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The Soybean Processing Decision

Exercising a Real Option on Processing Margins

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Abstract

The gross soybean processing margin (the gross return per bushel of soybeans processed) is the main decision variable that processors use in deciding when and if to make binding commitments to process soybeans on future dates. Understanding how processors choose processing margins for future processing dates from among those available on successive days may help to resolve the ongoing concern about the level of competitiveness in processing agricultural commodities. Processing returns are treated as being equivalent to the returns to a call option. This approach provides the opportunity to simulate processor choice of processing margin by evaluating the incentive of waiting for a larger processing margin versus the incentive of locking in the currently available processing margin for a future date. The approach captures the irreversibility of the decision to process soybeans. Once the decision is made to process soybeans it cannot be economically reversed because of the contractual penalties involved. Processing margins selected using evaluations of these incentives explained variation in soybean crush, whereas spot margins for the corresponding processing dates did not.

Keywords: real options, option exercise, processing decision, processing margins, futures prices, soybean crush

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Summary

The soybean processing decision is a complex decision concerning when and if to commit to employing soybean-processing resources on future dates. Understanding this decision may help to resolve the ongoing concern about the level of competition in processing agricultural commodities.

The decision when and if to process soybeans for a future date can be postponed until the date arrives. Further postponement is not possible when a future date arrives. In this situation, it must be decided to use the processing resources or idle them and forever lose the date's processing capacity. In addition, deciding to commit or pledging to use processing resources on a future date is economically irreversible because of the penalties involved in not fulfilling the commitment.

The key decision variable concerning when and if to commit processing resources on a future date is the soybean gross processing margin (GPM) for that date. GPM is the soybean meal plus soybean oil revenue per bushel of soybeans processed minus the soybean (per bushel) price. GPM can be "locked in" for a future date by committing to employ soybean processing resources on the date. The commitment is made by committing to deliver soybean oil and meal on the date at agreed-to prices and committing to accept delivery of soybeans on the date at an agreed price. Soybean processors each day can calculate the GPM on future dates using the observed futures prices of soybeans, soybean meal, and soybean oil on future dates. Each day, a processor must decide whether a GPM for a future date is high enough to accept or too low to accept. If the GPM is high enough, the processor will commit soybean-processing resources for that date. If the GPM is too low to accept, the processor keeps the processing resources available for a future date and a higher GPM.

The GPM that soybean processors receive from processing soybeans can be viewed as the returns to a call option. An option provides the right but the not the obligation to make a decision. Typically the right has an expiration date. Once the decision is made (the right exercised), it is irreversible. A call option provides the right to buy (receive) an asset by paying an exercise price. Using this right is called exercising the option. If an option involves the returns of a physical asset, it is called a real option.

Soybean processors in effect have a real call option on their processing resources. They can receive returns equal to the GPM by paying variable processing cost, their exercise price, or they can choose not to produce and wait for a larger GPM.

Viewing the returns to soybean processing as the returns to a call option provides opportunities to examine incentives faced by soybean processors, to simulate soybean processor decisions, and to measure processing returns. All are important in examining the level of competitiveness in soybean processing.

A recently developed option pricing model in conjunction with futures prices for soybeans,

soybean meal, and soybean oil was used to simulate decisions made by soybean processors. The futures prices were used to calculate daily GPMs that are available for future dates and the option-pricing model was used to choose the GPM levels instead of a soybean processor. A GPM was chosen for a processing date when the estimated value of waiting for a larger margin first fell to zero. The option-pricing model provided estimates of the value of waiting.

The futures GPMs chosen by the option-pricing model explained a significant amount of the variation in monthly soybean crush. A similar examination using spot GPMs did not. In addition, the examination indicated that the curve of the relationship between crush and the chosen futures GPMs becomes flatter as the soybean-processing capacity limit is approached, as suggested by economic theory. That is, as the capacity limit is approached, it takes successively larger increments of GPM to commit a given increment in the amount crushed.

The examination also showed the importance of controlling for the effect of processing capacity on the soybean processing decision when estimating the effect of GPM on the amount crushed. Capacity was controlled for by using percent capacity used and capacity not used as alternative dependent variables to be explained by the chosen futures and spot GPMs. The two dependent variables also offer ways to correct for a unit root in monthly crush. The correction is due to soybean-processing industry investment that increases capacity when tight and industry abandonment that reduces capacity when in excess.

The procedures developed in this bulletin may be helpful in understanding the meat processor (packer) behavior involved in selecting forward prices for purchasing cattle, hogs, and sheep from farmers reported under the Mandatory Livestock Reporting Act of 1999. Forward selling prices available on the dates of the reported forward purchase prices can be used along with the reported purchase prices to estimate forward GPMs. These estimated GPMs then could be examined using the procedures developed here.

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Introduction

The decision to process soybeans is treated in this report as the equivalent of a decision to exercise a call option. Such an approach provides a way to explore the incentive to process soybeans and a way to explore the measurement of processing margins.

