The Microeconomics of Agricultural Price Risk*

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Abstract

Much of neoclassical economics is concerned with prices—more specifically with relative prices. Similarly, economists have studied behavior in the face of risk and uncertainty for at least a century, and risk and uncertainty are without a doubt a feature of economic life. It is thus puzzling that price risk—that is, price volatility, or unexpected departures from a mean price level—has received so little attention. In this review, we discuss the microeconomics of price risk. We begin by reviewing the theoretical literature, a great deal of which is concerned with the effects of unstable agricultural prices on the welfare of producers, consumers, and agricultural households. We then discuss the empirical literature on the effects of price risk on economic agents. We emphasize policy responses to agricultural price risk throughout, discussing price stabilization policies from both a theoretical as well as an empirical perspective. Perhaps most importantly, we provide several suggestions for future research in the area of price risk given increasing risk on world agricultural markets due to both policy uncertainty and climate change.

Keywords: Price Risk, Price Uncertainty, Price Volatility, Price Stabilization, Hedging, Food, Agriculture

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Introduction

For much of its history, economics has been concerned with prices. In the case of neoclassical economics, this has meant studying the causes and consequences of changes in as well as the behavior of *relative* prices. Almost always, this has meant looking at what happens when going from one relative price level to another level, with the difference between the two being possibly only infinitesimal.

Similarly, economics has been concerned with risk and uncertainty. In the case of neoclassical economics, this has meant studying the causes and consequences of changes in income risk. More often than not, this has meant looking at how individuals or households behave in the face of risk (i.e., uncertainty whose underlying distribution is known to the agent) or Knightian uncertainty (i.e., uncertainty whose underlying distribution is unknown to the agent).

Given that prices are foundational to the discipline of economics and that risk and uncertainty are a fact of economic life, one would expect economists to have devoted a considerable amount of time and effort to the study of price risk.[1] Yet the index to Mas-Colell et al.'s (1995) *Microeconomic Theory*—the so-called bible on the topic, from which many of the readers of this article will have undoubtedly learned microeconomic theory—makes no mention of price risk, price uncertainty, or price volatility. Likewise, the index to the recently published *Chicago Price Theory* (Jaffe *et al.* 2019), which purports to be the definitive statement on price theory, only mentions risk in the context of the value of statistical life, and is silent on uncertainty and volatility, let alone price risk, price uncertainty, or price volatility.

For the sake of argument, let us consider an individual consumer or a (unitary) household's welfare. In both cases, welfare is ultimately represented by the indirect utility function $V(p, y)$, which denotes the level of utility attained by the individual or the household given a vector of prices p and income y. For a vector of consumption goods x, the indirect utility function is simply the utility function $u(x)$ at an optimum $x(p, y)$, i.e., $V(p, y) = u(x(p, y))$. But if one can look at the curvature of the (direct) utility function by looking at its second derivative $u'' = \frac{\partial^2 u}{\partial x^2}$, then one can also look at the curvature of the

[1] We use the expression "price risk" throughout this paper as shorthand for both "price risk" and "price volatility." Although popular accounts (and some economists who should now better) use "price volatility" to mean "changes in price levels," we use the expression in its financial sense, to refer to *unanticipated* departures from the mean of a given price. See Bellemare (2015) for a discussion of the distinction.

indirect utility function by looking its Hessian, and just as $\frac{\partial^2 V}{\partial y^2}$ can tell us how welfare changes with income risk, $\frac{\partial^2 V}{\partial p^2}$ can tell us how welfare changes with price risk.[2]

How do economic agents—individuals, households, firms, and farms—respond to price risk? Because the topic has not yet been treated by graduate texts, we review the literature on price risk. We do so by discussing the papers retained after searching the EconLit database papers with "price risk" and "food price volatility" in their titles. We retain papers that are theoretical in nature as well empirical papers that focus on food and agriculture.[3] Likewise, to keep our review focused, we ignore analyses of the general-equilibrium or macroeconomic effects of price volatility as well as analyses of the costs of commodity price stabilization.

The remainder of this paper is organized as follows. In section 2, we review early contributions analyzing the theoretical impacts of price uncertainty on consumers and producers—that is, those contributions looking at the responses of consumers and producers to price risk.[4] Section 3 then discusses refinements to those early contributions, looking successively at consumers, producers, and agricultural households, since the latter typically comprise both a production and a consumption side. Section 4 assesses empirical contributions on price risk. In section 5, we summarize and offer avenues for future research.

1. Definition and Early Contributions

We define "price volatility" in what follows as a measure of the average magnitude of the (unexpected) departure of a price p from its mean μ given that price's realizations t measured at a specific frequency for a given period of time T, such that $t \in \{1, \dots, T\}$. Formally, this means that we focus on a price distribution's standard deviation $\sigma = \sqrt{\frac{\sum_{t=1}^{T}(p_t-\mu)^2}{T}}$ and related measures such as that distribution's

[2] See Bellemare et al. (2013) for a fuller discussion.
[3] That is, we do not review empirical papers wherein price risk relates to non-agricultural commodities (e.g., oil or gold).
[4] Unless indicated otherwise, "price risk," "price uncertainty," or "price volatility" will always refer in this paper to output price risk, uncertainty, and volatility in relation to producers.

variance (i.e., the square of its standard deviation σ^2) or its coefficient of variation (i.e., its standard deviation divided by its mean σ/μ).[5,6]

The analysis of the effects of price volatility goes back to Waugh (1944), who wrote the first paper adapting neoclassical economic theory to the analysis of markets with price volatility. In this paper, Waugh studies the benefits of price instability for consumers, and he concludes that "against the common sense," consumers benefit from price instability because consumer surplus increases with the variation in prices.

The first paper looking at the effects of price volatility for producers was by Oi (1961), who looked at the desirability of price instability for firms under perfect competition. Oi found that, for firms maximizing short-run profit, at each point in time, uncertainty in product prices is beneficial to the firm with non-decreasing marginal utility, since an increase in prices implies an increase in the variance of profits and then an increase in the firm's expected profit.

In an article following up on his earlier contribution, Waugh (1966) responded to Oi's (1961) contribution by returning to his point regarding the benefits of price instability for consumers. Here, Waugh analyzed the indifference curves an individual consumer could reach with stable and volatile prices, and he concluded that an individual consumer would gain from price stabilization if prices were stabilized at or below the weighted means of the varying prices.

Massell (1969) combined Waugh (1944, 1966) and Oi's (1961) analyses on the welfare effects of price stabilization for consumers as well as producers. Analyzing the expected value of consumer and producer surpluses, Massell (1969) found that price stabilization (which, in his example, took the form of a buffer stock) would bring net gains for producers and consumers considered together. According to his results, consumers as a group are more likely to gain from price stabilization if the variance in quantity demanded is larger than the variance in quantity supplied, and if the demand curve is steeper than the

[5] There is no agreement on what to actually as a measure of risk, and the use of a distribution's standard deviation as a measure of that distribution's riskiness has been criticized for at least half a century, going back to Rothschild and Stiglitz (1970). From an expected utility (EU) perspective, two-moment (e.g., mean-variance) preferences and EU are consistent with one another only under certain restrictions (Meyer 1987). Quiggin & Chambers (2004) develop the restrictions required for general preference structures to be consistent with two-parameter decision making under risk (i.e., uncertainty where the distribution is known), and Chambers et al. (2014) to the more general case of Knightian uncertainty (i.e., uncertainty where the distribution is unknown).

[6] Jin and Kim (2012) find that measures like the standard deviation, variance and coefficient of variation, though they are easy to calculate, can exaggerate the results when a price series is nonstationary or has large fluctuations. They suggest an alternative measure of price variation which takes into account the structural breaks in the unconditional mean of the price series.

supply curve. Conversely, producers would gain from price stabilization if the variance in quantity supplied is larger than the variance in quantity demanded, and if the supply curve is steeper than the demand curve. In any case, the gain for one group (i.e., consumers or producers) would be more than enough to compensate the other group.

2. Extending the First Ideas

In this section, we review the theoretical advances that followed the first, foundational papers on price volatility. We first review the papers focusing on price volatility as it relates to consumers. We then review the papers focusing on price volatility as it relates to producers. Lastly, we review some theoretical papers on price stabilization with storage, futures markets and hedging, and trade.

