firm manager solves

$$\max_x E\left\{u(px - c(x) - F)\right\}, \tag{1}$$

The first-order necessary and second-order sufficient conditions are such that

$$E\{u'(\pi)(p - c'(x))\} = 0, \tag{2}$$

and

$$E\{u''(\pi)(p - c'(x))^2 - u'(\pi)c''(x)\} < 0 \tag{3}$$

Given the foregoing, we can establish the following result.

Theorem 1 (Sandmo, 1971) *Under the assumptions made so far, the presence of output price uncertainty causes an income risk-averse firm manager to underproduce relative to the case where output price is certain and* *equal to the mean of the price distribution.*

Proof. Equation 2 can be rewritten as

$$E\{u'(\pi)p\} = E\{u'(\pi)c'(x)\}. \tag{4}$$

Subtracting $E\{u'(\pi)\mu\}$ from both sides of equation 4 yields

$$E\{u'(\pi)(p - \mu)\} = E\{u'(\pi)(c'(x) - \mu)\}. \tag{5}$$

Expected profit $E(\pi) = \mu x - c(x) - F$, which can be rearranged to express profit as a function of expected profit and the difference between expected and realized prices such that $\pi = E(\pi) + (p - \mu)x$. Intuitively, this means that the difference between expected and realized profit is only due to the difference between the *ex post* realization of the stochastic output price p and the firm manager's expectation μ of that price.

The firm manager takes his decision on the basis of his expectation of what price will look like *ex post*; if that expectation is right, i.e., if $\mu = p$, then $E(\pi) = \pi$. But if $\mu \neq p$, there will be a discrepancy between expected and realized profit.

It follows from the foregoing that $u'(\pi) \leq u'(E(\pi))$ if $p > \mu$, so

$$u'(\pi)(p - \mu) \leq u'(E(\pi))(p - \mu), \tag{6}$$

an equality which holds for all values of p. Taking the expectations on both sides of equation 6 implies

$$E\left\{u'(\pi)(p-\mu)\right\} \leq u'(E(\pi))E(p-\mu), \tag{7}$$

where the right-hand side is equal to zero given that $E(p-\mu)=E(p)-\mu$, and $E(p)=\mu$, which means that the left-hand side is negative. This in turn means that $E\{u'(\pi)(c'(x)-\mu)\} \leq 0$, which means that $c'(x)<\mu$, or the firm manager's marginal cost of producing x is less than his marginal benefit of doing so. In other words, the firm manager produces less than he would when output price is certain, which establishes the result. ■

The result in Theorem 1 is what we are primarily interested in testing in this paper, but we also explore what happens when we take mean-preserving spreads of the price distribution, i.e., when $\mathrm{Var}(p)$ increases and $E(p)=\mu$ is held constant. Indeed, Sandmo (1971) remained agnostic about the effect of mean-preserving spreads, which he referred to as "stretches" of the price distribution. The next section discusses the experimental protocol we developed in order to mirror in the laboratory the theoretical conditions in Sandmo's article.

3 Experimental Design

We design and conduct two experimental treatments, which consist in output price (i) risk and (ii) ambiguity treatments. The former is designed to experimentally test Theorem 1 above (i.e., whether the introduction of price risk leads to a decrease in output) as well as the effect of mean-preserving spreads on a producer's choice of output. The latter is designed to identify the effect of output price ambiguity a producer's choice of output.

3.1 Risk Treatment

The risk treatment consists of two sets of games: (i) the output price risk game, which we describe below, and wherein the treatment consists of the introduction of output price risk in some of the rounds but not in others, and (ii) the Holt-Laury lottery game, where the treatment consists of income risk. By conducting both sets of games for each subject, we aim to control for the effect of income risk-aversion so as to isolate the effect of output price risk on output choice.

In the output price risk game, each subject assumes the role of the manager of a firm (or producer) producing a single commodity. To focus on the effect of output *price* risk, we assume away all uncertainty in production (e.g., uncertainty due to weather uncertainty, technological shocks, etc.)

We have chosen simple cost and profit functions with conditions that closely mimic those assumed in Sandmo (1971). We assume that fixed cost $F = 15$ and the variable cost function $c(x) = 2x^{1.4}$, which is an increasing and convex function of output. Accordingly, the profit function $\pi = px - 2x^{1.4} - 15$ is a concave function of output. Subjects' monetary reward from the price risk game is directly linked to the level of profits that they make in the game.

The level of output x that a subject can choose ranges from 0 to 20 and is expressed in thousands of units. It must be determined *ex ante* of the realization of output price. Once experimental subjects have made their production decisions, the price per unit is realized and is one of five values in the $5, 6, ..., 9$ set.

To facilitate decision-making, subjects are given charts that describe the relationship between output level, price, cost, and profit, along with graphs of the profit function under each of the five different possible prices in the $5, 6, ..., 9$ set. A combined chart summarizing the relationship between output and profit under all five price scenarios is also provided to facilitate comparisons and, ultimately, decision-making. Figure 1 shows the charts for the price scenario of \$5 per unit and the combined chart for all the price scenarios that subjects are provided with. See Appendix 1 for all charts and graphs shown to experimental subjects.

To determine the price of the output in each round, we follow the two-stage randomization strategy discussed above and depicted in Figure 2. This process is done publicly during each experimental session by showing experimental subjects the spreadsheet used to randomize the presence of price uncertainty and, conditional on there being price uncertainty, the price drawn from a bag filled with ping-pong balls marked with prices. Moreover, subject are told explicitly that there are no strategic considerations, i.e., their profit is not dependent on the behavior or profit of other experimental subjects.

In stage 1, we determine the extensive margin of the price uncertainty, i.e., whether there is any price uncertainty. In one third of the cases, subjects are presented with a certain price of \$7 per unit, which is the mean of the five possible prices. We refer to this as experimental setting 1. In two thirds of the cases, subjects are presented with an uncertain price. Conditional on facing an uncertain price, in stage two, we determine the level of price risk is determined by randomly selecting one of four price distributions—we refer to those as experimental settings 2 to 5—which are all mean-preserving spreads of one another.[5] This two-stage randomization strategy allows disentangling the effect of price risk relative to price certainty (i.e., the extensive price risk margin) on output choice and, conditional on there being price risk, the effect of an increase in the level of price risk (i.e., the intensive price risk margin) on output choice.

An objection to the above design could be that the mean of the price distribution as well as the price drawn in certainty cases, which was always equal to 7, should also have been randomized. We chose to keep the mean across all settings as well as the certainty price at 7 in order to study the effect of mean-preserving spreads. With that said, we encourage future researchers to explore what happens when both the mean and standard deviation of the price distribution are both assigned at random.

In each round, once we determined the setting from the two-stage randomization process, subjects were shown the shape of the price distribution of the corresponding setting in the form of histograms depicting a bag containing 20 ping-pong balls marked with prices. The slide shown for setting 1 (certainty case) and the slides for settings 2 to 5 (uncertainty cases) are shown in Figure 3. In any given round, all subjects receive the same treatment. In other words, there is no between-subject, within-round variation, and all of the variation in treatment here is between rounds and within subject. Though it would have been possible to design an experiment where

[5] In all settings, the mean value of the prices is \$7. In setting 1 (price certainty), the standard deviation of the price distribution is zero. In settings 2 to 5, the standard deviation is respectively 0.8, 1.17, 1.45, and 1.58.

price varies both between subjects within each round and within subject between rounds, this would have made the experiment more costly to implement, and it would not have added much to our understanding given the lack of strategic considerations and general equilibrium effects here. Furthermore, it turns out that the current design gives us enough statistical power to draw inferences.

Subjects choose how much to produce in each round *ex ante* of the realization of price uncertainty by looking at the picture of a chosen price distribution and the charts they are given. Once all subjects have recorded their output choice, we draw a ball from the bag with the corresponding setting to determine the *ex post* price and, for each subject, profit before moving on to the next round.

Subjects played 10 practice rounds and 20 actual rounds of this price game.[6] Profits from the actual rounds were mapped into a monetary reward function. We randomly chose one of the 20 actual rounds for each subject using a 20-sided die thrown by the subject herself in order to determine which round we would base that subject's experimental payout on. The experimental payoff from the production game was determined by adding a $25-base payoff plus a half of the subject's profit in the randomly selected price game round, her proceeds from the Holt-Laury lottery which we discuss below, and $45 payment for participation in the experiment. Because the subjects do not know *ex-ante* which of the 20 actual rounds will be chosen for the payoff, they are induced to truthfully reveal their preference in each

[6] During the practice rounds, subjects were encouraged to ask questions to ensure that they properly understood the structure of the game.

round, and it allows determining each subject's experimental payout at a considerably lower cost than if all rounds were added up.

3.2 Ambiguity Treatment

The only difference between the risk and the ambiguity sessions is that in the ambiguity session, when faced with price uncertainty, subjects are not shown the distribution of prices.