The determination and measurement of processing margins are important in the debate about the level of competition in food processing. Much of the debate focuses on the concern that processor contracting may be reducing the level of competition. However, contracting is frequently the way that processors insure adequate commodity supply and the way they price margin prior to processing. A major problem inhibiting progress in this debate is that the timing of the decisions to process as well as the prices involved have been proprietary information, making it difficult to measure and examine processing margins. This report examines historical soybean processing margin data using an appropriate option valuation model to determine if progress in understanding and measuring processing margins can be made without using proprietary information.[1]

The prices used in this bulletin are futures-contract prices for soybeans and soybean products. Forward-contract prices for soybeans and product, if available, could also have been used. In addition, futures and forward contract prices for other commodities and products can be used to examine the determination and measurement of processing margins.

The examination that follows shows that frequently there is an economic incentive to buy soybeans and to sell product with futures contracts prior to processing. It also shows that the soybean processing margin when this economic incentive first occurs is a better measure of the processing margin used by soybean processors than is the margin measured by spot prices at the time of processing.[2]

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[1] The Mandatory Livestock Reporting Act of 1999 requires meatpackers (processors) to report the forward contract prices paid to cattle, hog, and sheep producers. These new price data will offer better measurement of processing margins. The new data will also beg for an explanation of the timing of meatpacker decisions to buy livestock from farmers and hence provide opportunities to explore the notion that meatpackers view their processing margins like returns to call options.

[2] The farm to retail margin reported by the Economic Research Service, which includes the processing margin, has been measured using spot prices. Using the reported forward purchase prices required by the Mandatory Livestock Reporting Act of 1999 will improve the measurement of the farm to retail margin for cattle, hogs, and sheep.

The processing and the option exercising decisions are equivalent and, consequently, result in the same returns when three conditions are met:

- the option-exercise price equals variable processing cost,
- the soybean processing and the option exercise decisions are based on the same gross processing margin (GPM), and
- processors treat the decision to commit processing resources in a manner similar to the decision to exercise a call option on the GPM, and the processing commitment is made (the option is exercised) when the time value of waiting to decide falls to zero.

The GPM in this report is valued using the futures prices for soybeans, soybean meal, and soybean oil. It is the price of (revenue from) the meal plus oil per bushel of soybeans processed minus the price (cost) of a bushel of soybeans. Variable processing cost is the marginal cost of converting one bushel of soybeans into meal and oil. It is the cost that is avoided by deciding not to process soybeans.

The first condition imposes no restrictions on a call option. Exercise price can be set at any level. Soybean processors often use the futures market to price processing returns. Consequently, the second condition imposes no unusual restrictions on the soybean processing decision. The validity of the third condition is an unknown that is examined here.

Soybean Processing as a Real Option

The large and growing literature that treats the decision to invest as equivalent to the decision to exercise a call option provides help in understanding the decision to process soybeans (Amram and Kulatilala; Hubbard; and Trigeorgis). Options on investment opportunities in physical assets and on the use of existing physical assets—buildings, equipment, and land—are known as real options.

The exercise price of a call option on an investment opportunity is the cost of the investment (the amount invested), and the gross option return is the discounted expected value of the investment returns. This type of call option is exercised (the investment is made) when the gross return rises above the exercise price sufficiently to compensate for loss of the flexibility to delay. Flexibility to delay would have no value if an investment decision could be undone without cost. The soybean processing decision is examined, in part, by examining how much the GPM must rise above variable processing costs to compensate for the loss of the flexibility to delay. Similarly, the flexibility to delay processing decisions would have no value if unfulfilled processing commitments could be canceled or disregarded without cost and replaced with "commitments" that offer a processor a higher margin.

Examining investment decisions as a decision to exercise or hold a call option has been shown to be a useful approach for a public entity or a conservation trust in estimating the amount of compensation to offer landowners for selling some of their investment options (development rights) (Wiebe, Tegene, and Kuhn). The investment options in that case are conservation easements that restrict development (investment) choices. Examining the investment decision this way is similar to evaluating how much to offer a soybean processor to sell processing capacity (resources). Uncommitted capacity provides a processor the right but not the obligation (a real option) to process soybeans.

An approach used in the real option's literature is to consider the per period (for example, annual) production capacities provided by an investment as offering a series of call options on the capacity (McLaughlin and Taggart). These call options are called production options by McLaughlin and Taggart and are contained within (imbedded in) an investment option.[3]

Each production option has a gross return equal to the price of the output minus variable costs or zero depending on whether the price of the output turns out to be larger or smaller than variable costs, respectively. The sum of the discounted estimated values of these per period call options estimates the expected returns to capacity (capital). The production options examined by McLaughlin and Taggart are similar to the call options on the GPM examined in this bulletin.

Investment options with their imbedded production and other options can be valued using option valuation models developed for exchange-traded options or valued using option valuation models that are derived to account for special conditions of the investment decision (Tegene, Wiebe, and Kuhn). The valuation requirements are an appropriate option valuation model and data that tracks the returns to an investment (Amram and Kulatilaka). The tracking assets in this bulletin are soybeans, soybean meal, and soybean oil, and the production resources are soybean-processing capital.

McLaughlin and Taggart specified their production options as European call options and suggested that these options could be valued using the Black-Scholes option valuation model (Black and Scholes). This option valuation model is not appropriate for examining the soybean GPM, because it does not allow for less than zero gross returns, that is, for an inverse crush where product revenue is less than the price of soybeans. An option valuation model that allows negative GPM outcomes is used in this report to examine the soybean processing decision.