2.1. Consumers

Stiglitz (1969) generalized the analysis of consumer behavior in the face of price uncertainty to more than one commodity, and he showed that linearity of income-consumption curves was necessary for risk-neutrality, which had been implicitly assumed for in earlier papers. Since linear income-consumption curves have not been found to fit the data, he argued, individuals cannot be argued to be risk-neutral, and so Stiglitz suggested avoiding the assumption that consumers are risk-neutral.

Deschamps (1973) analyzed the relationship between risk aversion and demand functions and showed which utility and demand functions comply with the hypothesis that absolute risk aversion is a function of income but not of prices, and that risk aversion is constant (i.e., independent of a compensated price variation, which eliminates the income effect due to price change).

Hanoch (1977) found an interesting relationship between income risk aversion and price risk aversion: a "necessary condition for a consumer to be risk loving with respect to price fluctuations is that income … risk aversion is not too large" (Hanoch 1977: 419). Using the concept of duality for preferences and demand functions, Hanoch concluded that there are many representations and interpretations of income risk aversion, so that demand behavior under certainty does not inform or reflect the nature of consumer attitudes towards risk.

Turnovsky et al. (1980) analyzed the welfare effects of price stabilization for consumers, but instead of doing so by looking at consumer surplus, they did so using the indirect utility function. They showed that consumers' preference for price (in)stability depends on four parameters: the income elasticity of the demand for the commodity whose price is volatile, the price elasticity of the demand for the same commodity, the share of the consumer's budget spent on that commodity, and the consumer's Arrow-Pratt coefficient of relative risk aversion. Consumers prefer price instability the larger the two elasticities and the smaller is the degree of risk aversion, while the response to increases in the budget share is indeterminate. For plausible parameter values there is still possible to have consumers preferring price instability, as in Waugh (1944). Turnovsky et al. (1980) also found that if only one price is stabilized, a risk neutral consumer loses out from price stabilization. If more than one price stabilized, however, the consumer can either benefit or lose out.

For consumers, Newbery & Stiglitz (1981) studied the benefits of price stabilization and showed that since prices are often correlated with income, price variations reduce the variability of consumers' real income (which, according to Newberry and Stiglitz, is what individuals care most about), and thus if the major source of price variability is the variability of demand, price stabilization can make consumers worse off.

3.2. Producers

The papers following Oi (1961) also focused on risk aversion and how producers respond to price risk (i.e., how much they adjust their production in response to it). McCall (1967) computed the optimal competitive level of output for three kinds of firms: a firm whose manager is risk-averse, a firm whose manager is risk-neutral, and a firm whose manager is risk-loving, in which case profits are the argument of the manager's utility function. McCall finds that in response to price risk, the output produced by a firm whose manager is risk-loving is greater than that of a firm whose manager is risk-neutral, and that output produced by a firm whose manager is risk-neutral is greater than that of a firm whose manager is risk-averse.

Baron (1970) generalized McCall's (1967) results and showed that the optimal output level is a nonincreasing function of the producer's absolute risk aversion. His results show that a firm whose manager is risk-averse is willing to sacrifice part of its expected profit to hedge against price risk. Baron (1970) went a step further and analyzed aggregate supply and characterized the industry equilibrium.

He concluded that, for the same average price, increases in risk aversion decrease output, so that aggregate supply can be negatively sloped in the short run, in which case Baron showed that multiple equilibria can occur. Similarly, Sandmo (1971) concluded that output under price uncertainty is smaller than output under certainty in cases where the firm's manager is risk-averse, generalizing a similar statement done by McCall (1967), who had assumed constant absolute risk aversion.

Batra & Ullah (1974) extended Sandmo's (1971) short-run model by using a two-input long-run equilibrium model for a competitive firm. They showed that decreasing absolute risk aversion causes firms to decrease their output in response to increases in price risk.

While Turnovsky et al. (1980) studied consumers, Schmitz et al. (1981) studied the welfare of producers and their preferences for price stability. In doing so, they generalized the conditions under which producers prefer price stability to price instability by assuming the manager has a von Neumann-Morgenstern utility function, for both single- and multi-product firms. For both types of firms, they find that as relative risk aversion increases, a preference for price stability becomes more likely, but a preference for instability becomes more likely as the firm's profit margin and supply elasticity increase. In general, the firm should prefer price stability for those products that represent a larger share of its total revenue, preferring price instability for those products that represent only a small proportion of total revenue.

As for consumers, Newbery & Stiglitz (1981) argued again for producers that they are concerned with income variability more than with price variability, and they found that stabilizing price might lead to larger income variability for producers. Even though the prices of different products can be individually unstable (e.g., crops), their returns as a whole can be stable. Thus, a price stabilization program for a single commodity might induce "large supply responses and have an adverse effect on prices and returns without reducing income risk" (Newbery & Stiglitz 1981: 15).

3.3. Consumers and Producers

Analyzing consumers and producers together, Newbery & Stiglitz (1981) concluded that

> "(i) Producers gain and consumers lose from price stabilization if the source of instability lies on the supply side.

(ii) Consumers gain and producers lose from price stabilization if the source of instability lies on the demand side.

(iii) In both cases, gainers could afford to over-compensate the losers, so there are net benefits from price stabilization." (Newbery & Stiglitz 1981: 18).

Under the assumptions the authors make, the distributional effects seem to be making the producers worse off. Moreover, the empirical evidence they discuss suggests that producer price variability is larger than the consumer's, likely due to the activities of arbitrageurs.

Instead of looking at the market equilibrium, Finkelshtain & Chalfant (1991) theoretically assess price risk for agricultural households, which do not only produce a crop but also consume part of their production (Singh et al. 1986). In doing so, Finkelshtain & Chalfant (1991) combine Sandmo's (1971) with the marketed surplus literature and find that production under uncertainty, with a more general measure of the Arrow-Pratt risk aversion, can lead to larger output levels than under certainty. The authors find that if the household is a net seller (i.e., if it consumes less than what it produces) and the good produced is normal, a risk-averse producer will produce less under price uncertainty, just as Sandmo (1971) had predicted for pure producers. This also holds, however, if the household is risk-neutral. If the household is a net seller and risk-neutral, production increases with output price uncertainty. But if the household is a net buyer and the good is inferior (as is the cases for many staples; see Barrett 1996a), it will always over produce under uncertainty, regardless of their risk preferences. For net buyers, if the good is normal, low levels of risk aversion would result in under production, but higher levels of risk-aversion would imply over production under uncertainty.

Likewise, Finkelshtain & Chalfant (1997) also focus on agricultural households, but in this case analyzing the preference of those agents for partial or complete price stabilization. Using their earlier model from Finkelshtain & Chalfant (1991), the authors find that under complete stabilization, a larger price elasticity of demand for the marketed surplus good means that net buyer households benefit more from price instability because of greater substitution possibilities. Thus, the benefits from price stabilization are increasing both in the relative risk aversion and in the share of farm revenue in total household income. But as the share of production consumed by the household decreases, the consumption effect is less important, and the household behaves more like a pure producer, which increases its willingness to pay to stabilize the output price—a point which we return to below when discussing Bellemare et al. (2013).

Comparing complete versus partial price stabilization, Finkelshtain & Chalfant (1997) find that, for risk averse households, complete price stabilization dominates partial stabilization in the consumption sector. But they also find that partial stabilization in the production sector dominates complete stabilization. In other words, agricultural households are willing to pay more to stabilize prices only in the production sector than for complete (i.e., production and consumption sectors) stabilization, and more than for stabilizing price solely in the consumption sector. In sum, agricultural households can benefit from price stabilization on the production side, but from price instability on the consumption side due to the possibility of substituting consumption goods.

Looking at food security and crop diversification, Fafchamps (1992) includes food price risk for the consumer-producer household in a crop portfolio choice model under multivariate risk. With this model, Fafchamps intends to explain that smallholder farmers in developing countries are more likely to produce staples than cash crops because they need to achieve food security through food self-sufficiency.