The same two-stage randomization strategy is applied again in the ambiguity treatment. In one third of the rounds, subjects are presented with a certain price of $7 per unit, i.e., setting 1. In two thirds of the rounds, subjects are presented with a range of possible prices—the only information given to the subjects is that the price can be one of five values of $5, $6, $7, $8, or $9 per unit. Unlike in the risk treatment, no picture of the price distribution is shown. In step two, conditional on facing an uncertain price, we draw a ping-pong ball from one of the four price distributions, i.e., settings 2 to 5, which are not shown to the subjects. In each round, subjects have to make their production decision *ex ante* of the resolution of price uncertainty.

Proceeding this way allows us to accomplish two things. Recall that Sandmo (1971) assumes that the distribution of prices is known to producers (i.e., the producers are faced with output price risk instead of price ambiguity, although Sandmo does allow price risk to be subjective, albeit known) and does not say anything about price ambiguity. The first stage of randomization allows studying the effect of output price risk ambiguity relative to price certainty. The second stage of randomization allows preventing experimental subjects from guessing the shape of the price distribution. Indeed, had we drawn from a single (ambiguous) setting in uncertainty cases, subjects would have managed to get a good idea of what that setting's distribution looked like given 10 practice rounds and 20 actual rounds. In other words, the second stage of randomization is necessary here in order to keep subjects from guessing the true price distribution, and thus maintain a state of ambiguity over prices.

3.3 Holt-Laury Income Risk Lottery Game

Along with the price game (before the price game for half of our subjects, and after the price game for the other half), experimental subjects play the lottery game developed by Holt-Laury (2002). The list of choices used in the Holt-Laury game is shown in Appendix 2. We do this to make sure that our findings are not driven by income risk preferences, i.e., to isolate the effect of price risk preferences. In the Holt-Laury game, subjects are provided with a list with ten rows. Each row contains two options, A and B, which are different specifications of a lottery. Option A is always less risky than option B. The expected value of the payoff starts higher for option A than for option B in the top row, but the difference between the two decreases as the row number increases.

Subjects choose which option to take starting from the top row. The game is designed so that most subjects will eventually switch from A to B, and switching to B at a higher row number means that a subject is more (income) risk-averse. Once a subject switches to B, the game ends. In other words, in order to make sure that our setup satisfies the axioms of expected utility theory, we enforced monotonic switching. This is common practice in these types of games (see, for example, Liu, 2013).

To determine the payoff in the Holt-Laury lottery game, each subject rolled a 10-sided die twice: once to randomly select a row number in order to determine which specification of the lotteries A or B we would base that subject's experimental payout on, and then to play the chosen lottery in that specification to determine the subject's payoff for this part of the experiment. The monetary payoff in this case was identical to the dollar amount shown in the table.

3.4 Order of Games

We conducted a total of four experimental sessions, two in December 2014 (one risk session, and one ambiguity session) and another two in March 2015 (again, one risk session, and one ambiguity session). Experimental subjects were different for each session, i.e., a person could not take part in any of these sessions more than once. In both the risk and ambiguity sessions, each experimental subject played two sets of games—the price game and the Holt-Laury income risk game. In both the December 2014 sessions, subjects played the price game first and then played the Holt-Laury game. In order to control for potential effects, if any, of the order in which the price uncertainty and Holt-Laury income risk games were played, we switched the order of the games for the two March sessions so that the subjects played the Holt-Laury income risk game first. By doing so, we can examine whether switching the order of games changes our risk and ambiguity findings. Indeed, it is not unlikely that "priming" respondents by having them think about one type of risk before the other might affect their behavior.

4 Data and Descriptive Statistics

The experiments for this paper were conducted at Cornell University's Lab for Experimental Economics and Decision Research (LEEDR), which does not allow researchers to use deception in their experiments. We conducted four experimental sessions: two in December 2014, and two in March 2015. In each of December and March, we conducted one price risk session, and one price ambiguity session, and the Holt-Laury lottery game was played in each of all four sessions. As was discussed above, the only difference between the December 2014 and March 2015 sessions is that in December, the Holt-Laury lottery game was played after the price games, and in March, the Holt-Laury game was played before the price games.

Our experimental subjects were undergraduate students at Cornell University. We recruited 24 subjects per session for a total of 96 subjects. Subjects were recruited online via an announcement on the LEEDR listserv. The online recruitment process used by LEEDR did not allow one person to sign up for more than one experimental session.

For the price games, each subject played 10 practice rounds of the risk or ambiguity game played in that session, followed by 20 actual rounds. The actual rounds generates 480 subject-round observations per session, or 960 subject-round observations for the price risk part of our study, and 960 subject-round observations for the price ambiguity part of it.

After we were done with the experiment, we asked subjects to fill out a demographic information sheet recording their age, gender, ethnicity, and nationality. In some sessions, we lost an individual (i.e., 20 actual subject-round observations) because some subjects forgot or refused to fill out their demographic information sheet.

Tables 1 and 2 respectively present summary statistics for the December 2014 and March 2015 price risk sessions. Similarly, tables 3 and 4 respectively present summary statistics for the December 2014 and March 2015 price ambiguity sessions. In all four sessions, the mean price drawn does not differ significantly from the mean price of 7 in all distributions, nor does the mean output chosen differ significantly from 10, the profit-maximizing output choice when the price is equal to 7. In three out of four sessions, subjects face an uncertain—that is, risky or ambiguous—output price in about two thirds of cases, as one would expect given our randomization strategy, but in the March ambiguity session, subjects faced an uncertain output price in 90 percent of cases. Mean profit was similar in both price risk sessions, but it differed sharply between the December and March ambiguity sessions. Subjects are remarkably consistent in how income risk-averse they are: across all four sessions, the Holt-Laury switch point is not significantly different from 7. Because they are used as controls, and thus are not of primary interest, we present but do not discuss demographic controls. Figures 4 and 5 depicts the histogram of output choice under uncertainty in risk session and ambiguity session, respectively. In Figure 4, the shape of the distribution of output choice under price risk treatment do not look much different in December and March. However, in Figure 5, under price ambiguity treatment, we see much more dispersion in the choice of output level. We will revisit the results of the ambiguity treatment in the discussion of our experimental results.

5 Empirical Framework

For the price risk games, we estimate the following equation:

$$y_{1it} = \alpha_1 + \beta_1 I(\sigma_t > 0) + \gamma_1 \sigma_t + \delta_1 r_i + \tau_1 t_t + \theta_1 x_i + \nu_{1i} + \epsilon_{1it}, \tag{8}$$

where the subscript 1 denotes the equation of interest for price risk, y_{1it} denotes the subject i's output choice in round $t \in \{1, ..., 20\}$, $I(\sigma_t > 0)$ is an indicator variable equal to one if subjects have to make their output choice in the face of price risk and equal to zero otherwise, σ_t denotes the standard deviation of the price distribution used in round t, r_i denotes subject i's switch point in the Holt-Laury lottery game, x_i is a vector of demographic controls specific to subject i, ν_{1i} is a random effect specific to subject i, and ϵ_{1it} is an error term with mean zero.

For the price ambiguity games, we estimate the following equation:

$$y_{2it} = \alpha_2 + \beta_2 I(\sigma_t > 0) + \delta_2 r_i + \tau_2 t_t + \theta_2 x_i + \nu_{2i} + \epsilon_{2it}, \tag{9}$$

where the subscript 2 denotes the equation of interest for price ambiguity, and the variables on the right-hand side denote the same things as in the equation of interest for price risk.

Although the dependent variable in equations 8 and 9 is a nonnegative integer and thus lends itself in principle to the estimation of count data models such as Poisson or negative binomial regressions, we estimate both equations via ordinary least squares. We do so because in likelihood-based procedures like Poisson or negative binomial regressions, there is a slight possibility that a coefficient is identified off of the specific functional form imposed on the error term. Though this is less of an issue with the estimated coefficients for those variable which we assign experimentally—that is, for β_1, γ_1, and β_2—it could be an issue for those variables which are not randomly assigned by us. Moreover, the coefficients from a least squares regression are directly interpretable as marginal effects. That being said, we did estimate Poisson specifications of equations 8 and 9 (not shown, but available upon request) as part of preliminary work for this paper and found that their results were almost identical to our core least squares results.

Lastly, there remains to discuss the use of random over fixed effects. Here, we estimate random effects regressions because when considering fixed versus random effects, the latter are superior to the former with experimental data given that the variables of interest are clearly orthogonal to the error term and because the fixed effects estimator is inefficient. That being said, we did estimate fixed effects specifications of equations 8 and 9 (not shown, but available upon request) as part of preliminary work for this paper and found that their results were almost identical to our core random effects results.

6 Experimental Results and Discussion

We present two types of result. First, we present reduced-form regression results for each of our price risk and price ambiguity treatments, i.e., estimation results for equations 8 and 9 above. For both the price risk and price ambiguity treatments, we present three sets of results, viz. results for the December 2014 session, results for the March 2015 session, and pooled results for both sessions with an indicator variable controlling for whether the Holt-Laury lottery game was played first, before the price game.

Second, we present structural evidence by using our data to estimate a marketable surplus regression similar to those estimated by Bellemare, Barrett, and Just (2013). We then use the information from that marketable surplus regression to construct, for each subject-round, a price risk aversion coefficient, which we then use to predict how our subjects should behave in the face of price risk. We conclude this section by a necessary discussion of the limitations of our results.