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[3] Production options, abandonment options, alternative-capital-use options, and follow-on investment options imbedded within an investment option are frequently used in the literature of real options (Trigeorgis). Imbedded options introduce decisionmaking following a decision to invest. The subsequent decisionmaking increases the expected value of potential investments by cutting losses from bad outcomes and by increasing returns from taking advantage of new opportunities. A production option offers the ability to cut losses from bad outcomes.

McLaughlin and Taggart make explicit the notion that an investment decision is influenced by the operating-decision rule(s) about how the resulting capital is to be used. The operating rule for their production option is that the decision to (not to) produce will be made if returns turn out to be greater (less) than variable costs at the beginning of a production period. Their examination, however, did not include the possibility of exercising an option to produce prior to a production period. Doing so would include additional decisionmaking, about when to commit production capacity. Implicitly, the decision they examine is based on spot prices at the beginning of the production period. This bulletin examines the decision to commit soybean processing resources by examining the incentive to exercise the option to process soybeans prior to production (processing) periods.

The central question in the real option's literature is, "How much, if any, does the value of an investment opportunity have to increase to reduce to zero the value of waiting for a larger investment return? " This bulletin uses an option valuation model to examine an operating decision—the decision to commit existing soybean-processing resources. An important question examined here is, "How much, if any, does the GPM have to increase to reduce to zero the value of waiting for a larger GPM? " [4]

The exercise of a call option is the purchase of the underlying option asset (e.g., the GPM) at the exercise price. Soybean processors do not, however, buy the GPM at the exercise price. They do something equivalent—they make a commitment to produce the GPM at variable cost. Committing to own the GPM whether by committing to buy it or produce it at a later date is equivalent to committing to a long position in soybean product and a short position in soybeans at a later date.

The notion that the option to produce product is exercised just before or in conjunction with selling the GPM is important because ignoring the exercise of this option by just concentrating on selling the GPM at its current price misses a key factor in the decision to process.[5] It misses considering the flexibility to delay making a commitment to produce product, that is, the

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[4] Investment and processing decisions are inverses of one another. The investment decision is concerned with converting liquid assets into fixed assets. The processing decision is concerned with converting fixed assets into liquid assets.

A holder of an investment option has a long position in liquid assets and decides if and when to convert these assets into fixed assets with a stochastically fluctuating benefit. In the real options literature, the conversion is made when the expected value of the benefit increases sufficiently above the cost of the investment. A holder of a fixed asset decides if and when to commit the use of the fixed asset for each period in a series of production periods over the life of the investment. The decision is made to commit the investment resources prior to a production period when the return or margin for the period rises sufficiently above the resource's variable costs.

[5] Only considering the sale of the GPM can easily lead to assuming that the GPM is sold when it first becomes larger than variable processing costs. However, when the GPM is larger than variable costs and there is time remaining until the processing period, the best choice, based on the market value of the flexibility to delay, might be to wait rather than to sell the GPM.

flexibility of waiting for a larger margin. This flexibility may have market value implying that it may influence the timing of the decision to produce product. Robert Merton in his Nobel prize lecture stated, ". . . in an uncertain environment having the flexibility to decide what to do after some uncertainty is resolved definitely has value" (Merton, p. 339). The flexibility to delay making a commitment and also the flexibility to make no commitment at all is the essence of an option, regardless of whether it is an exchange-traded option, an investment option, or a production option.

The market value of the flexibility to delay for a processor is the amount, if any, that the GPM would have to increase immediately to drive the option time value to zero and make the option price (premium) equal to the GPM.[6] An appropriate option valuation model can estimate the amount that the GPM would need to increase to make the option premium equal to the GPM and, consequently, provide insight into the decision to commit processing resources immediately or to wait for a larger return.

Grenadier emphases that decisions about option exercise, particularly real options, are made with imperfect information about key variables, particularly the expected variability of the underlying asset(s). Although the soybean GPM is widely traded by simultaneously buying (selling) soybeans and selling (buying) soybean oil and meal on the futures market and on the cash forward market, there is considerable uncertainty about its expected variability over a future period. As a result, prediction of the timing of the decision to commit processing resources, using an option valuation model to estimate the market value of the flexibility of waiting, would likely differ among users of the option valuation approach. Nevertheless, the option approach does offer the possibility of improving our understanding of how processing decisions are made and improving our ability to measure processing margins.

There would be less uncertainty about expected variability if options on the soybean GPM were publicly traded, because option-market prices provide market-determined information about the expected variability of the underlying asset(s). Estimates of the expected variability are made by solving an option valuation model for variability, using a market-option price. The usual procedure is to solve for an option price, using an estimate of market variability.

Grenadier discusses the cascading effect in which the first firm to exercise a real option induces other firms holding similar real options to immediately exercise them. This effect results from imperfect prediction of option value and the conclusion that the firm exercising may have better information. The cascading effect is not examined in this report. Sequences of forward purchase prices reported under the Mandatory Livestock Reporting Act of 1999 may provide opportunities to examine the cascading effect.

[6] The time value of waiting is the amount that an option premium would decrease from its current value to its value at option expiration, if the price of the underlying asset at option expiration were the same as the current level. Option time value is zero when the option expires, because further delay is not possible.