3.4. Storage

All papers reviewed up until this point ignored the costs of attaining price certainty. Price stabilization schemes, however, have often been implemented via storage, i.e., using stored grains as a buffer to smooth price volatility over time.

Gustafson (1958) first studied the optimal carryover levels for grains and argued that it is necessary to establish a storage rule (i.e., a functional relationship between the supply and carry-overs) so the relevant variables, including the net benefits, can be determined. Newbery & Stiglitz (1981) dedicate part of their landmark book on price stabilization to providing a dynamic view of the price stabilization problem and argue that, dynamically, the price stabilization problem becomes a problem of optimal storage rules.

Newbery & Stiglitz (1981) also note that in a market economy, total price stabilization would not only be costly, it may as well be infeasible or inefficient. Indeed, assuming that prices are random every period, then there would be a period in which stocks are exhausted and thus wherein prices cannot be stabilized. Moreover, if the stabilization price is set at a high level, there would be an overstock so part of the commodity has to be freely disposed of.

Wright & Williams (1984) developed a model with costly storage looking at competitive firms. They found that the total welfare effects (i.e., the sum of consumer and producer surpluses) of introducing storage in a market with stochastic supply depend on the elasticities of demand and supply curves. Assuming constant elasticity of demand, consumers gain and producers lose out from storage. But the introduction of storage can be beneficial for both consumers and producers if the supply is substantially more elastic than the demand.

Additionally, since the model in Wright & Williams' (1984) is dynamic, it matters whether the introduction of storage is anticipated or unanticipated. Unless the supply is very inelastic, the authors find, producers experience a large welfare gain from the unanticipated introduction of storage because production cannot respond in the first period following the introduction of storage. If the introduction of storage is anticipated, however, the expected effect on producer surplus is always negative: the carryover from the first period would raise consumption as well as the consumer surplus while reducing producer surplus in subsequent periods.

3.5. Price Expectations

Most of the papers heretofore mentioned made the assumption, either explicit or implicit, that price expectations were rational. Although this section is far from an exhaustive review of the considerable literature on price expectations, we believe it is necessary to briefly mention the seminal papers on the topic, given that this is an issue that has received the attention of agricultural economists, and it is an important issue in relation to the behavior of producers under price risk.

Waugh (1964) presents a general recursive cobweb diagram based on naïve expectations (i.e., that prices are going to be the same today as yesterday). Waugh states that a simple supply and demand graph looks like a cobweb when going from prices to quantities: if the price is high, quantity supplied will be larger, which would make prices decline, thus under the new scenario with low prices consumers will demand more of the good, making prices increase again. The convergence or divergence of this model toward the market-clearing price, however, depends on the price elasticities of the supply and demand curves. The cobweb model is then the simplest dynamic model aimed to explain the cyclical behavior in quantities and prices (Tomek & Kaiser 2014). In a naïve price expectations scenario, price stabilization would improve forecasting and lead to more stable production levels (Newbery & Stiglitz 1981: 29).

Before that, however, Nerlove (1956) developed a model of adaptive expectations which consisted in predicting the current price based on past (i.e., lagged) prices, assigning declining weights to older prices. In this paper, Nerlove (1956) found that making the assumption of adaptive expectations makes it possible to obtain higher elasticities of acreage response to price.

Muth (1961) proposes the rational expectations framework, under which he assumes decision-makers are fully aware of the market structure, i.e. expected prices can be accurately predicted. This framework has the advantage of being theoretically consistent with previous papers. Later, Feige & Pearce (1976) introduced the concept of quasi-rational expectations based on a time series model estimation. Although this is a more justifiable approach than the rational expectations, it still may not be realistic.

Besides these seminal papers, some papers have developed rational expectations models linked specifically to price risk. Seale & Shonkwiler (1987), for instance, develop and estimate a rational-expectation supply response model that incorporates price risk and, consistent with Sandmo's (1971) theoretical prediction, they find that stabilizing prices for producers would increase production. Holt (1989) proposes a bounded-price (i.e., support price) variation model under rational expectations that includes higher moments of the price distribution (i.e., price risk) into the supply equation. Holt's application, which looks at the US corn market, suggests that price risk is an important predictor of production, but not as important a predictor as the average price. More recently, using an experimental approach, Mattos & Zinn (2016) study how grain producers form their reference prices, and find that higher refence prices are related to increasing current market prices, the expectation of prices to increase, and the highest price observed in the marketing season.

3.6. Futures, Hedging, and Price Risk Management

Massell (1970) found that, for producers, a buffer stock provides a greater increase in welfare than a forward contract, but the buffer stock is more expensive to implement. He suggests that in evaluating which stabilization scheme to implement, a government need to weight the gains and losses for consumers and producers and the costs of implementing each scheme.

Gardner (1976) uses futures prices (instead of using past prices) as expected prices to estimate supply elasticity, finding that futures prices are a reasonable tool to estimate supply responses (i.e., price elasticities) for soybeans and cotton.

Futures, however, are not the only financial instrument available, and they are also not necessarily the most appropriate instrument to hedge against price risk. Ladd & Hanson (1991) examine the optimal response to price uncertainty in commodity markets where both futures and options contracts are available as risk-management tools, and they find that the futures have a superior hedging ability relative to options contracts. Ladd & Hanson (1991) also state that there is value added for the decision maker from adding a futures market when only a cash market exists. Nonetheless, Moschini & Lapan (1992), analyzing the problem of hedging price risk under production flexibility (i.e., when the profit of the firm is nonlinear in the risky price), show that hedging with futures (whose payoff is linear in the risky price) does not provide a perfect hedge, leaving a role for hedging with options even when the use of futures contracts is allowed.

More recently, Broll et al. (2013) give some theoretical insights into optimal cross-hedging strategies for farmers' contracts. A risk-averse farmer sells commodities to two markets where both prices are random, but only one of these has a futures market, then the farmer's optimal forward position is an over-hedge (full-hedge, under-hedge) strategy if the two prices are strongly positively correlated (uncorrelated, negatively correlated).

4. Testing the Theory: Empirical Assessments of Responses to Price Risk

In this section, we turn to the empirics of price risk, focusing on estimates of the impacts of price risk on producer and consumer decision making and welfare as well as on estimates of the impacts of price stabilization schemes and the use of hedging mechanisms to cope with price risk—generally food price risk.[7]

4.1. Responses to Price Risk

This subsection reviews the papers looking at the impacts of price risk on production decisions (e.g., acreage responses) and on producers' (including agricultural households) welfare. Although we would have liked to summarize the papers looking at the impacts of price risk on consumer behavior, we did not find any papers related to food or agriculture.

[7] There is also a rather large literature on the causes of food price volatility and its links to economic policy (e.g., the ethanol mandate) and macroeconomic factors. Because we had to limit the scope of our paper to response to price risk, and not to the causes thereof, we do not cover those papers here.

Chavas & Holt (1990) were first to empirically assess the linkages between expected utility theory and supply responses to price changes. The authors find that for US corn and soybean production, risk plays a role, following the predictions of the expected utility model. The estimated risk elasticities were small, but interestingly soybean acreage appears more risk responsive to price risk than corn acreage, which is attributed to a more aggressive government intervention in corn markets. Moreover, Chavas and Holt found that there was room for cross-commodity risk reduction: increasing the support price of one crop would lead to more acreage of the other crop.

Similarly, Krause & Koo (1996) estimated acreage responses to price risk for four crops and found significant negative supply responses to own-price risk. Fousekis & Pantzios (2000) found that, for an increase in the variance of output price of 100%, an increase of 9.1% in the expected output price is required for Greek farmers to maintain their supply level. More recently, Haile et al. (2014) look at global acreage response and found a negative impact of own-price volatility on the annual global supply (via acreage) of wheat, corn, soybeans, and rice. Min & Kaiser (2014) find that adding a risk variable (i.e., a 10-year rolling standard deviation of the price of soybean futures) to futures price models of soybean acreage response yields better statistical results and higher own and cross-price elasticities.