6.1 Reduced-Form Evidence

Recall that in the price risk treatment, subjects were shown the picture of the price distribution from which the price is drawn in each round. In the price ambiguity treatment, no picture was shown to subjects when the price was uncertain, and the only information given was the possible price range, i.e., [5, 9]. Below, we present results for each treatment in turn.

6.1.1 Effect of Price Risk on Output Choice

Tables 5 and 6 display the random effects regression results from estimating equation 8, using the data from the price risk treatment sessions in December 2014 and March 2015, respectively. Table 7 presents the results from pooling the data from both December and March experiments.

Both the December and the March results indicate that going from price certainty to price uncertainty induces subjects to *increase* their choice of output, and the effect is highly significant. Sandmo's only sharp prediction was that price risk (i.e., price uncertainty of a known shape) would make producers hedge by cutting back on how much they produce. Based on our results, we reject that hypothesis.

Conditional on facing an uncertain price, however, subjects *decrease* their level of output as the degree of uncertainty (i.e., the standard deviation of the price distribution) increases, and this result is of the same sign and significance in both the December and March experiments. Moreover, the relationship is monotonic: Table 8 displays mean output choice according to the varying level of standard deviation of prices associated with experimental settings 1 through 5. We see a jump in mean output choice from the certainty optimum level of 10 to 10.9 as we move from price certainty to setting 2 (where standard deviation is 0.8). Higher settings (i.e., higher standard deviations of the price distribution), however, monotonically reduce output choice. When the standard deviation is 1.58, the mean output choice becomes less than the certainty optimum of 10. Therefore, being exposed to price uncertainty while knowing the distribution of prices makes subjects choose a higher level of output, but there appears to be a certain threshold degree of price risk (in this experiment, the threshold lies in the range [1.45, 1.58]) that eventually induces subjects to cut back below the certainty optimum level of output.

We control for income risk-aversion by incorporating the Holt-Laury income risk lottery game. We also find that there is a negative and significant relationship between one's Holt-Laury switch point and one's output choice in the December experiment, where the price risk game was played before the Holt-Laury game. In other words, being more income risk-averse (via a higher Holt-Laury switch point) is associated with a decrease in output choice. In the March experiment, where the Holt-Laury game was before the price game, income risk aversion is no longer significant. When pooling the data from December and March, however, the association between one's Holt-Laury switch point and one's output choice is again significant. Given that the Holt-Laury switch point cannot be given a causal interpretation, this is merely suggestive of the fact that increases in income risk aversion might cause subjects to hedge against price risk. Intuitively, this makes sense, given that a subject's income is determined by the price level.

We see no evidence of learning effects, as the coefficient on round is statistically insignificant. Although we find no evidence of learning effects, we do find some effect of the result from the rounds that are immediately previous to the current rounds (not shown, but available upon request). Indeed, subjects tended to produce significantly more (less) when they experienced a loss (gain) in the previous round. This is consistent with Kahneman and Tversky's (1979) experimental results, whose subjects were risk-loving over losses and risk-averse over gains.

A colleague noted that, in order to truly test Sandmo's prediction that risk-averse individuals respond to price risk by hedging, we need to interact our uncertainty dummy with the Holt-Laury switch point. Even when doing so, there is remains a slight difference between what the regression is estimating and Sandmo's prediction—Sandmo is *assuming* an (income) risk-averse firm manager, so risk-aversion towards income is *given* as an assumption, whereas by interacting the two variables (i.e., uncertainty dummy and Holt-Laury switch point), what we are truly testing is how increases in income risk aversion in the presence of price uncertainty affect the level of production.

Given that we cannot rule out the possibility that some of the subjects are risk-neutral or risk-loving, it is not possible to test Sandmo's prediction completely. Taking the Holt-Laury results at face value, however, our key results (i.e., a positive effect of uncertainty and a negative effect of an increase in standard deviation) are preserved when we restrict our subjects to those who are income risk-averse, i.e., those whose Holt-Laury switch point is greater than 4.[7] Results do not change when we restrict our analysis to subjects with Holt-Laury switch points greater than 5, 6, 7, and so on.

Another colleague pointed out that the positive effect of price uncertainty that we observe maybe due to a "house money" effect—an increased risk-seeking behavior due to a prior gain, defined by Thaler and Johnson (1990)—or an endowment effect due to the $45 given to our subjects for showing up

[7] According to Holt-Laury (2002), subjects who switch from option A to B in row 1 through 3 are classified as (income) risk-loving, subjects who switch in row 4 are risk-neutral, and subjects who switch in row 5 or higher are risk-averse.

regardless of their performance in the games. If there were truly a house money effect in this case, however, we would expect our subjects to be risk-seeking across the board as we increase the standard deviation of the price distribution, and not just for the switch from price certainty to price uncertainty. We actually observe the opposite result. Also, if there were a house money effect, a gain in the previous round might also increase the risk-taking by inducing subjects to produce more, but here too we find the contrary.

6.1.2 Effect of Price Ambiguity on Output Choice

Tables 9 and 10 display the random effects regression results from estimating equation 9, using the data from the price ambiguity treatment sessions in December 2014 and March 2015, respectively. Table 11 presents the results from pooling the data from both December and March ambiguity experiments.

We get mixed results, depending on whether subjects play the Holt-Laury income risk game before or after the price game. When they play the Holt-Laury game after the price game, price ambiguity makes subjects hedge against uncertainty by producing less than they otherwise would under price certainty. When they play the Holt-Laury income risk game before the price game, price ambiguity makes them speculate over uncertainty by producing more than they otherwise would. These opposite effects explain why, in the pooled results, we find no significant effect of price ambiguity and a positive and significant effect for whether the Holt-Laury game is played first. We conclude from these results that playing the Holt-Laury game before the price ambiguity game might "prime" our subject by making them think about their risk preferences, and pushes them to be price risk-loving.

We also find that when the Holt-Laury game is played after the price ambiguity treatment, income risk-aversion (i.e., the Holt-Laury switch point) has no significant effect on the level of output. When the Holt-Laury game is played first, however, subjects who displayed higher degree income risk-aversion chose significantly lower levels of output. This is similar to what we found in the price risk case.

These results suggest that, in the ambiguity treatment where the price distribution is unknown (beyond its range), the order in which we present games, and thus the order in which we force subjects to think about price uncertainty and income uncertainty, significantly alters the finding. This is unlike the price risk treatment experiments, where the order of the games did not change the results.

Another possible reason for the conflicting results is the high price draws during the March ambiguity session. Figure 6 depicts a histogram of the prices drawn in 10 practice and 20 real rounds for December (top) and March (bottom). Although the mean price drawn in December and March are significantly different from \$7 in both December and March sessions, we did draw much higher prices in the March experiment. Also, \$5—the lowest possible price—was never drawn during the March session. The difference in the prices drawn is striking in figure 7 which depicts only the prices drawn during the practice rounds in December (top) and March (bottom). During the practice session in December, no high prices (\$8 or \$9) were drawn. During the practice session in March, no low prices (\$5 or \$6) were drawn.

Given that the subjects were unaware of the shape of the price distributions in the ambiguity treatment, high draws of prices in March may have made them be more optimistic about the prices, and thus caused them produce more on average, given the incentive structure of the experiment.

This is not unrelated to the learning effect we find evidence of. Unlike in the risk treatment, we do find evidence of significant learning effects of learning in the ambiguity treatment. In December, subjects tended to produce less as the game proceeded. In March, they tended to produce more as the game proceeded. This suggests two things. First, when subjects do not have any information besides the possible range of prices, they rely on past realization of prices when forming their expectations one way or the other. Second, depending on whether the past realization of prices are relatively high or low, subjects adjust to produce more or less.

Along with the learning effects we find evidence of, we also find some effects of the result from the rounds immediately previous to the current rounds (not shown, but available upon request from the authors). Price and profit in the previous round do have an impact on output choice in current round. As profit or price in the previous round increases, subject tend to produce more, implying some kind of overconfidence effect. When both are included, neither are significant. Also, in stark contradiction with our risk findings, we find that subjects tended to produce significantly more (less) when they experienced a gain (loss) in the previous round, i.e., the opposite of what a prospect-theoretic framework would predict.

Unlike in the risk treatment sessions, we cannot rule out a house money effect in the ambiguity treatment where subjects have very limited information on the data generating process. The fact that the subjects have earned some money from playing the Holt-Laury game first (although the actual payment took place after all games were played and the experiment was concluded) may have caused them to speculate over the price ambiguity with the money earned in the price risk game. We do find some evidence of a house money effect, as gains from previous rounds made subjects to produce more.

6.2 Structural Evidence

The reduced-form findings just discussed are interesting in and of themselves, but we can go one step further with the data we generated as part of our price risk sessions by estimating the coefficient of price risk aversion developed by Barrett (1996) for the single-commodity case and expanded to the case of multiple commodities by Bellemare, Barrett, and Just (2013).