A processor is not likely to exercise the option to produce and then continue to own (hold a long position in) the GPM. This action would subject a processor to needless price risk. For example, a processor could exercise and then, in effect, continue to hold a long position in the GPM until product is produced by committing (contracting) to buy commodity and to sell product at their spot price outcomes on dates appropriate for the future processing period. However, these transactions would expose a processor to the needless potential loss from the spot GPM's being below the processor's variable cost on the contract settlement date. This loss can be avoided by just holding the option to process until the processing date and letting it expire by not producing product. Any gain from contracting on the basis of the spot price outcomes could be matched by just buying commodity and selling product at the spot price outcomes on the appropriate dates.

The preceding argument shows that the option to commit processing resources prior to a processing period must be based on futures and forward prices and not on spot pries.

Literature Review

Studies of the GPM for soybeans have largely focused on developing profitable trading rules from relationships found in historical prices for soybeans, soybean meal, and soybean oil futures (Simon). The trading rules identify when processors and speculators should buy soybeans and sell product. Returns from the trading rules for processors provide profits, if they are larger than the returns from selling the GPM using only spot markets or from selling the GPM by routine hedging in the futures market. Returns from trading rules for speculators, based on buying and selling futures only, provide profits if they are greater than transaction costs.

Trading rules can often be criticized for lack of theoretical support. Those based on reversion to the mean of a GPM may be reflecting a tendency of the GPM to move toward variable costs due to market fundamentals. However, the GPM may not move toward variable costs, as a processing period approaches, if all or most of the processing capacity has been committed.

This report does not draw on the literature that develops normative trading rules by searching for relationships in historical prices. Instead, it draws on a report by Schaub and others and a paper by Paul and Wesson that describe and examine the processing decisions that soybean processors actually make, not on decisions they "should" make.[7] It also draws on a paper that examined USDA-Forest Service auctions of standing timber (Brannman). That paper provides empirical evidence for treating production returns like the returns to call options. McLaughlin and Taggart's discussion on production options imbedded within investment options, mentioned

[7] Surprisingly, only these two papers and two others were found that examined and explained the decisions that soybean processors have made. The other two were not discussed because they combined the soybean storage and processing decisions. This report considers the soybean processing decision as a separate decision. However, the procedures used here can be modified to consider the storage and processing decisions as a joint decision.

earlier, provides conceptual but not empirical support for this report. They did not test their hypothesis of imbedded production options. In addition, this report draws on options trading in the GPM for crude oil refining for hints of how soybean processors might consider their GPM returns.

Schaub and others report that "Soybean processors attempt to 'lock in' through use of the futures market, as much crush as possible when margins are favorable and as little as possible when margins are unfavorable" (p. 24). They also report that the GPM tends to be largest immediately after harvest and then typically declines steadily as the processing season progresses. They did not consider the possibility that exercising the option to process may be linked to the selling decision and that this linkage might provide exceptions to their observation about the timing of the forward-selling decision. If the expected GPM variability is positively related to the size of the GPM and processors treat processing returns as the returns to call options, then processors may at times "lock in" margin later, when the GPM is favorable (large).[8] A large GPM might typically have a high variability, if it generally reflects a scarcity of processing resources (capacity) relative to the demand for these services.

Paul and Wesson specified and estimated shortrun industry supply curves for the quantity of soybeans processed (crushed) using data for the 1952 through 1963 crop years. Supply curves for monthly crush using forward GPM prices provided a statistically significant supply relationship with significant price elasticities ranging from +0.13 to +0.24 (Paul and Wesson, p. 936 and p. 947). The forward GPM prices were based on monthly cash forward prices for soybeans and product with appropriate delivery dates for each processing period.

Paul and Wesson (p. 947) reported that using spot margins, instead of the forward margins to explain monthly crush "… did not yield useful results." Data plots for the forward and spot margins and crush, shown on page 943, are consistent with the estimated supply curves.

The results of their paper suggest that a forward price margin of 1 month measures the soybean GPM more accurately than the spot margin. The option evaluation approach may be able to provide information about the timing of forward sales and, hence, information about which forward price to use.

An observation reported by Brannman, about USDA-Forest Service standing-timber auctions, may provide insight into the decision to process soybeans. The observation is that per unit bid prices for standing timber are positively correlated with contract duration. For example, 5-year contracts generally have higher per unit bid prices than 1-year contracts. Brannman reasoned that a contract offered a series of per period (for example, monthly) call or production options on timber harvesting. The bid price per unit of timber would tend to be higher for the longer contracts because the value of the underlying call or production options tends to increase directly with their time remaining until expiration, reflecting the generally greater probability of

[8] Option time value (other variables held constant) is directly related to GPM variability. Consequently, larger GPM variability may be associated with positive option time values resulting in waiting rather than immediately committing production resources.

a large price increase.

It is a straightforward exercise, using an option valuation model, to demonstrate that the price of a call option on the GPM increases as the time until option expiration is increased, while holding other variables constant (including the GPM). The time value of waiting increases, while the other option-price component, exercise returns, remains the same. The increase in time value implies smaller incentives to exercise, although the option premium increases. The positive relationship between time remaining until option expiration and the option time value, made explicit by an option valuation model, may explain the reluctance of soybean processors to sell the GPM several years prior to processing. Processors cannot capture option time values by selling product and buying soybeans in the forward and future markets. Processors might hedge processing outcomes further into the future by selling call options on the GPM, if they were publicly traded. Hedging by selling call options on the GPM would capture option time values.