Some papers have focused on the production response to price risk for animal products. Hurt & Garcia (1982) find that hog (output) and corn (input) futures price risk have a negative impact on aggregate sow farrowings (i.e., piglet births). Tronstad & McNeill (1989) also estimate the aggregate sow farrowing response to price risk (measured using futures and cash prices) and find that excluding price risk from the analysis would underestimate own-price elasticity for hogs. For the broiler industry, Holt & Aradhyula (1990) characterize the conditional mean and variance of expected price in an aggregate supply equation and find that price risk (i.e., the expected variance of price) is negatively and largely related to broiler production. Branch & Tilley (1991) look at catfish harvest response to price risk in the US and find that risk variables are negatively associated with the output-price supply elasticity and positively associated with the input-price supply elasticity, suggesting reducing price risk in inputs and output prices would increase production.

More recent papers have focused on the relationship between price risk and income. Coffey (2001) uses a linear programming model to show that there is a tradeoff between input price risk and net income. He finds that producers can manage input price risk and choose the optimal input bundle (with less variable prices) at the cost of increasing the expected mean input price, thereby reducing net income. Ridier & Jacquet (2002), for their part, analyze the impact of decoupling direct payments from

production on producers' decisions, taking account of price uncertainty and risk aversion. For beef cattle farms in France, they find that decoupling decreases the share of cattle activities on the farm and production techniques become less intensive, but there is also a positive impact on income stabilization.

Other papers focused on price risk and the relationship between different agents in an industry. Hueth et al. (1999) examined the structure of contractual relations between growers and first handlers in Californian fruit and vegetable markets. Their findings suggest the intermediaries can benefit by acting as insurers for growers, and by allowing growers to get part of their compensation early in the season. They also state, however, that the larger the insurance coverage, the more discouraged the growers would be from working hard and investing in quality produce. Hueth & Ligon (1999) argue that this moral hazard problem is the result of imperfect quality measurement, at least in the market for fresh tomatoes, and although the price provides some information on quality, an efficient contract does not protect growers from all idiosyncratic price risk. For livestock in northern Kenya, Barrett & Luseno (2004) decompose price risk and find that the variability of inter-market price explains most of producer price risk in animals, while the terminal market prices variability accounts for relatively little price risk.

Coyle (1992) incorporated stochastic input prices in addition to a stochastic output price, and he argued that this provides a more appropriate framework for modeling utility maximization than does a deterministic cost function. In his framework, doing so leads to output supply and factor demand equations that are linear in coefficients, which makes them tractable for empirical research too.[8]

Using a similar approach to Coyle's (1992), Abdulkadri et al. (2006) find that deterministic models overestimate economies of scale and underestimates economies of scope. White & Dawson (2005) use a value-at-risk model to estimate price risk for a representative farm in the UK and find that returns show excess kurtosis, and that a GARCH model fits the data the best. Regarding how to measure risk in the field, Pluske & Fraser (1995) showed that the contingent valuation method can serve to measure the risk attitude of farmers on the basis of their maximum valuation for information to reduce price risk, the decrease in variance of output price and their expected revenue. Moreover, Coyle (2007) suggests

[8] Driscoll (1994) criticizes Coyle's (1992) article stating that in his analysis mean and variance were treated as independent variables and thus linear homogeneity and supply functions hold. Coyle (1994) responded to this criticism arguing that Driscoll is wrong because the duality theory (and thus the properties of the risk-neutral and risk-averse models) is independent of the subjective probability distribution of prices. However, Coyle (1994) mentions that a more important issue is his assumption that the mean-variance utility function is linear, which allows the risk-averse firm model to have many of the properties of the risk-neutral duality model.

modifying price indices to account for price risk and shows how to aggregate price risk over commodities in production.

Other papers have looked at the relationship between price risk and other variables, or the consequences of price risk. Barrett (1996a) uses data shows that the inverse farm-size productivity relationship is to the presence of price risk: As smaller farms are more likely to be net buyers, thus food-security stress "elicits supranormal labor activity" (Barrett 1996a: 211), which means that smaller farms tend to be more productive on average than larger farms. Bellemare et al. (2013) generalize Barrett's (1996a) empirical approach to the case of multiple commodities, develop an estimable matrix of price risk aversion coefficients, and derive a measure of household willingness to pay for price stabilization.[9] Using longitudinal data on rural Ethiopian households, they find that the average household in their data would be willing to pay almost 20 percent of its income to stabilize prices, but that willingness to pay for price stabilization is increasing in household income. This is broadly consistent with findings form the theoretical literature, which posit that pure producers tend to be hurt by price risk considerably more than pure consumers, who may actually benefit from price risk. Bellemare (2015) finds that although rising food prices cause social unrest, price volatility does not, contrary to popular food-crisis narratives.

More recently, Lee (2019) has found that the price risk preferences estimated by Bellemare et al. (2013) can explain migration behavior in Ethiopia. Specifically, she finds that as household willingness to pay to stabilize prices increases, a household is more likely to see one of its members migrate out in an effort to hedge against price risk by diversifying the various sources of household income.

4.2. Policy Responses to Price Risk: Commodity Boards and Price Stabilization Schemes

Newbery and Stiglitz's book was written in a context where international organizations pushed price stabilization programs around the world. Newbery & Stiglitz (1981) find empirically that price stabilization (buffer stock) schemes might generally be hurting developing countries without futures markets more than it helps them, and they argue for stabilizing real incomes instead of prices. Nonetheless, price stabilization remained a common objective of economic policy, and the idea of price stabilization dies hard.

[9] In another paper, Barrett (1996b) suggests that food price risk differs between rural and urban areas due to food storage infrastructure concentrated in urban areas, so there are negative effects of price risk on the relative welfare of rural households who switch from being net food sellers to net food buyers every season.

An interesting example of a price stabilization institution is the Canadian Wheat Board (CWB) which held monopsony power over wheat and barley from 1943 to 2012. Clark & Fleming (1990) found that the initial payments (i.e., price floors) set by the CWB, though uncertain, created only minimal price distortions. More recently, Brewin (2014) focused on the use of the CWB's monopsony power to extract premia from the market using price discrimination and, on the basis of simulations, finds that any benefits generated by the CWB were modest compared to the potential gains and losses of not having the CWB.

Some developing countries have also implemented boards of trade to stabilize prices. Commodity exchanges have appeared in developing countries mainly as part of the structural adjustment programs that were put in place in the 1980s and 1990s, in some countries of Asia and Africa (Rashid 2015). For the National Cereals and Produce Board (NCPB) of Kenya, Jayne et al. (2008) estimate that its complete stabilization of maize prices (i.e. stabilizing price for producers and for consumers) implied increases on wholesale prices, and income transfers from net producers to net consumers when the price was set below the market price, but income transfers from net consumers to a small number of large maize producers when the NCPB set prices above the market price. Mason & Myers (2013) study the effects of the Food Reserve Agency (FRA) in Zambia and find that price stabilization of maize benefits producers but negatively affected net buyers, who are mainly urban consumers or the rural poor. For the National Food Reserve Agency of Tanzania (NFRA), Pierre et al. (2018) find little evidence of impact, and only in the short-run, of its interventions on wholesale maize market prices, and argue this is due to the regional maize market integration, so trade partners like Kenya may be playing an important role.

Regarding other price stabilization policies around the world, Gouel (2014) reviews the literature for developing countries and concludes that these policies could hardly bring gains since they are usually bad for trade partners, and storage policies are costly (and have failed to stabilize prices to boot). For Gouel (2014), then, an effective policy to stabilize domestic prices involves implementing more than buffer stocks, but it would impose larger costs on trade partners, which leaves countries in a zero-sum game noncooperative equilibrium. For Africa, Tickner (2008) notes that governments are taking a range of measures to stabilize prices, but those measures are usually short-term and costly: food price controls, limits or bans on exports, import tariff reductions, and food buffer stocks.

Some studies focus on the impacts of country and sector-specific price stabilization policies. For Pakistan, Kurosaki (1996) finds that the characteristics of the price-support mechanism are important. For Canada, Schaufele et al. (2010) find that the highly subsidized AgriStability program targeting cattle

producers behaves more like an income support program than a risk management tool, so producers increase their certainty equivalent wealth between 12% and 22%. For India, Varkey & Kumar (2013) find that high volatility of rubber prices is related to reduced cultivated area, reduced expenditure on agricultural management practices, and reductions in yield. For Vietnam, Fulton & Reynolds (2015) argue that the actions of state-owned agencies restricting the trade of rice to alleviate price volatility were implemented to strategically benefit elites while also exacerbating international food price volatility given Vietnam's status as a net exporter.