From Barrett (1996), we know that in the single-commodity case, an individual i's coefficient of price risk aversion in round t, A_{it}, is such that

$$A_{it} = -\frac{x_{it}}{p_t}[\beta_{it}(\eta - R_i) + \epsilon], \tag{10}$$

where M denotes individual i's marketable surplus, i.e., how much she produces in round t; p denotes the price drawn in round t, β denotes individual i's budget share of marketable surplus in round t, i.e., the value of her marketable surplus divided by her income if that round were to be chosen as the paying round; η is the income elasticity of marketable surplus; R_i is individual i's Arrow-Pratt coefficient of relative risk aversion; and ϵ is the price elasticity of marketable surplus.

As it turns out, all those components of equation 10 are either available in, computable from, or estimable from our experimental data. Specifically:

1. x_{it} is a subject's output choice in each round.

2. p_t is the price drawn at random in each round.

3. β_{it} is computed by multiplying the previous two variables to obtain the value of subject i's marketable surplus in round t and dividing that value by subject i's income if round t were chosen as the round on which that subject's compensation is based.

4. η is estimable from a regression of marketable surplus on income and other variables.

5. R can be determined from the results of the Holt-Laury lottery game if a functional form assumption is made for $u(\cdot)$. Here, we follow Holt and Laury (2002) in assuming that $u(\pi) = \frac{\pi^{1-r}}{1-r}$, and by using the values of a subject's coefficient of relative risk-aversion in table 3 of Holt and Laury.

6. ϵ is estimable from a regression of marketable surplus on price and other variables.

Specifically, the marketable surplus regression from which η and ϵ are obtained is such that

$$\ln M_{it} = \alpha + \epsilon \ln p_t + \eta \ln m_{it} + \tau t + \delta d_i + \xi_{it}, \tag{11}$$

where, in a slight abuse of notation, and as in Bellemare, Barrett, and Just (2013), $\ln(\cdot)$ denotes an inverse hyperbolic sine transformation of a variable, a log-like transformation commonly used in applied microeconomics, and which allows keeping zero-valued and negative observations, M denotes marketable surplus (i.e., output choice), p denotes the price drawn, m denotes the subject's income in the current round, t denotes the round, d is a vector of subject-specific fixed effects, and ξ is an error term with mean zero.

Equation 11 is estimated by ordinary least squares, and those results can be found in table 12. From those results, we note that for a 1 percent increase in price, there is an associated increase in output of 1.15 percent, i.e., supply is relatively price-elastic. Likewise, for a 1 percent increase in income, there is an associated 1.2 percent decrease in output.

We use the results in table 12 to calculate A above. Then, following the derivations in Bellemare, Barrett, and Just (2013), we multiply each A_{it} by $0.5 \times \sigma_t$ in order to recover the willingness to pay (WTP) of individual i to stabilize the price (i.e., set it equal to its mean of 7 and set its standard deviation equal to zero) in round t. Figures 8 and 9 plot kernel density estimates of both our subjects' coefficients of price risk aversion as well as their WTP to stabilize prices.

The average WTP is $-\$0.16$, i.e., the average subject-round would require to be given \$0.16 in order to be compensated for the disutility incurred by price stabilization (i.e., the average subject-round is estimated to be price risk-loving), and WTP ranges from $-\$1.77$ to \$1.03. Note that, in absolute value, those numbers are well below the average profit made by our experimental subjects in those rounds.[8] Fifty-five percent of subject-rounds (i.e., 523 out of 960) are estimated to be price risk-loving, 33 percent (i.e., 312 out of 960) to be price risk-neutral, and 13 percent (i.e., 125 out of 960) to be price risk-averse.

The bottom line is that the high proportion of estimated price risk-loving subject-rounds is consistent with our reduced-form findings. Indeed, recall that the introduction of output price risk caused the average respondent to produce *more* rather than less, in contrast with Sandmo's (1971) theoretical result. This is somewhat encouraging for the pursuit of structural work in this line of research.

6.3 Limitations

The findings above are interesting, but we should note here that our experimental protocol is only representative of cases where a firm and its manager are one and the same. For example, it is representative of sole-proprietorships in industries characterized by a high degree of price uncertainty, and of farmers, whose production environments are also characterized by a high degree of price uncertainty, especially in places where insurance programs are absent, as in most developing countries. Moreover, our experimental protocol is only representative of cases where there are no futures and options markets that might allow firm managers to insure against price risk.

Moreover, our experimental findings must be interpreted with caution,

[8] When expressed as a proportion of "income," this WTP ranges from about -6.1 to 1.8 percent of a subject-round's income.

because as with many such findings, we conducted our experiments with undergraduate students, who may or may not behave similarly to real-world firm managers faced with price uncertainty. The external validity of our results is obviously very limited, and it would be greatly improved by conducting similar experiments at a different university, or by conducting lab-in-the-field experiments, where real-world firm managers (e.g., farmers in a developing country, to mimic an environment where price is uncertain and there is no insurance) would serve as experimental subjects.

7 Summary and Conclusions

We have used experimental methods to study the behavior of producers—specifically, of firm managers—in the face of price uncertainty. Because price uncertainty can mean either price risk (i.e., price uncertainty of a known distribution) or price ambiguity (i.e., price uncertainty of an unknown distribution), we report the results of experiments aimed at eliciting output choice in the face of both output price risk or output price ambiguity.

We find that the presence of price uncertainty of a known form (i.e., price risk), as opposed to price certainty, causes experimental subjects to produce more than they do under a certain price, a finding that is in contradiction with Sandmo's (1971) prediction that the presence of price risk would cause risk-averse firm managers to produce less. Then, conditional on there being price risk, we find that increases in price risk cause subjects to reduce how much they produce. Here, we control everywhere for subjects' income risk preferences in order to isolate the effect of price risk.

Moreover, we find that the presence of uncertainty of an unknown form (i.e., price ambiguity), as opposed to price certainty, causes experimental subjects to produce less or more than they do under a certain price, depending on whether the part of the experiment aimed at eliciting their income-risk preferences comes before or after the part aimed at eliciting their behavior in the face of price uncertainty. We offer a few explanations as to why that might be the case, with one involving a kind of priming effect, and the other involving overconfidence.

Finally, we use the data from our price risk experiment to construct structural estimates of our subjects' price risk aversion coefficients, initially derived by Barrett (1996) for the one-commodity case and expanded by Bellemare, Barrett, and Just (2013) for the multiple-commodity case. We find that the average subject is slightly price risk-loving, a result that is consistent with our reduced-form results, and which is encouraging for the pursuit of structural work in this area.

Assuming for a moment that they are externally valid, our findings have interesting implications for policy. Indeed, many insurance programs for farmers are predicated on the notion that agricultural producers are price risk-averse, i.e., that the presence of price uncertainty causes them to hedge by producing less than they would under price certainty. Our reduced-form findings for price risk and for price ambiguity when the Holt-Laury game is played before the price game, however, show that the presence of price uncertainty causes subjects to choose to produce *more* than they do under price certainty, and our structural findings for price risk show that the average subject-round is price risk-loving, though there is a good amount of heterogeneity in price risk preferences. This suggest that government programs aimed at insuring agricultural producers against price uncertainty would benefit from being redesigned from a mechanism designed perspective aimed at having producers truthfully revealing their price risk preferences, in order to minimize the costs and maximize the benefits of such programs.

That being said, our results have little external validity given that our experimental subjects were American undergraduates, who may or may not behave like real-world firm managers faced with price uncertainty would. External validity would be greatly improved by conducting similar experiments at a different university, or by conducting them as lab-in-the-field experiments, where real-world firm managers (e.g., farmers in a developing country, to mimic an environment where price is uncertain and there is no insurance) would serve as experimental subjects. For now, we leave those additional experiments for future research.

References

[1] Bardhan, Pranab, and Christopher R. Udry (1999), *Development Microeconomics*, Oxford: Oxford University Press.

[2] Bellemare, Marc F., Christopher B. Barrett, and David R. Just (2013), "The Welfare Impacts of Commodity Price Volatility: Evidence from Rural Ethiopia," *American Journal of Agricultural Economics* 95: 877-899.

[3] Bellemare, Marc F., Christopher B. Barrett, and David R. Just (2015), "The Welfare Impacts of Commodity Price Volatility: Reply," Working Paper, University of Minnesota.

[4] Finkelshtain, Israel, and James Chalfant (1991), "Marketed Surplus under Risk: Do Peasants Agree with Sandmo?," *American Journal of Agricultural Economics* 73: 557–567.

[5] Holt, Charles A., and Susan K. Laury (2002), "Risk Aversion and Incentive Effects," *American Economic Review* 95: 1644-1655.

[6] Kahneman, Daniel, and Amos Tversky (1979), "Prospect Theory: An Analysis of Decision under Risk," *Econometrica* 47(2): 263-291.

[7] Liu, Elaine M. (2013), "Time to Change What to Sow: Risk Preferences and Technology Adoption Decisions of Cotton Farmers in China," *Review of Economics and Statistics* 95(4): 1386-1403.