The explanation offered by Brannman may not be for an isolated case. Many types of production opportunities, in addition to timber-harvesting opportunities, may be treated by decisionmakers as the returns offered by call options. McLaughlin and Taggart suggest this is the case by specifying an investment option as a series of production options—one for each period of an investment's duration. It is not too farfetched to suspect that soybean processors treat their returns to production capacity like the returns to a call option.

Additional evidence that returns to production opportunities are treated like returns to call options is the trading of call options on the crude oil gross processing margin on the New York Mercantile Futures Exchange. These options, which began trading in 1994, are based on the futures prices for crude oil and refinery products. They would not continue to trade if they did not provide hedging opportunities for refiners in addition to those offered by futures contracts on crude oil and crude oil products. Taking advantage of these additional hedging opportunities requires understanding that the returns on the crude oil GPM are the returns of a real option on existing capital assets.

A crude oil refiner can hedge its collection of real options (one for each production period) from owning refining resources by selling GPM call options that trade on the New York Mercantile Futures Exchange (Shimko). If the futures-exchange call option sold by a refiner expires below its exercise price, the refiner keeps the option premium. However, if the option is exercised against a refiner, because the GPM is larger than the exercise price, then the refiner must provide a payment equal to the GPM minus the exercise price to the option buyer. The refiner keeps the option premium. The first outcome increases income when the GPM outcome is low. The second generally decreases income when the GPM outcome is high. The net result of both outcomes is a decrease in revenue variability. The reduction in revenue variability is controlled by the exercise-price choices of the exchange options sold.

Selecting an Option Valuation Model

An appropriate option valuation model must contain the variables that processors use in deciding to commit processing resources. It must also model these variables in way a that captures the economic incentives faced by processors. This section explains the selection of an option valuation model that fulfills these requirements.

A call option provides the right (without obligation) to buy an asset at a specified price (the exercise price) or to a payment equal to the asset's price minus the exercise price. As mentioned earlier, the exercise prices for the call options examined in this report are processors' variable costs per bushel of soybeans processed. The asset in a call option is defined broadly. It can be anything that has market value, such as a commodity, a financial instrument, an investment opportunity, or physical plant and equipment. It can also be differences in the prices of other assets (Margrabe). The GPM examined in this report is the difference between product price (revenue) per bushel of soybeans processed and soybean price (which is treated like the asset in a call option).

Exercising a call option, even before the expiration date, provides an immediate return equal to the difference between the asset's price and the exercise price. The call option owner may receive a direct payment equal to the difference between the asset's price and the exercise price, or the call option owner may receive the asset in exchange for the exercise price. The two returns are equal except for any transaction costs in immediately selling the asset received. For the soybean processor, however, the GPM is realized only after the soybeans are processed and sold, not when the commitment to process is made (when the option to produce is exercised).

The amount to discount an estimated option premium from only being able to exercise at the beginning of a processing period equals the premium or price difference between an American and a European call option on the GPM. A European option can be exercised only at option expiration. That is, payment equal to the exercise value, the GPM in this report, can be received only at the option's expiration. As a result, European options have lower premiums than American options prior to expiration. We explore the price difference between an American and a European call option on the GPM and the effect this price difference may have on the decision to process.

An option valuation model developed by Rubinstein was chosen to examine the soybean-processing decision because it can estimate the prices of American and European options on the difference between two asset prices (Rubinstein). The option valuation literature refers to this type of option as a spread option.[9] The asset prices in Rubinstein's valuation model can be specified as futures prices. Also, this option valuation model considers the impact of potential negative GPMs (inverse crushes) on option valuation.

[9] Options on two or more assets are called rainbow options in the options valuation literature.

An alternative approach to examining the soybean-processing decision, not considered in this report, involves a slightly different real option. The approach involves examining an option on the soybean GPM where the GPM is valued by selling product in the futures market and buying soybeans in the spot market. Exercising this option involves purchasing soybeans in the spot market and selling product in the futures market. Soybeans are stored until the beginning of the processing period and then used for processing. The returns would be to both storage and processing resources. This real option is not examined in this report. It is an important real option for soybean processors and can be examined using the Rubinstein valuation model.[10]

This report also does not consider the option to store soybean oil or meal after processing to earn storage return. An added complication, also not considered, is to introduce the decision of selling stored soybeans or processing them at the beginning of the processing period, depending on which choice provides the larger revenue.

The Rubinstein Option Valuation Model

This option valuation model uses the bivariate log-binomial probability distribution to estimate option prices based on two assets that may be correlated. It is an extension of the original and widely used Cox-Ross-Rubinstein option valuation model from one to two assets (Cox, Ross, and Rubinstein).

The binomial price movements over a series of equal time intervals until option expiration are made to approximate the continuous price movements from the bivariate lognormal distribution as closely as necessary for estimating option prices. The approximation is improved by reducing the time interval and, consequently, increasing the number of price movements. In addition, the binomial approximation specified by Rubinstein maintains the estimated correlation level between the two asset prices. This capability is crucial for the analysis in this report, because the high level of positive correlation between soybean price and revenue per bushel of soybeans processed has a large influence on the option value and, consequently, on the decision to process.[11]

The description of Rubinstein's option valuation model so far looks like a straightforward simulation of asset and option price outcomes. However, this is not the case.