Other papers assess willingness to pay for price stabilization instead of looking at specific price stabilization policies. For Uganda's coffee farmers in a post-liberalized market, Hill (2010) finds that both actual and perceived price risk are substantial and vary across households based on the prices received in past seasons. Thus, she suggests that interventions providing information on how prices are determined would be helpful for farmers. As noted earlier, Bellemare et al. (2013) find that price stabilization in Ethiopia would increase the welfare of the average household, but it would be a regressive policy since the welfare gains are increasing with household income.[10]

Although some price stabilization policies seem to have some positive impacts, whether they are optimal remains to be seen. For India, Gouel et al. (2016) use a rational expectations storage-trade model to compare storage, trade, and both policies at once for the management of wheat price volatility, and they find that adopting simple rules can achieve similar welfare gains to fully optimal (and necessarily more complex and costly) policies. Their analysis also supports the Indian approach of combining trade and storage policies to target price stability, although it ignores the response from the rest of the world. Pieters & Swinnen (2016) model the trade-off between volatility and price distortions (from reducing volatility through government intervention in agricultural and food markets) and identify a distortion-volatility optimality frontier. The authors find that some countries have reduced short-run price volatility while allowing structural price changes to pass through to producers and consumers, but in many countries policies are still far from optimal.

[10] McBride (2016), however, finds that changing an assumption made by Bellemare et al. (2013) about how to treat zero-income observations reverses that result, which means that price stabilization could also be a progressive policy. In their response to her, Bellemare et al. (2016) suggest such assumptions must necessarily be made when using observational data, and so experimental studies may be better suited to the theory.

4.3. Policy Responses to Price Risk: Futures and Hedging

Futures are instruments to hedge against price risk, and futures markets are usually present in developed countries, where farmers can follow futures prices to form expectations about prices in the future. Futures markets are not well developed in developing countries, however. The advantage of relying on futures markets instead of price stabilization schemes is that they are near costless for governments to set up.

For developing countries, Morgan et al. (1999) illustrated the effectiveness of futures markets and provided a summary of recent attempts by producer nations to employ hedging to minimize price risk. Morgan (2001) concludes that policy attempts to reduce the effects of price volatility have historically failed and have not helped the smaller and poorer producers, so market-based mechanisms for risk management should be preferred, although they can only cover some of the price risks. Specifically, Lu & Neftci (2008) suggest that developing economies exposed to commodity price risk could use a sovereign Eurobond with an embedded option on a specific commodity price; this could help developing countries establish a credit derivatives market, which would also enhance the marketability and liquidity of sovereign bonds.

Some papers have looked at hedging against price risk for specific commodities. For coffee, Mohan & Love (2004) find that changes in spot prices are not explained by changes in lagged futures prices, thus the coffee futures market information does not help producers hedging price risk. Mohan (2007) uses historical data of actual put-options contracts to find that the costs of hedging are relatively low and outweighed by the benefits for most producers. Additionally, Gemech et al. (2011) find that hedging based on coffee futures and options involves costs, but the benefits from producers allocating resources more efficiently can offset them, especially for risk-averse producers, suggesting the need to provide farmers access to suitable price-risk hedging mechanisms.

For grains, Faruqee et al. (1997) assessed the risk management needs of the wheat market in Pakistan, and they showed that market-based methods of risk management (using futures, options, and swaps) could reduce the impact of international price volatility without distorting price signals or the government incurring in high costs. For maize farmers in South Africa, Brown et al. (2000) find that the use of price risk management tools (measured with an index) is positively related to the use of maize storage facilities, off-farm employment, use of crop insurance and education. Jordaan & Grové (2008), also for farmers in South Africa's, show that risk averse farmers tend to forward-price a larger proportion of their crop, consistent with expected utility theory. Dana et al. (2006) show that hedging

against maize prices with futures or options in Malawi and Zambia on the South African Exchange can help spread import costs over time, thereby reducing price variability. Singh et al. (2009) show that the presence of futures markets can increase price stability and also benefit actors in the farm sector in India. Also in India, Bansal et al. (2015) find that futures converge to spot prices, so they have hedging efficiency. For the US, Serra & Gil (2013) find evidence of price volatility transmission between ethanol and corn markets, but that stock building can significantly reduce corn price volatility.

From a more general perspective on grain markets, McKenzie & Kunda (2009) study the 2008 food crisis, which led to higher liquidity demands for country elevators and show the potential liquidity benefits of making available an over-the-counter margin credit swap contract to grain hedgers. Comparing wheat futures on the Chicago Board of Trade and the European futures market, Revoredo-Giha & Zuppiroli (2013) find that hedging with futures is a viable option for dealing with price risk.

For hedging against price risk in the meat markets, Braga (1996) analyzed the case of the elimination of the tripartite subsidy for cattle and hog farmers in Canada, and the development of private market instruments to deal with price risk. Since not only producers but also meat packers and processors faced price risk, Bailey & Brorsen (1985) suggest that packers could sign short-term contracts with buyers and reduce price risk by following a routine long-hedging strategy. More recently, Muth et al. (2008) analyze fed cattle price and price risk differences across marketing arrangements and find that they offered the best tradeoff between price level and price risk; forward contracts and auction barns prices were more volatile. Neyhard et al. (2013) perform simulations on combinations of futures and options contracts on milk and feed for a representative dairy farm and find that they do not improve the level or reduce the variance of net farm income, compared to the current marketing procedure (monthly cash milk pricing and monthly feed purchases), which seems to be a strong built-in natural hedge for dairy farmers. In a similar manner, Bloznelis (2018) finds that hedging price uncertainty of salmon with its futures is only moderately effective.

Addressing hedging over multiple commodities, Al Janabi (2009) proposes using the liquidity-adjusted value-at-risk method to handle market risk analysis under normal and severe market settings simultaneously, taking into account the effects of illiquidity of traded commodities. For cattle in Texas, Power et al. (2013) find the nonparametric copula-based GARCH dynamic model performs better than other hedging models in terms of lower tail risk (i.e., expected shortfall), but that there is no significant difference in terms of portfolio variance reduction.

Finally, Welch et al. (2013) suggest that there is a need for farmers training on market-based hedging instruments, as they find that farmers who received intensive risk management training are more likely to hedging with futures and options.

4.4. The Role of Insurance

If price stabilization is not a good solution to the problem of price risk in the developing world, and if futures markets and other risk-management instruments are not widely available in developing countries, can insurance play a role?

A recent albeit narrow literature has focused on price-risk insurance schemes. Arai (1994) elucidated the issue of optimal insurance against consumption price risk. The author used a fixed-wage contract and a fixed-utility wage contract to show that, under the optimal contract, the welfare of the insured will be larger than under price certainty. Goodwin et al. (2000) evaluate the distributional implications of different non-market-based methods for estimating price risk and deriving insurance premium rates. Mahul (2000) examines the design of an optimal policy where price risk is uninsurable (i.e., cannot be hedged against), but where crop insurance is available under which the producer selects a yield guarantee and a price at which a unit loss of output is compensated, and he finds that price risk induces prudent producers to reduce their optimal price choice.

Some studies have compared other hedging or insurance mechanisms with price risk insurance. Wojciechowski et al. (2000) suggest that existing marketing tools and insurance can be used to reduce cotton producers' revenue risk in Georgia, but the optimal level of yield and price insurance coverage depends on an individual producer’s risk aversion. Coble & Knight (2002) state that, traditionally in the US, crop insurance has been a mechanism to protect against yield risk while futures and price-oriented government programs have been used to protect against price risk, but the recent introduction of crop revenue insurance has distorted their separation. Mahul (2003) shows that futures and crop yield insurance are complements for French wheat farms while futures and crop revenue insurance are substitutes. Bielza et al. (2007) analyze the problem of choosing between alternative market risk management instruments (hedging with futures, forward contracts and insurance) for Spanish potato producers, and they find that revenue insurance subsidies are generally inefficient and that futures do not provide a cost-effective means to manage price risks.