[8] McBride, Linden E. (2015), "The Welfare Impacts of Commodity Price Volatility: Comment," Working Paper, Cornell University.

[9] Sandmo, Agnar (1971), "On the Theory of the Competitive Firm under Price Uncertainty," *American Economic Review* 61: 65-73.

[10] Singh, Inderjit, Lyn Squire, and John Strauss (1986), *Agricultural Household Models*, Baltimore, MD: Johns Hopkins University Press.

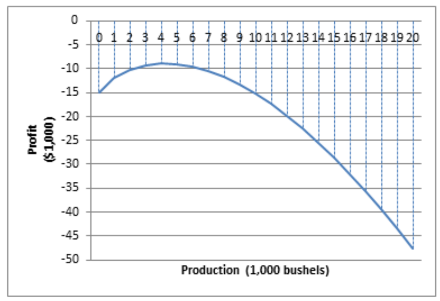
[11] Thaler, Richard E., and Eric J. Johnson (1990), "Gambling with the House Money and Trying to Break Even: The Effects of Prior Outcomes on Risky Choice," *Management Science* 36(6): 643-660.

[12] Turnovsky, Stephen J., Haim Shalit, and Andrew Schmitz (1980), "Consumer's Surplus, Price Instability, and Consumer Welfare," *Econometrica* 48: 135-152.

Figure 1. Chart and Graph for the Price Scenario \$5/unit (top) and the Summary Chart and Graph (bottom)

1. Wheat production, cost, and profit when price of wheat is **$5/bushel**.

(1) Wheat Production (1,000 bushels)	(2) Price ($/bushel)	(3) Cost $= 2 \times (1)^{1.4}+15$ (\$ 1,000)	(4) Profit $= (1)\times(2)-(3)$ (\$1,000)
0	5	15	-15.00
1	5	17	-12.00
2	5	20	-10.28
3	5	24	-9.31
4	5	29	-8.93
5	5	34	-9.04
6	5	40	-9.57
7	5	45	-10.49
8	5	52	-11.76
9	5	58	-13.35
10	5	65	-15.24
11	5	72	-17.41
12	5	80	-19.85
13	5	88	-22.54
14	5	95	-25.47
15	5	104	-28.63
16	5	112	-32.01
17	5	121	-35.60
18	5	129	-39.40
19	5	138	-43.39
20	5	148	-47.58



6. Profits when price of wheat is **$5/bushel-$9/bushel**.

Wheat Production	Profit				
	P = \$5	P = \$6	P = \$7	P = \$8	P = \$9
0	-15.00	-15.00	-15.00	-15.00	-15.00
1	-12.00	-11.00	-10.00	-9.00	-8.00
2	-10.28	-8.28	-6.28	-4.28	-2.28
3	-9.31	-6.31	-3.31	-0.31	2.69
4	-8.93	-4.93	-0.93	3.07	7.07
5	-9.04	-4.04	0.96	5.96	10.96
6	-9.57	-3.57	2.43	8.43	14.43
7	-10.49	-3.49	3.51	10.51	17.51
8	-11.76	-3.76	4.24	12.24	20.24
9	-13.35	-4.35	4.65	13.65	22.65
10	-15.24	-5.24	4.76	14.76	24.76
11	-17.41	-6.41	4.59	15.59	26.59
12	-19.85	-7.85	4.15	16.15	28.15
13	-22.54	-9.54	3.46	16.46	29.46
14	-25.47	-11.47	2.53	16.53	30.53
15	-28.63	-13.63	1.37	16.37	31.37
16	-32.01	-16.01	-0.01	15.99	31.99
17	-35.60	-18.60	-1.60	15.40	32.40
18	-39.40	-21.40	-3.40	14.60	32.60
19	-43.39	-24.39	-5.39	13.61	32.61
20	-47.58	-27.58	-7.58	12.42	32.42

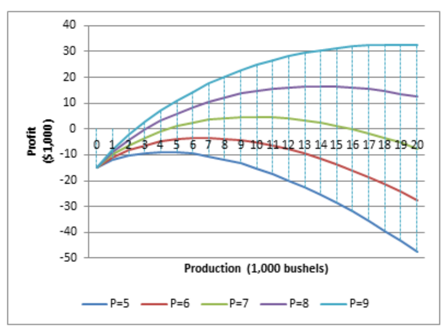


Figure 2. Two-Stage Randomization Process

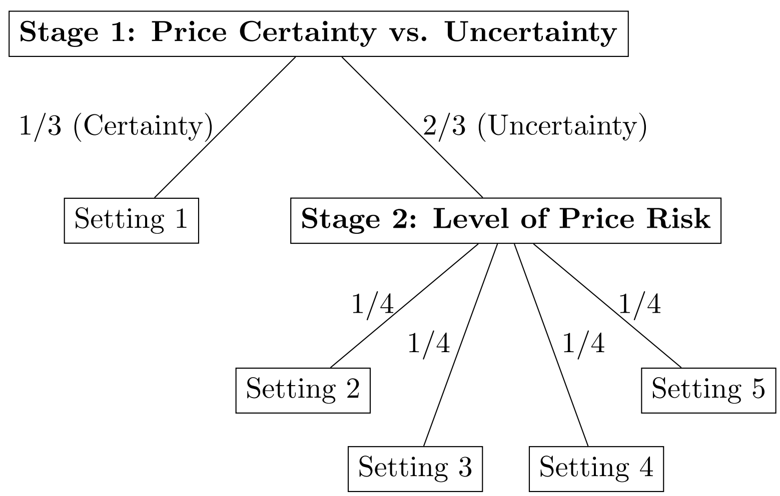


Figure 3. Pictures Presented for Settings 1 through 5

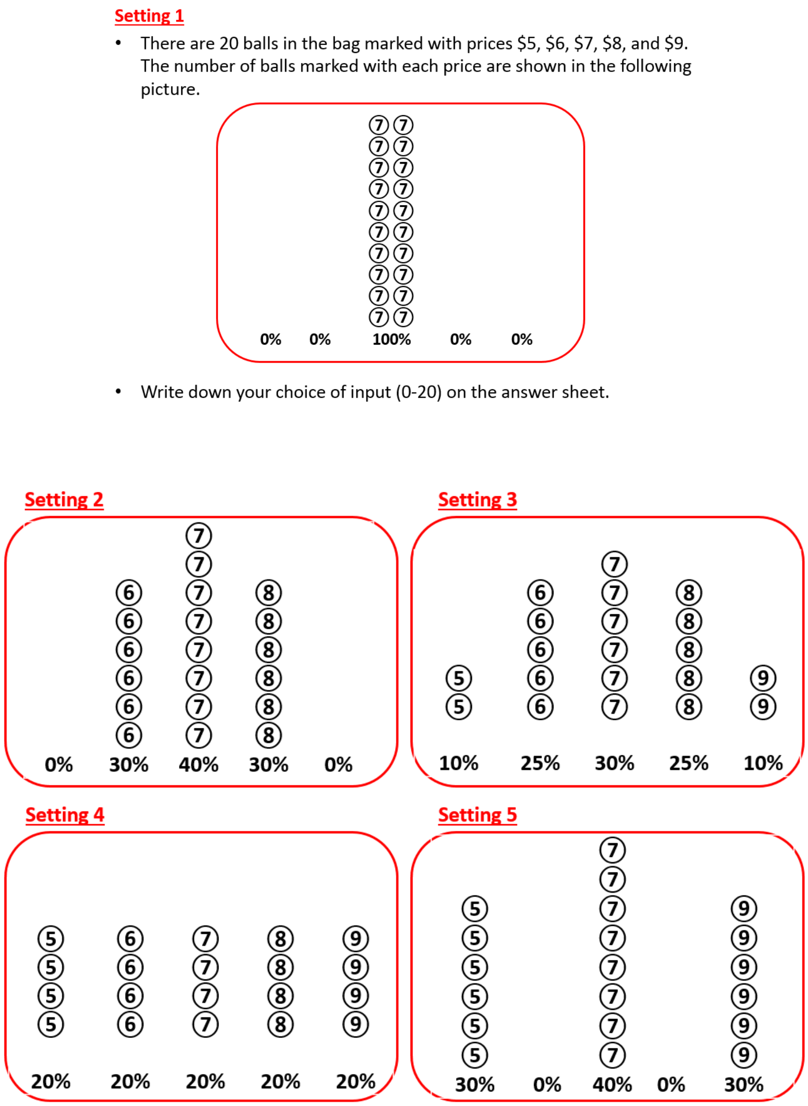
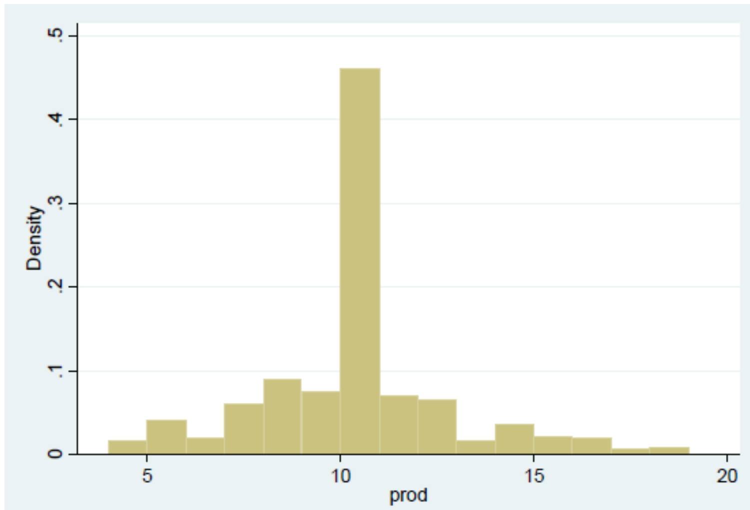