The price movements of both assets are specified, so that the return on a hedge portfolio of the two assets and a risk-free bond are the same whether both asset movements are up or both down

[10] One of the prices in Rubinstein's option valuation model can be specified to be a spot price and the other a futures price. In this case the soybean price would be a spot price and the revenue per bushel of soybeans would be a futures price or a cash forward price.

[11] Increases in the positive level of correlation between the two asset prices reduce the option price on a GPM (Haug, p. 123).

or whether one is up and the other is down over a time interval. Since the hedge's return is unaffected by the price movements over a time interval, it earns the riskless rate of return—the T-bill rate in this report. In addition, the proportion of the two assets with a risk-free bond in the hedge portfolio is chosen to make the portfolio's return duplicate the option's return, thus making the value of the option equal to the value of hedge portfolio. This approach is an application of the arbitrage option-pricing approach pioneered by Black and Scholes and by Merton and used by Cox, Ross, and Rubinstein for one binomial variable. The portfolio is altered after the two asset price movements over a time interval to keep its value immune from the two price movements over the next time interval. The alteration does not require additional funds nor does it produce revenue.

The price movements of the two assets are specified, so that the total number of price outcomes grows at a manageable rate. Rubinstein achieved a manageable growth rate by requiring alternative combinations of individual movements for the two assets to have the same total possible price movements. If none of the combinations of price movements were equal, then the total number of possible price movements would increase by a factor of 4 each period. The total number of possible joint-price movements for 100 periods would be 2^{200}, a number far too large for each possible outcome to be calculated by a computer program.[12] After 100 price moves by each asset, there are 101 times 101 or 10,201 possible joint-price outcomes in Rubinstein's option valuation model, because many combinations of individual price movements for the two prices are equal. The joint price outcomes are easily handled by systematically arranging them in a 101-by-101 matrix.

The price per bushel of soybeans is specified as the price of asset 1 and the revenue from the meal and oil produced per bushel of soybeans as the price of asset 2 in Rubinstein's model at time M = 0. This is the time when the option is valued. Results are not affected by reversing the asset number designations.

Table 1 shows all the possible combinations of price movements for asset 1 and asset 2 starting at time M = 0 for up to four total price movements. The variables d and u are one downward and upward movement of asset 1. A and B are upward and downward movements of asset 2 associated with an upward movement of asset 1. C and D are upward and downward movements of asset 2 associated with a downward movement of asset 1. The values of d, u, A, B, C, and D are constructed such that each move uA, uB, dC, and dD occurs with 1/4 probability. This simplifies the calculation of option premiums (Briys et al., p. 322). This probability is the so-called risk-neutral probability in the option valuation literature.

The exponents show the number of price movements. For example, d^2 implies two downward moves of asset 1. The sum of the exponents for d and u and for A, B, C, and D show the total number of movements for assets 1 and 2, respectively. The movement combinations, du^3 and B^2AC from M = 4 implies 4 total price moves for asset 1 and 4 price moves for asset 2. The calculated prices of asset 1 and asset 2 for M = 4 for these price moves would be du^3S_1 and

[12] The total number of outcomes after n time periods equals $2^{(2n)}$. For 100 periods, the number of outcomes equals $2^{(200)} = 1.6069 \times 10^{60}$.

$B^2AC\,S_2$, where S_1 and S_2 are the asset prices for M = 0.

The matrix for M = 4 shows all the possible combinations of four price moves for each of the two assets. Similarly, the matrices for M = 1, 2, and 3 show all the possible price combinations for 1, 2, and 3 price moves for each asset. It is straightforward to increase the number of price movements as much as needed for estimating option prices. Increasing the number of price moves to a given expiration date decreases the time interval of each price move. M equal to 100 (100 price moves for each asset) provides sufficient accuracy for the analysis in this report. Option prices are in cents per bushel of soybeans processed and accuracy to the nearest cent is sufficient. Increasing M beyond 100 did not change the option price estimates at this level of accuracy.

The formulas for calculating the individual price movements are shown below (Haug, pp. 122 and 123).

$d = \exp(\mu_1\Delta_t + \sigma_1(\rho\Delta_t)^{(1/2)})$

$u = \exp(\mu_1\Delta_t - \sigma_1(\rho\Delta_t)^{(1/2)})$

$A = \exp[\mu_2\Delta_t + \sigma_2(\rho\Delta_t)^{(1/2)}\ (\rho + (1 - \rho)^{(1/2)})]$

$B = \exp[\mu_2\Delta_t + \sigma_2(\rho\Delta_t)^{(1/2)}\ (\rho - (1 - \rho)^{(1/2)})]$

$C = \exp[\mu_2\Delta_t - \sigma_2(\rho\Delta_t)^{(1/2)}\ (\rho - (1 - \rho)^{(1/2)})]$

$D = \exp[\mu_2\Delta_t - \sigma_2(\rho\Delta_t)^{(1/2)}\ (\rho + (1 - \rho)^{(1/2)})]$

where

$\mu_1 = b_1 - \sigma_1^2/2$

$\mu_2 = b_2 - \sigma_2^2/2$

b_1 = cost of carrying (holding) asset 1

b_2 = cost of carrying (holding) asset 2 [13]

σ_1 = standard deviation of asset 1

σ_2 = standard deviation of asset 2

[13] b_1 and b_2 are zero in this report reflecting the zero cost of holding (storing) a futures contract.