Some authors have looked at the interlinking of credit and price risk insurance. Karlan et al. (2011) find that loans with an indemnity that forgives 50 percent of the loan if crop prices drop below a certain threshold (compared to a standard loans) have a high uptake rate, but the indemnity has little impact on uptake or other outcomes of interest. This suggests linking loans to price insurance may not be the most effective way to hedge against price risk. Shee & Turvey (2012), however, find that risk-contingent credit, when applied to the cash-price risk of Indian pulse crops, can increase the supply of credit to collateral-constrained limited resource farmers.

More recent papers have tried to determine what the optimal price risk insurance looks like. Maré, et al. (2015) calculate the maximum value of crop hail insurance under price risk and stochastic yield. Goodwin et al. (2018) suggest that the Black-Scholes option pricing model used by the USDA to measure the variance of expected (harvest-time) prices, which is used in rating revenue coverage in the federal crop insurance program, is preferred to other alternatives.

Finally, Bellemare et al. (2019) document how participation in agricultural value chains allows producers to partially insure against price risk. Using survey data from Madagascar, they show that the incomes of households that participate in contract farming as growers are significantly less variable than the incomes of other households. They further show that the mechanism whereby this happens is via fixed-price contracts (i.e., forward pricing), which allows households to transfer part of the (price) risk they face to processors. This means that contract farming can effectively serve as partial insurance in situations of insurance market failures, which are common in developing countries.

4.5. Experimental Approaches to Price Risk

As Bellemare & Lee (2016) suggest, experimental-economic methods can inform our understanding of price risk, and so we briefly discuss the nascent experimental literature on price risk.

Hey (1993) explored how individuals tackle a complex dynamic storage decision-making problem under price risk (how much inventories to hold to spread price risk over time) and finds that subjects perform better with time, but they do not behave in line with expected utility theory.

In experiments conducted in experimental labs at two US universities and in the field with farmers in Peru, Bellemare et al. (2019) study the effect of price risk on producer behavior. Using a protocol that mimics Sandmo's (1971) theoretical framework, they find that contrary to Sandmo's theoretical prediction, producers (including risk-averse producers) do not respond to the presence of price risk by

decreasing the quantity they choose to produce. Further, they find that as the degree of price risk increases conditional on their already being some price risk, subjects decrease how much they produce, which is consistent with decreasing absolute risk aversion (Batra & Ullah 1974). Ultimately, they find that producer responses to price risk are nonmonotonic and generally inconsistent with expected utility theory, and they provide some evidence that prospect theory might be better suited to explain producer behavior in the face of price risk.

5. Summary and Concluding Remarks

From the very first two papers introducing price instability to the economic analysis of the behavior of consumers (Waugh 1944) and producers (Oi 1961), it has been suggested that price stabilization is not beneficial. As it turns out, however, further theoretical developments have shown that under certain conditions, and for certain agents, price stabilization can indeed be beneficial.

One the one hand, empirical studies suggest however that in general, price stabilization institutions and policy responses which aim at stabilizing prices are costly and have been beneficial only in a few specific cases. Moreover, price stabilization does not seem to benefit those which the policies sought to help: the poorest of small farmers, who tend to be net consumers. On the other hand, market-based instruments to deal with price risk, such as futures markets, are in general good for hedging against price risk, but they are not widely available in developing countries. Additionally, a small number of recent studies suggest there might be a role for insurance against price risk as a hedging mechanism.

Most of the empirical studies reviewed here have tested theoretical findings developed under the broad expected utility theory framework. Only a handful of recent some experimental studies have assessed the pertinence of expected utility theory to explain the decision-making behavior of individuals in the face of price risk.

In sum, our review of the literature suggests that price stabilization is in general not beneficial, so governments should avoid investing in price stabilization policies, or they should at least consider carefully their implications for both consumers and producers. More fruitfully, developing-country governments could promote the creation of futures markets and other market-based price risk management strategies which seem to work well in general, are not costly for governments, and can let farmers decide for themselves whether they want to stabilize their prices.

This review offers multiple avenues for future research. From a theoretical viewpoint, there is a need for developing price risk theories among frameworks beyond expected utility theory, such as prospect theory (Kahneman & Tversky 1979). In addition, it would be useful to explore the implications of looking at price risk over different periods of time and of price series measured at different frequencies, since doing so may lead to very different measures of price risk. Similarly, higher moments of the price distribution may well be useful in studying the behavior of agricultural producers and consumers. Here, a distribution's third moment—its skewness—and its relation to the third derivative of the utility function—which is directly related to a consumer's prudence (Kimball 1990) may be useful in explaining behavior. All of these topics would lend themselves quite well to lab experiments.

We have also found a lack of empirical studies, either observational or experimental, regarding consumer behavior in the face of price risk. Broadening this literature may imply borrowing findings trying to understand consumer behavior processes from the fields of behavioral economics and neuroeconomics, since the prospect of uncertain prices might affect welfare more than the experience of it.

As mentioned before, the literature on insuring price risk is incipient, so there is a need for more studies on the topic which explore conditions the under which insurance can become a useful tool for the management of price risk, especially for small farmers.

In our review of the literature, we found no papers about price ambiguity, or Knightian uncertainty, related to food and agriculture, so this is another possibly fruitful area of research, especially for developing countries, where price forecasting information may be more difficult to come by.

References

Abdulkadri AO, Langemeier MR, Featherstone AM. 2006. Estimating economies of scope and scale under price risk and risk aversion. *Appl. Econ*. 38(2):191–201

Al Janabi MAM. 2009. Commodity price risk management: valuation of large trading portfolios under adverse and illiquid market settings. *J. Deriv. Hedge Funds* 15(1):15–50

Arai K. 1994. The optimal insurance against consumption price risks. *Hitotsubashi J. Econ.* 35(1):23–35

Bailey D, Brorsen BW. 1985. Hedging carcass beef to reduce the short-term price risk of meat packers. *West. J. Agric. Econ.* 10(2):330–37

Bansal RK, Zala YC, Parmar DJ. 2015. Futures market in mitigating price risk: an explorative analysis of castor market. *Indian J. Econ. Dev.* 11(1): 369–77

Baron DP. 1970. Price uncertainty, utility, and industry equilibrium in pure competition. *Int. Econ. Rev.* 11(3):463–80

Barrett CB. 1996a. On price risk and the inverse farm size-productivity relationship. *J. Dev. Econ.* 51(2): 193-215

Barrett CB. 1996b. Urban bias in price risk: the geography of food price distributions in low-income economies. *J. Dev. Stud.* 32(6):830–49

Barrett CB, Luseno WK. 2004. Decomposing producer price risk: a policy analysis tool with an application to northern Kenyan livestock markets. *Food Policy.* 29(4):393–405

Batra RN, Ullah A. 1974. Competitive firm and the theory of input demand under price uncertainty. *J. Pol. Econ.* 82(3):537-48

Bellemare MF. 2015. Rising food prices, food price volatility, and social unrest. *Am. J. Agric. Econ.* 97(1):1-21

Bellemare MF, Barrett CB, Just DR. 2013. The welfare impacts of commodity price volatility: evidence from rural Ethiopia. *Am. J. Agric. Econ.* 95(4):877-99

Bellemare MF, Barrett CB, Just DR. 2016. The welfare impacts of commodity price volatility: reply. *Am. J. Agric. Econ.* 98(2):676-78

Bellemare MF, Lee YN. 2016. Attitudes to price risk and uncertainty: the earnest search for identification and policy relevance. *Can. J. Agric. Econ.* 64(4):599–612

Bellemare MF, Lee YN, Just DR. 2019. Producer attitudes toward output price risk: experimental evidence from the lab and from the field. *Am. J. Agric. Econ.* In press.

Bellemare MF, Lee YN, Novak L. 2019. *Contract farming as partial insurance.* Work. Pap., Univ. Minn.