Figure 4. Producer Output Choice Under Uncertainty: Risk Sessions in December (top) and March (bottom)



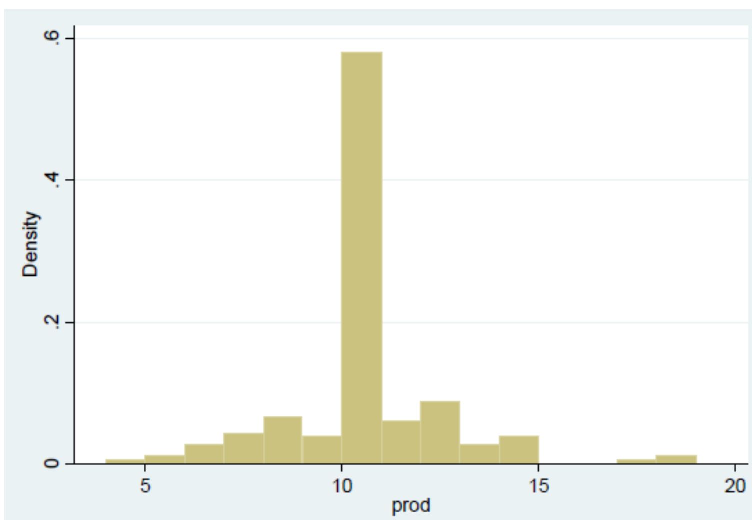


Figure 5. Producer Output Choice Under Uncertainty: Ambiguity Sessions in December (top) and March (bottom)

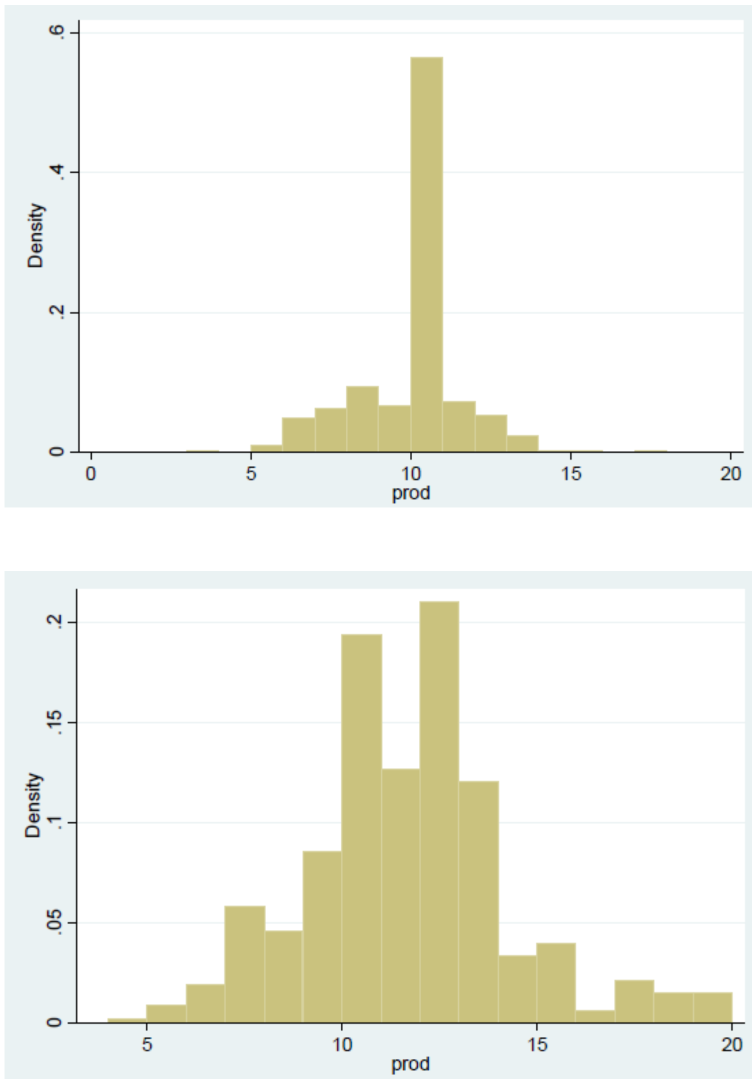


Figure 6. Price Drawn in Ambiguity Sessions: Practice and Real Rounds in December(top) and in March(bottom)

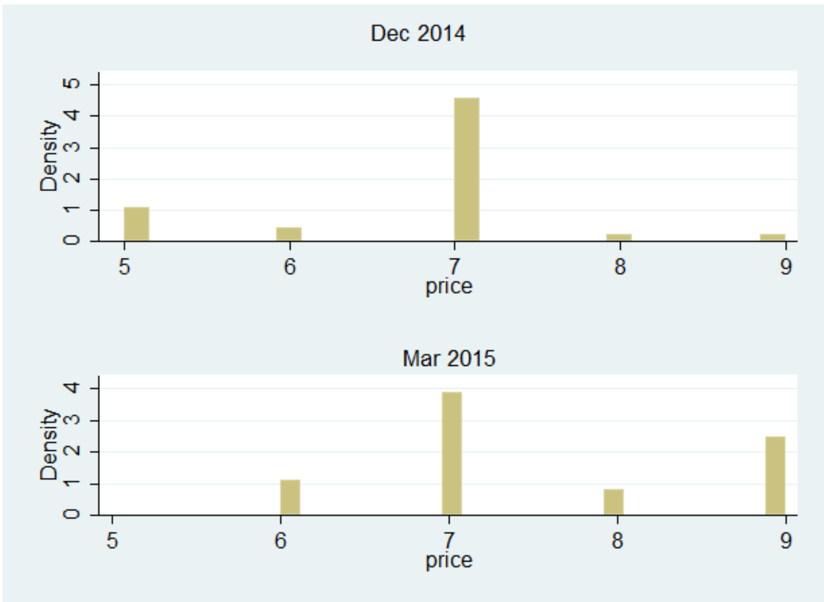


Figure 7. Price Drawn in Ambiguity Sessions: Practice Rounds in December(top) and in March(bottom)