ρ = correlation between asset 1 and asset 2

$\rho\Delta_t$ = time interval size
= time until option expiration divided by the number of price movements specified until option expiration

K = exercise price

Table 2 shows how to use the asset price movements from table 1 to calculate a call option price on the spread, e.g., the soybean GPM, given the two asset prices at M = 0 with option expiration at M = 3.[14] It is straightforward, although tedious, to show the calculations for option expiration at a large M value.[15] Doing so, however, would not provide any additional information about the procedure.

The calculations in table 2 are begun at option expiration, M = 3, by calculating all possible returns to variable processing cost (product revenues per bushel of soybeans processed minus the soybean price minus the exercise price). Return, max[0, $d^3S_1 - D^3S_2 - K$], is one of 16 the possible returns at M = 3. Call option prices are set equal to the calculated returns at option expiration when greater than zero; otherwise, they are set equal to zero. This procedure simulates exercising the option and letting the option expire, respectively. The GPMs resulting from mostly down moves of product price and mostly up moves of soybean price may be less than zero, simulating an inverse crush.

Next, option prices are calculated for M = 2. Each option price is the maximum of immediate exercise value for its M = 2 price outcomes for product and soybean prices and the average of the four possible option price outcomes previously calculated for M = 3. This procedure simulates the choice between immediate exercise and keeping the option alive—an important consideration in examining the soybean-processing decision. For Call(2,1,1), each of the four possible price outcomes at M = 3 for product and soybeans is one price move from d^2 and D^2, respectively. The immediate exercise value for Call(2,1,1) is $d^2S_1 - D^2S_2 - K$.

The options prices are then calculated for M = 1 and then for M = 0 in exactly the same way as explained for M = 2. The valuation procedure is completed when Call(0,1,1) at M = 0, is calculated. The option valuation model proceeds in the same manner regardless of the value of M selected.

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[14] The Rubinstein option valuation model can be used to calculate prices for many types of options that involve two correlated assets by simply changing the payout function for option exercise. In this report the payout function is the GPM minus the exercise price. This flexibility provides opportunities for error checking of computer code by comparing option valuation estimates against reported results: for example, against the results reported for the option to exchange one asset for another (Margrabe).

[15] Haug has provided computer code in Visual Basic for calculating option prices for Rubinstein's option valuation model.

The calculations shown for M = 0, 1, and 2 are for American options (options whose value equals the immediate exercise value when the exercise value is greater than the value of continuing to hold the option). For example, at M = 2, Call(2,1,1) is immediately exercised if $d^2S_1 - D^2S_2 - K$ is greater than 1/4[Call(3,1,1) + Call(3,1,2) + Call(3,2,1) + Call(3,2,2)]. The same procedures are followed for European options with the exception that immediate exercise is not considered at M = 0, 1, and 2. As discussed earlier, the inability to exercise a European option prior to option expiration makes its price less than that of a corresponding American option.

Data

Data for the following variables are required for valuing options on the soybean GPM with the Rubinstein valuation model.

1. prices for soybeans, soybean oil, and soybean meal
2. soybean oil and meal yield per bushel of soybeans
3. time remaining until option expiration
4. exercise price (variable processing cost)
5. risk-free interest rate

Daily closing prices for nine futures-contract combinations for soybeans, soybean meal, and soybean oil and the product yields per bushel of soybeans were used to calculate daily soybean GPMs.[16] The futures prices are from the Chicago Board of Trade. The product yields per bushel of soybeans were 48 pounds of meal and 11 pounds of oil (Johnson et al.). These prices and product yields were also used to estimate soybean price variance, product revenue variance per bushel of soybeans, and the correlation of soybean price and product revenue. As discussed in the previous section, the variance of each asset price (soybean price and product revenue in this report) and their correlation are required by the Rubinstein model.

Futures contracts for soybeans, soybean oil, and soybean meal jointly expire during January, March, May, July, August, and September. GPMs were estimated using the daily closing futures prices for the three contracts that expire during each of these six months. Options on these GPMs are specified to expire on the first of January, March, May, July, August, and September and are referred to by these months. The prices of soybean oil and soybean meal for these contracts can be interpreted as discounted to the beginning of the processing period.

GPMs were also estimated for three additional futures contract combinations. These are August soybeans and September soybean oil and soybean meal, September soybeans and October soybean oil and soybean meal, and November soybeans and December soybean oil and soybean meal. Option expiration is specified to be on the first of August, September, and November, respectively—the beginning of the expiration (delivery) months for the soybean-futures

[16] A futures contract is referred to by the month in which it expires.

contracts used. Soybean meal and oil prices are discounted to the beginning of the processing period for these contract combinations.

The options for two of these three contract combinations expire on the same day as the August and September options. Consequently, only the November-December combination was used in the analysis along with the six previous options to explain the amount of soybeans crushed. The November-December combination is referred to as the November option.

Each of the seven contract combinations used to explain the amount of soybeans crushed is used by processors to price-forward soybean-processing margins. Consequently, they are appropriate for examining the soybean-processing decision.

Daily GPMs are estimated for the seven contract combinations from January 1989 through May 2000, except for 1991. Census did not report monthly soybeans crushed in 1991. The analysis concerns determining if the option pricing model used can select GPMs from these contract combinations that can explain the monthly amount crushed.