Bielza M, Garrido A, Sumpsi JM. 2007. Finding optimal price risk management instruments: the case of the Spanish potato sector. *Agric. Econ.* 36:67–78

Bloznelis D. 2018. Hedging salmon price risk. *Aquac. Econ. Manag.* 22(2):168–91

Braga F. 1996. Over-the-counter derivatives and price risk management in a post-tripartite environment: the case of cattle and hogs. *Can. J. Agric. Econ.* 44(4):369–74

Branch W, Tilley DS. 1991. Catfish producer harvest response to production and asymmetric price risk. *South. J. Agric. Econ.* 23(2): 29–38

Brewin DG. 2014. Limitations on the market power generated by the single desk of the Canadian Wheat Board. *Can. J. Agric. Econ.* 62(4):491–517

Broll U, Welzel P, Wong KP. 2013. Price risk and risk management in agriculture. *Contemp. Econ.* 7(2):17–20

Brown A, Ortmann GF, Darroch MAG. 2000. Factors affecting the use of price risk management tools by large commercial maize producers in South Africa. *S. Afr. J. Econ. Manag. Sci*. 3(1):75–96

Chambers RG, Grant S, Polak B, Quiggin J. 2014. A two-parameter model of dispersion aversion. *J. Econ. Theory.* 150:611–41

Chavas J-P, Holt MT. 1990. Acreage decisions under risk: the case of corn and soybeans. *Am. J. Agric. Econ.* 72(3):529–38

Clark JS, Fleming CS. 1990. Estimating price distortions caused by Canadian Wheat Board initial payment policy. *Can. J. Agric. Econ.* 38(4):923–30

Coble KH, Knight TO. 2002. Crop insurance as a tool for price and yield risk management. In *A Comprehensive Assessment of the Role of Risk in U.S. Agriculture*, ed. RE Just, RD Pope, pp. 445–68. Boston: Springer

Coffey BK. 2001. An analysis of the effects of feed ingredient price risk on the selection of minimum cost backgrounding feed rations. *J. Agric. Appl. Econ.* 33(2): 353–65

Coyle BT. 1992. Risk aversion and price risk in duality models of production: a linear mean-variance approach. *Am. J. Agric. Econ.* 74(4): 849–59

Coyle BT. 1994. Risk aversion and price risk in duality models of production: reply. *Am. J. Agric. Econ.* 76(2):320–23

Coyle BT. 2007. Aggregation of price risk over commodities: an economic index number approach. *Am. J. Agric. Econ.* 89(4):1085–97

Dana J, Gilbert CL, Shim E. 2006. Hedging grain price risk in the SADC: case studies of Malawi and Zambia. *Food Policy.* 31(4): 357–71

Deschamps R. 1973. Risk aversion and demand functions. *Econometrica* 41(3): 455-65

Driscoll P. 1994. Risk aversion and price risk in duality models of production: comment. *Am. J. Agric. Econ.* 74(4): 318–19

Fafchamps M. 1992. Cash crop production, food price volatility, and rural market integration in the Third World. *Am. J. Agric. Econ.* 74(1):90–99

Faruqee R, Coleman JR, Scott T. 1997. Managing price risk in the Pakistan wheat market. *The World Bank Econ. Rev.* 11(2):263–92

Feige EL, Pearce DK. 1976. Economically rational expectations: are innovations in the rate of inflation independent of innovations in measures of monetary and fiscal policy? *J. Pol. Econ.* 84(3):499–522

Finkelshtain I, Chalfant JA. 1991. Marketed surplus under risk: do peasants agree with Sandmo? *Am. J. Agric. Econ.* 73(3):557–67

Finkelshtain I, Chalfant JA. 1997. Commodity price stabilization in a peasant economy. *Am. J. Agric. Econ.* 79(4):1208–17

Fousekis P, Pantzios C. 2000. Output price risk and productivity growth in Greek agriculture. *SPOUDAI*. 50(3–4):106–24

Fulton ME, Reynolds T. 2015. The political economy of food price volatility: the case of Vietnam and rice. *Am. J. Agric. Econ.* 97(4):1206–26

Gardner BL. 1976. Futures prices in supply analysis. *Am. J. Agric. Econ.* 58(1):81–84

Gemech F, Mohan S, Reeves A, Struthers J. 2011. Market-based price-risk management: welfare gains for coffee producers from efficient allocation of resources. *Oxf. Dev. Stud*. 39(1):49-68

Goodwin BK, Harri A, Rejesus RM, Coble KH. 2018. Measuring price risk in rating revenue coverage: BS or no BS? *Am. J. Agric. Econ.* 100(2):456-78

Goodwin BK, Roberts MC, Coble KH. 2000. Measurement of price risk in revenue insurance: implications of distributional assumptions. *J. Agric. Resour. Econ.* 25(1):195–214

Gouel C. 2014. Food price volatility and domestic stabilization policies in developing countries. In *The Economics of Food Price Volatility*, ed. Chavas J-P, Hummels D, Wright BD, pp. 261–306. National Bureau of Economic Research. University of Chicago Press

Gouel C, Gautam M, Martin WJ. 2016. Managing food price volatility in a large open country: the case of wheat in India. *Oxf. Econ. Pap.* 68(3): 811–35

Gustafson R. 1958. *Carryover levels for grains: a method for determining amounts that are optimal under specific conditions*. Tech. Bull. 1178, US Dep. Agric., Washington, DC

Haile MG, Kalkuhl M, von Braun J. 2014. Inter- and intra-seasonal crop acreage response to international food prices and implications of volatility. *Agric. Econ.* 45(6):693–710

Hanoch G. 1977. Risk aversion and consumer preferences. *Econometrica* 45(2):413-26

Hey JD. 1993. Dynamic decision making under uncertainty: an experimental study of the dynamic competitive firm. *Oxf. Econ. Pap.* 45(1):58–82

Hill RV. 2010. Liberalisation and producer price risk: examining subjective expectations in the Ugandan coffee market. *J. Afr. Econ.* 19(4):433–58

Holt MT. 1989. Bounded price variation models with rational expectations and price risk. *Econ. Lett.* 31:313–17

Holt MT, Aradhyula SV. 1990. Price risk in supply equations: an application of GARCH time-series to the U.S. broiler market. *South. Econ. J.* 57(1):230–42

Hueth B, Ligon E, Wolf S, Wu S. 1999. Incentive instruments in fruit and vegetable contracts: input control, monitoring, measuring, and price risk. *Rev. Agric. Econ.* 21(2):374–89.

Hueth B, Ligon E. 1999. Producer price risk and quality measurement. *Am. J. Agric. Econ.* 81(3):512–24

Hurt CA, Garcia P. 1982. The impact of price risk on sow farrowings, 1967-78. *Am. J. Agric. Econ.* 64(3):565–68.

Jaffe S, Minton R, Mulligan CB, Murphy KM. 2019. *Chicago Price Theory*. Princeton/Oxfordshire: Princeton University Press

Jayne TS, Myers RJ, Nyoro J. 2008. The effects of NCPB marketing policies on maize market prices in Kenya. *Agric. Econ.* 38:313–25

Jordaan H, Grové H. 2008. Factors affecting the use of forward pricing methods in price risk management with special reference to the influence of risk aversion. *Agrekon* 47(1):102–15

Kahneman D, Tversky A. 1979. Prospect theory: an analysis of decision under risk. *Econometrica* 47(2): 263–92

Karlan D, Kutsoati E, McMillan M, Udry C. 2011. Crop price indemnified loans for farmers: a pilot experiment in rural Ghana. *J. Risk Insur.* 78(1):37–55

Kimball M. 1990. Precautionary saving in the small and in the large. *Econometrica* 58(1):53–73

Krause MA, Koo WW. 1996. Acreage responses to expected revenues and price risk for minor oilseeds and program crops in the Northern Plains. *J. Agric. Resour. Econ.* 21(2):309–24

Kurosaki T. 1996. Government interventions, market integration, and price risk in Pakistan's Punjab. *Pak. Dev. Rev.* 35(2):129–44

Ladd GW, Hanson SD. 1991. Price-risk management with options: optimal market positions and institutional value. *J. Futur. Mark.* 11(6):737–50

Lee YN. 2019. *Does food price volatility drive migration? Evidence from rural Ethiopia*. Work. Pap., Univ. Guelph

Lu Y, Neftci S. 2008. *Financial instruments to hedge commodity price risk for developing countries*. Work Pap. 08/6, Int. Monet. Fund