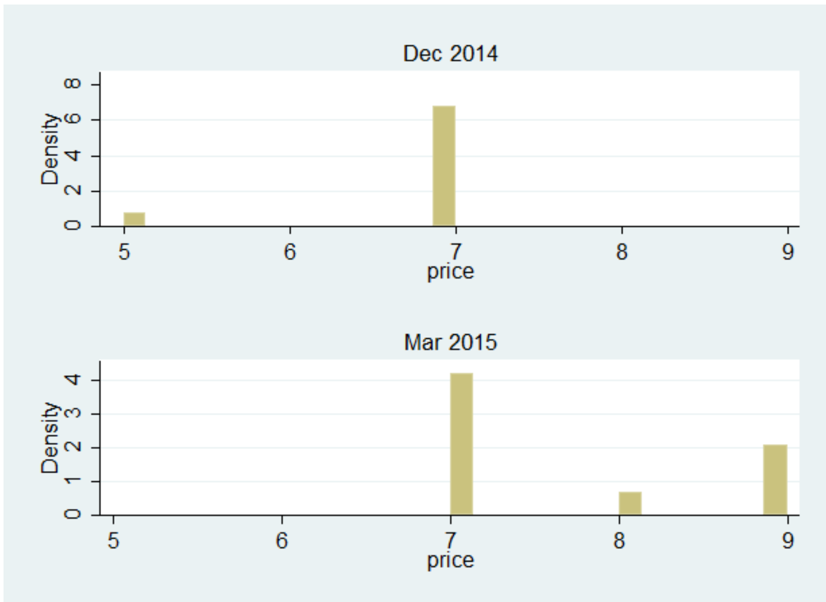


Figure 8. Kernel Density Estimate of the Coefficient of Price Risk Aversion

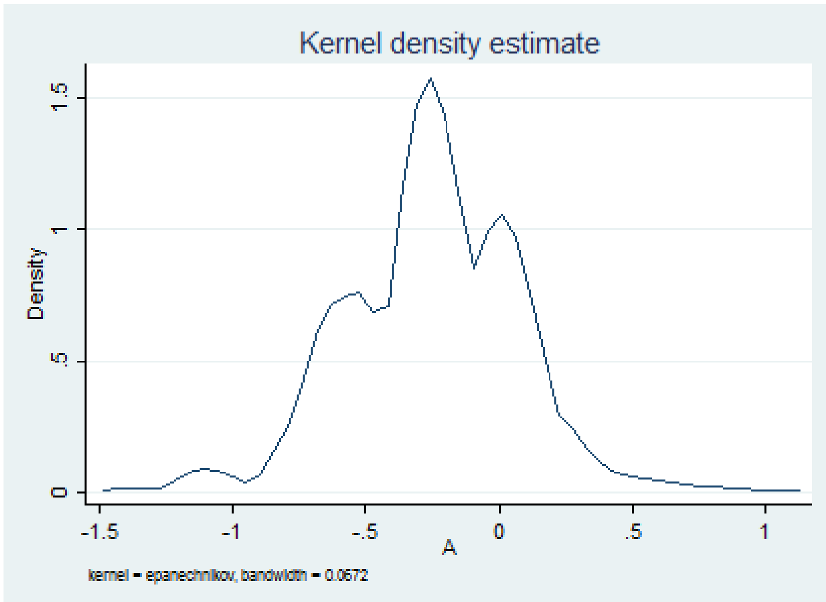


Figure 9. Kernel Density Estimate of the Willingness to Pay to Stabilize Prices

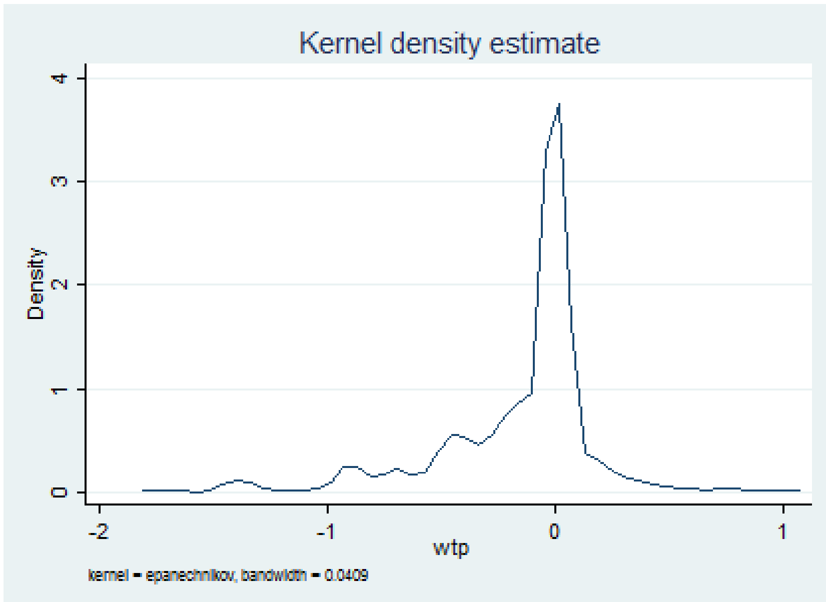


Table 1. Descriptive Statistics:
December Risk Session (N=480)

Variable	Mean	(Std. Dev.)	Min	Max
Output Level	9.92	(2.46)	4	19
Price	6.85	(1.11)	5	9
Uncertainty	0.70	(0.46)	0	1
Standard Deviation	0.97	(0.68)	0	1.58
Profit	2.86	(11.61)	-43.39	31.99
Holt-Laury Switch Point	6.70	(1.51)	4	10
Age	20.67	(0.94)	18	22
Female	0.42	(0.49)	0	1

Table 2. Descriptive Statistics:
March Risk Session (N=480)

Variable	Mean	(Std. Dev.)	Min	Max
Output Level	10.11	(2.00)	4	19
Price	6.90	(1.05)	5	9
Uncertainty	0.65	(0.48)	0	1
Standard Deviation	0.85	(0.68)	0	1.58
Profit	3.43	(10.90)	-43.39	32.61
Holt-Laury Switch Point	7.46	(1.36)	5	10
Age	20.29	(1.14)	19	24
Female	0.70	(0.46)	0	1

Table 3. Descriptive Statistics:
December Ambiguity Session (N=460)

Variable	**Mean**	**(Std. Dev.)**	**Min**	**Max**
Output Level	9.58	(1.64)	3	18
Price	6.65	(1.02)	5	9
Uncertainty	0.60	(0.49)	0	1
Profit	1.21	(9.71)	-22.54	32.60
Holt-Laury Switch Point	6.91	(1.91)	4	10
Age	20.65	(0.92)	19	23
Female	0.61	(0.49)	0	1

Table 4. Descriptive Statistics:
March Ambiguity Session (N=460)

Variable	**Mean**	**(Std. Dev.)**	**Min**	**Max**
Output Level	11.20	(2.67)	4	20
Price	7.50	(1.19)	6	9
Uncertainty	0.90	(0.30)	0	1
Profit	10.03	(13.05)	-13.63	32.61
Holt-Laury Switch Point	7.08	(1.80)	4	10
Age	20.79	(1.69)	18	25
Female	0.58	(0.49)	0	1

Table 5. Random Effects Regression Results: Risk Session, December

Variable	Coefficient	(Std. Err.)
Uncertainty	2.163***	(0.649)
Standard Deviation	-1.655***	(0.442)
Holt-Laury Switch Point	-0.366***	(0.147)
Round	0.003	(0.018)
Age	0.295	(0.268)
Female	-0.496	(0.530)
Constant	5.948	(5.265)
N	480	
Ethnicity Dummies	Yes	
R^2 Overall	0.10	
Wald $\chi^2(9)$	24.44	

Table 6. Random Effects Regression Results: Risk Session, March

Variable	Coefficient	(Std. Err.)
Uncertainty	1.873***	(0.486)
Standard Deviation	-1.170***	(0.362)
Holt-Laury Switch Point	-0.053	(0.140)
Round	-0.023	(0.019)
Age	0.232	(0.171)
Female	-0.973	(0.480)
Constant	6.671	(3.490)
N	460	
Ethnicity Dummies	Yes	
R^2 Overall	0.11	
Wald $\chi^2(9)$	26.83	

Table 7. Random Effects Regression Results: Risk Session, Pooled

Variable	Coefficient	(Std. Err.)
Uncertainty	2.041***	(0.400)
Standard Deviation	-1.491***	(0.277)
Holt-Laury Switch Point	-0.214**	(0.099)
Round	-0.002	(0.012)
Holt-Laury First	0.413	(0.318)
Age	0.252*	(0.148)
Female	-0.713**	(0.340)
Constant	6.066**	(2.955)
N	940	
Ethnicity Dummies	Yes	
R^2 Overall	0.09	
Wald $\chi^2(9)$	45.44	

Table 8. Standard Deviations of the Price Distributions and Mean Output Choice

Standard Deviation	Output Choice
0	10
0.80	10.9
1.17	10.06
1.45	10.04
1.58	9.59

Table 9. Random Effects Regression Results: Ambiguity Session, December

Variable	Coefficient	(Std. Err.)
Uncertainty	-0.571***	(0.132)
Holt-Laury Switch Point	0.055	(0.121)
Round	-0.019*	(0.011)
Age	-0.182	(0.256)
Female	-0.660	(0.453)
Constant	14.344**	(5.624)
N	460	
Ethnicity Dummies	Yes	
R^2 Overall	0.10	
Wald $\chi^2(8)$	26.95	

Table 10. Random Effects Regression Results: Ambiguity Session, March

Variable	Coefficient	(Std. Err.)
Uncertainty	1.425***	(0.324)
Holt-Laury Switch Point	-0.535***	(0.160)
Round	0.052***	(0.017)
Age	-0.037	(0.149)
Female	-0.721	(0.539)
Constant	14.397	(3.124)
N	480	
Ethnicity Dummies	Yes	
R^2 Overall	0.28	
Wald $\chi^2(8)$	59.14	

Table 11. Random Effects Regression Results: Ambiguity Session, Pooled

Variable	**Coefficient**	**(Std. Err.)**
Uncertainty	0.027	(0.149)
Holt-Laury Switch Point	-0.222**	(0.102)
Round	0.014	(0.010)
Holt-Laury First	1.263***	(0.380)
Age	-0.087	(0.128)
Female	-0.855**	(0.377)
Constant	13.541***	(2.740)
N	940	
Ethnicity Dummies	Yes	
R^2 Overall	0.24	
Wald $\chi^2(9)$	49.87	

Table 12. OLS Results for the Marketable Surplus Equation

Variable	**Coefficient**	**(Std. Err.)**
Price	1.145***	(0.122)
Income	-1.235***	(0.156)
Round	-0.002	(0.001)
Intercept	4.850***	(0.388)

APPENDIX I. Experimental Protocol

1. General Instructions

- This is an experiment in the economics of individual decision making. We are trying to understand how people make production decisions when they are unsure of the price they will receive. We have designed simple decision-making games in which we will ask you to make choices in a series of situations.
- There are two sets of games. In the first set of games, you will be given a series of lotteries to choose from. In the second set of games, you will be making decisions assuming that you are a farmer producing a single commodity, wheat. More detailed explanations will follow in each set.
- You will spend 90 to 120 minutes in this study playing economic games. You will automatically receive $45 for participation and in addition may earn between $1.31 and $45.16 depending on your performance and also on the luck on the experiment.
- You should make your own decision and should not discuss your decisions or the decision scenarios with other participants. Also, please turn off your cell phones.
- You need to have a good understanding on how your decisions affect your payoff. Please raise your hand at any time during the session if you have any question.

2. Instructions for Output Price Uncertainty Game – Risk Treatment

- You are a farmer who produces and sells only one commodity, wheat.

- The selling price of wheat in dollars per bushel will be one of the five possible values: $5, $6, $7, $8, and $9, and it will be realized *after* you make your production decision to reflect the real-world output price uncertainty.

- You will be given charts 1 through 5 which document the amount of cost to be incurred according to production levels 0 through 20 (in 1,000 bushels), and the corresponding profit (in $1,000) that will occur *under the five different price scenarios*. These charts contain all the information about how your production decision, cost of production, and your profit relate to one another. Chart 6 is a summary of charts 1 through 5 and shows only the relationship between the production level and the profit.

- Prices will be determined in the following way: In each round, you will be presented a picture of a bag with 20 balls. Each of the 20 balls have different prices (⑤, ⑥, ⑦, ⑧, and ⑨) marked. There are five bags with different composition of balls. In each round, a bag will be selected randomly. The average of the prices marked on the 20 balls will always be $7, but the composition of balls marked with different prices will change each round.

- Given a picture of a bag, you decide how much wheat to produce, knowing *only the composition of prices marked in the bag, not the actual price that will be drawn*.

- Here is an example:

		⑦⑦		
		⑦⑦		
		⑦⑦		
		⑦⑦		
		⑦⑦		
		⑦⑦		
		⑦⑦		
		⑦⑦		
		⑦⑦		
		⑦⑦		
0%	0%	100%	0%	0%

In the bag depicted above, all the balls are marked with price $7. Therefore, you are 100% sure that the wheat price will be $7 per bushel.

		⑦		
	⑥	⑦	⑧	
	⑥	⑦	⑧	
	⑥	⑦	⑧	
⑤	⑥	⑦	⑧	⑨
⑤	⑥	⑦	⑧	⑨
10%	25%	30%	25%	10%

In the bag depicted above, among the 20 balls, there are 2 balls each with $5 and $9 marked, 5 balls each with $6 and $8 marked, and 6 balls with $7 marked. There is a 10% probability that a random draw from this bag will be the price of $5, and a 25% probability for the price of $6, etc.

Here is another example.

⑤	⑥	⑦	⑧	⑨
⑤	⑥	⑦	⑧	⑨
⑤	⑥	⑦	⑧	⑨
⑤	⑥	⑦	⑧	⑨
20%	20%	20%	20%	20%

In this bag, we can see that all possible wheat prices are equally likely to occur. In comparison to the last given situation, it is more likely to have more extreme prices than the first round.

- Given such information, you will be asked to choose any integer between 0 and 20 as your production level. You may refer to the charts 1-6 to facilitate your decision.
- Your goal is to maximize the profit (price times quantity produced minus cost of production), since maximizing profit is identical to maximizing your payoff.
- Note that there is no subsistence constraint, meaning that there is no minimum required level of production for your survival. Nor is there a requirement to make a positive profit in order for you to survive. Negative profits mean that you lose some of the money that you are endowed with.

- *After* you have chosen how much to produce, a ball will be drawn randomly from the bag which will determine your selling price. You will sell your wheat at that price, which will determine your profit.
- You will first play 10 rounds of practice games. After the practice games, you will play 20 rounds of the real games. In the real games, your profits will affect your actual payoffs from the games.
- In this set of the games, you start from base payoff of $25. In a given round, your profit will be between -47.58 and 32.61. After the 20 actual rounds, we will randomly select a round. Your payoff from these games will be determined in the following way: $25 base payoff + a half of your profit in the randomly selected round. For example, if you have made a loss of 30 in the selected round, your final payoff will be $25 + (-$30 X 0.5) = $10. If you have made a profit of 28, your final payoff will be $25 + ($28 X 0.5) = $39.
- Your final payoff in this set of the games will range between $1.21 and $41.31.

3. Instructions for Output Price Uncertainty Game – Ambiguity Treatment

- You are a farmer who produces and sells only one commodity, <u>wheat</u>.
- The selling price of wheat in dollars per bushel will be one of the five possible values: $5, $6, $7, $8, and $9, and it will be realized *after* you make your production decision to reflect the real-world output price uncertainty.
- You will be given charts 1 through 5 which document the amount of cost to be incurred according to production levels 0 through 20 (in 1,000 bushels), and the corresponding profit (in $1,000) that will occur *under the five different price scenarios*. These charts contain all the information about how your production decision, cost of production, and your profit relate to one another. Chart 6 is a summary of charts 1 through 5 and shows only the relationship between the production level and the profit.
- In each round, you will be given one of the two situations:

  (1) You know that your selling price will be exactly $7;

  (2) You know that the price will be one of the five values -- $5, $6, $7, $8, and $9.

  Under a given situation, you will be asked to determine how much wheat to produce by choosing any integer between 0 and 20 as your production level. You may refer to the charts 1-6 to facilitate your decision.
- Your goal is to maximize the profit (price times quantity produced minus cost of production), since maximizing profit is identical to maximizing your payoff.
- Note that there is no subsistence constraint, meaning that there is no minimum required level of production for your survival. Nor is there a requirement to make a positive profit in order for you to survive. Negative profits mean that you lose some of the money that you are endowed with.
- *After* you have chosen how much to produce, a ball will be drawn randomly from a bag, which will determine your selling price. You will sell your wheat at that price, which will determine your profit.
- You will first play 10 rounds of practice games. After the practice games, you will play 20 rounds of the real games. In the real games, your profits will affect your actual payoffs from the games.

- In this set of the game, you start from base payoff of $25. In a given round, your profit will be between -47.58 and 32.61. After the 20 actual rounds, we will randomly select a round. Your payoff from these games will be determined in the following way: $25 base payoff + a half of your profit in the randomly selected round. For example, if you have made a loss of 30 in the selected round, your final payoff will be $25 + (-$30 X 0.5) = $10. If you have made a profit of 28, your final payoff will be $25 + ($28 X 0.5) = $39.
- Your final payoff in this set of the games will range between $1.21 and $41.31.

4. Instructions for Holt-Laury Income Risk Lottery Game

- In this set of games, you will be presented a table of ten paired lotteries, A and B, from which you are asked to choose one that you prefer.
- Below is an example of the options that you will be given:

Option A	Option B
1/10 of \$2.00, 9/10 of \$1.60	1/10 of \$3.85, 9/10 of \$0.10

  If you choose option A, there is a probability of 0.1 that you will be receiving \$2.00, and a probability of 0.9 that you will be receiving \$1.60. If you choose option B, there is a probability of 0.1 that you will be receiving \$3.85 which is much bigger than \$2.00 in option A. However, there is also a 0.9 probability that you will be receiving only \$0.10.

- Stop once you have chosen the option B.
- Your payoff from this round of game will be determined in the following way: A random number will be drawn to determine the row number of one of your choices. Then, according to the probability that the row of the choice dictates, either option A or B will be drawn, which will determine your payoff.
- Your payoff from this round will range between \$0.1 and \$3.85.

APPENDIX II. Answer Recording Sheet

Set I: Single-Commodity Production Game

- **Practice Rounds**

Round	Choice of Production Level (1,000 bushels)
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

- **Actual Rounds**

Round	Choice of Production Level (1,000 bushels)
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	

Set II: Lottery Choice Game

	Option A	Option B	Your Choice (circle one)
1	1/10 of $2.00, 9/10 of $1.60	1/10 of $3.85, 9/10 of $0.10	A , B
2	2/10 of $2.00, 8/10 of $1.60	2/10 of $3.85, 8/10 of $0.10	A , B
3	3/10 of $2.00, 7/10 of $1.60	3/10 of $3.85, 7/10 of $0.10	A , B
4	4/10 of $2.00, 6/10 of $1.60	4/10 of $3.85, 6/10 of $0.10	A , B
5	5/10 of $2.00, 5/10 of $1.60	5/10 of $3.85, 5/10 of $0.10	A , B
6	6/10 of $2.00, 4/10 of $1.60	6/10 of $3.85, 4/10 of $0.10	A , B
7	7/10 of $2.00, 3/10 of $1.60	7/10 of $3.85, 3/10 of $0.10	A , B
8	8/10 of $2.00, 2/10 of $1.60	8/10 of $3.85, 2/10 of $0.10	A , B
9	9/10 of $2.00, 1/10 of $1.60	9/10 of $3.85, 1/10 of $0.10	A , B
10	10/10 of $2.00, 0/10 of $1.60	10/10 of $3.85, 0/10 of $0.10	A , B

Please stop once you have chosen the option B.

❖ **Demographics**

- Age:_________
- Sex: M / F
- Ethnicity/Race:

  (1) Hispanic or Latino

  (2) American Indian or Alaska Native

  (3) Asian

  (4) Black or African American

  (5) Native Hawaiian or Other Pacific Islander

  (6) White
- Nationality: ___________

Thank you for your participation! ☺