Mahul O. 2000. Optimum crop insurance under joint yield and price risk. *J. Risk Insur.* 67(1):109–22

Mahul O. 2003. Hedging price risk in the presence of crop yield and revenue insurance. *Eur. Rev. Agric. Econ.* 30(2):217–39

Maré F, Grové B, Willemse J. 2015. Estimating the maximum value of crop hail insurance under stochastic yield and price risk. *Agrekon* 54(4):28–44

Mas-Colell A, Whinston MD, Green JR. 1995. *Microeconomic Theory*. New York/Oxford: Oxford University Press

Mason NM, Myers RJ. 2013. The effects of the Food Reserve Agency on maize market prices in Zambia. *Agric. Econ.* 44:203-16

Massell BF. 1969. Price stabilization and welfare. *Q. J. Econ.* 83(2):284–98

Massell BF. 1970. Some welfare implications of international price stabilization. *J. Pol. Econ.* 78(2):404–17

Mattos FL, Zinn J. 2016. Formation and adaptation of reference prices in grain marketing: an experimental study. *Agric. Econ.* 47(6):621–32

McBride L. 2016. A comment on “The welfare impacts of commodity price volatility: evidence from rural Ethiopia”. *Am. J. Agric. Econ.* 98(2):670–75

McCall JJ. 1967. Competitive production for constant risk utility functions. *Rev. Econ. Stud.* 34(4):417–20

McKenzie AM, Kunda EL. 2009. Managing price risk in volatile grain markets, issues and potential solutions. *J. Agric. Appl. Econ.* 41(2):353–62

Meyer J. 1987. Two-moment decision models and expected utility maximization. *Am. Econ. Rev.* 77(3):421–30

Min JH, Kaiser HM. 2014. A note on the role of price risk in soya bean supply functions. *Appl. Econ. Lett.* 21(1):55–59

Mohan S. 2007. Market-based price-risk management for coffee producers. *Dev. Pol. Rev.* 25(3):333–54

Mohan S, Love J. 2004. Coffee futures: role in reducing coffee producers’ price risk. *J. Int. Dev.* 16(7):983–1002

Morgan CW. 2001. Commodity futures markets in LDCs: a review and prospects. *Prog. Dev. Stud.* 1(2):139–50

Morgan CW, Rayner AJ, Vaillant C. 1999. Agricultural futures markets in LDCs: a policy response to price volatility? *J. Int. Dev.* 11(6):893–910

Moschini G, Lapan H. 1992. Hedging price risk with options and futures for the competitive firm with production flexibility. *Int. Econ. Rev.* 33(3):607–18

Muth JF. 1961. Rational expectations and the theory of price movements. *Econometrica* 29(3):315–35

Muth MK, Liu Y, Koontz SR, Lawrence JD. 2008. Differences in prices and price risk across alternative marketing arrangements used in the fed cattle industry. *J. Agric. Resour. Econ.* 33(1):118–35

Nerlove M. 1956. Estimates of the elasticities of supply of selected agricultural commodities. *J. Farm Econ.* 38(2):496–509

Newbery DMG, Stiglitz JE. 1981. *The Theory of Commodity Price Stabilization: A Study in the Economics of Risk*. Oxford/New York: Clarendon Press, Oxford University Press

Neyhard J, Tauer L, Gloy B. 2013. Analysis of price risk management strategies in dairy farming using whole-farm simulations. *J. Agric. Appl. Econ.* 45(2):313–27

Oi WY. 1961. The desirability of price instability under perfect competition. *Econometrica* 29(1): 58-64

Pierre G, Pauw K, Magrini E. 2018. The effect of the National Food Reserve Agency on maize market prices in Tanzania. *Rev. Dev. Econ.* 22(2): 540–57

Pieters H, Swinnen J. 2016. Trading-off volatility and distortions? Food policy during price spikes. *Food Policy* 61:27-39

Pluske J, Fraser R. 1995. Can producers place valid and reliable valuations on wool price-risk information? *Rev. Mark. Agric. Econ.* 63(2):284–91

Power GJ, Vedenov DV, Anderson DP, Klose S. 2013. Market volatility and the dynamic hedging of multi-commodity price risk. *Appl. Econ.* 45(27):3891–903

Quiggin J, Chambers RG. 2004. Invariant risk attitudes. *J. Econ. Theory* 117: 96–118

Rashid S. 2015. *Commodity exchanges and market development: what have we learned?* Paper presented at the 29th International Conference of Agricultural Economists, Milan.

Revoredo-Giha C, Zuppiroli M. 2013. Commodity futures markets: are they an effective price risk management tool for the European wheat supply chain? *Bio-based Appl. Econ.* 2(3):237–55

Ridier A, Jacquet F. 2002. Decoupling direct payments and the dynamics of decisions under price risk in cattle farms. *J. Agric. Econ.* 53(3):549–65

Rothschild M, Stiglitz JE. 1970. Increasing risk: I. a definition. *J. Econ. Theory* 2(3):225–43

Sandmo A. 1971. On the theory of the competitive firm under price uncertainty. *Am. Econ. Rev.* 61:65-73

Schaufele B, Unterschultz JR, Nilsson T. 2010. AgriStability with catastrophic price risk for cow-calf producers. *Can. J. Agric. Econ.* 58(3):361–80

Schmitz A, Shalit H, Turnovsky SJ. 1981. Producer welfare and the preference for price stability. *Am. J. Agric. Econ.* 63(1):157–60

Seale JL, Shonkwiler JS. 1987. Rationality, price risk, and response. *South. J. Agric. Econ.* 19(1):111–18

Serra T, Gil JM. 2013. Price volatility in food markets: can stock building mitigate price fluctuations? *Eur. Rev. Agric. Econ.* 40(3):507–28

Shee A, Turvey CG. 2012. Collateral-free lending with risk-contingent credit for agricultural development: indemnifying loans against pulse crop price risk in India. *Agric. Econ.* 43(5):561–74

Singh I, Squire L, Strauss J. 1986. *Agricultural Household Models: Extensions, Applications, and Policy*. Baltimore: Johns Hopkins University Press, World Bank research publication

Singh NP, Shunmugam V, Garg S. 2009. How efficient are futures market operations in mitigating price risk? An explorative analysis. *Indian J. Agric. Econ.* 64(3): 324–32

Stiglitz JE. 1969. Behavior towards risk with many commodities. *Econometrica* 37(4):660–67

Tickner V. 2008. Africa: international food price rises & volatility. *Rev. Afr. Pol. Econ.* 35(117):508–14

Tomek WG, Kaiser HM. 2014. *Agricultural Product Prices*. Ithaca/London: Cornell University Press. 5th ed.

Tronstad R, McNeill TJ. 1989. Asymmetric price risk: an econometric analysis of aggregate sow farrowings, 1973-86. *Am. J. Agric. Econ.* 71(3):630–37

Turnovsky SJ, Shalit H, Schmitz A. 1980. Consumer's surplus, price instability, and consumer welfare. *Econometrica* 48(1):135-52

Varkey LM, Kumar P. 2013. Price risk management and access to finance for rubber growers: the case of Price Stabilisation Fund in Kerala. *Indian J. Agric. Econ.* 68(1):67–88

Waugh FV. 1944. Does the consumer benefit from price instability? *Q. J. Econ.* 58(4):602–14

Waugh FV. 1964. Cobweb models. *J. Farm Econ.* 46(4):732–50

Waugh FV. 1966. Consumer aspects of price instability. *Econometrica* 34(2):504–08

Welch M, Anderson D, Robinson J, Waller M, Bevers S, et al. 2013. Have concerns over futures market integrity impacted producer price risk management practices? *Choices* 28(4)

White B, Dawson PJ. 2005. Measuring price risk on UK arable farms. *J. Agric. Econ.* 56(2):239–52

Wojciechowski J, Ames GCW, Turner SC, Miller BR. 2000. Marketing of cotton fiber in the presence of yield and price risk. *J. Agric. Appl. Econ.* 32(3):521–29

Wright BD, Williams JC. 1984. The welfare effects of the introduction of storage. *Q. J. Econ.* 99:169-92