The soybean price and product revenue variances are based on the continuous rates of price and revenue change. They are calculated using the daily closing soybean price and the daily product revenue per bushel of soybeans. Daily closing prices for soybean meal and oil are used to calculate the revenue per bushel of soybeans. The calculations are shown in the following two equations.

$$\sigma^2 = \sum_{j=1}^{n}\{\ln(S_{k,j}/S_{k,j-1}) - \mu\}^2/n-1 \qquad \text{where } \mu = \{\sum_{j=1}^{n}\ln(S_{k,j}/S_{k,j-1})\}/n$$ [17]

k = 1 is soybean price and 2 is revenue per bushel of soybeans

The daily variance from the preceding equation is converted to an annual variance by multiplying the daily variance by 252—the assumed number of trading days in a year. The variances were calculated using the price and revenue ratios for the previous 10 trading days (n = 10).

The correlation between assets 1 and 2 is the correlation of the corresponding values for assets 1 and 2 under the summation sign in the equation for variance.

The time to option expiration (the third data requirement in the preceding list) is specified as the number of calendar days remaining to the beginning of the delivery month for the soybean futures contract used in calculating a GPM.

[17] $\ln(S_{k,j}/S_{k,j-1})$, the natural logarithm of $(S_{k,j}/S_{k,j-1})$, is the continuous rate of change from the close of trading day j-1 to the close of the next trading day j.

Variable processing cost (the fourth data requirement) is set at 30 cents per bushel. Variable processing cost is proprietary information. However, industry consensus is that, "…in broad terms, crushers begin making a profit once the crush margin climbs above 30 cents " (Plummer). A large number of soybean-processing plants were closed or planning to close in the first several months in 2000 due to the Chicago Board of Trade crushing margins remaining in the mid-20-cent range during January and February (Reuters).

A risk-free interest rate (the fifth data requirement) was estimated using daily T-bill yields downloaded from the web site maintained by the Federal Reserve Bank of St. Louis.[18] The calculations are shown in the following two equations:

T-bill price = $10,000[1 - 0.01(yield)(n/360)] where yield is the reported 90-day yield (n = 90 days). The 90-day T-bill yield is reported each trading day.

Risk-free interest rate = (365/n)ln($10,000/T-bill price) where n = 90 days

The preceding risk-free rate is on an annualized basis.

Analysis

GPMs were chosen using the option pricing model and then used to explain monthly soybean crush for January, March, May, July, August, September, and November.[19] Spot GPMs were also used to explain the soybean crush for these months. Two hypotheses were examined. One is that the chosen futures GPMs estimate the GPMs that processors use to make processing commitments and, consequently, can explain the amount processed. The other is that the spot GPMs are not used to make processing commitments and cannot explain the amount processed.

A study of the food procurement auction operated by USDA's Farm Service Agency found that food processors' bids for supplying food products are higher when mills are running near full capacity (MacDonald et al., p. 37). The bids were forward bids, not spot bids. This result suggests that there may be a positive relationship between total amount processed and forward food product margins. The study did not examine the relationship between the total amount processed and processing margins.

Choosing the Futures GPMs

Figure 1 (all figures are on p. 27) shows the histogram of the 47 GPMs chosen by the option pricing model. The GPMs are typical of price distributions in that they are skewed toward their higher values. Another typical characteristic of the chosen GPMs is that the GPMs logarithms have fatter tails than a normal distribution. The mean of the GPMs was $0.72 and the standard

[18] The Internet address for this website is www.stls.frb.org.
[19] Soybean crush data were taken from the U.S. Bureau of the Census report *Fats and Oilseeds Crushings*.

deviation was $0.20.

The following rule was used in conjunction with the option pricing model to choose the GPMs. Option time value must fall to and remain at zero for five successive trading days before accepting the corresponding GPM to represent the level at which processors commit to process. A GPM was not chosen when all of the daily GPMs examined for a futures contract combination had zero time values. In this situation, there was no identifiable GPM with a first, zero time value to choose. Seventy-three contract combinations were examined from January 1989 through May 2000—seven per year for each full year (except for 1991 when the U.S. Census did not report crush data and three in 2000). The GPMs in 1991 were ignored because the analysis concentrates on using chosen futures GPMs to explain the amount of soybeans crushed.

Premiums and time values of European options on the GPM were estimated and compared with their American option counterparts. The purpose was to explore the effect of having to wait until the processing period to receive payment equal to GPM. The GPMs in figure 1 are based on American option pricing.

The comparisons show that European option premiums and time values were less than 1 cent per bushel smaller than their American option counterparts. They imply that the results in this report would not be affected by using European rather than American options. As explained earlier, payment equal to the GPM for a European option would be at the time that soybeans are processed. If European options were used, the decision rule would be to sell the GPM when the time value first falls below zero. Our comparisons show that this occurs when the time value of American options on the GPM falls to zero.

Figure 2 shows the dates and corresponding levels of the chosen GPMs. GPMs were not chosen for 1993 nor for May 1995 through May 1997. GPM volatility may have been underestimated in these periods, resulting in underestimating option premiums and time values. The procedure for choosing futures GPMs did, however, provide a sufficient number of observations for examining the relationship between the chosen GPMs and soybean crush.

A way that might improve the estimation of GPM volatility is to first estimate the volatility of soybeans, soybean oil, and soybean meal using an option pricing model and data from their option markets. The next step would be to calculate GPM volatility from the estimated component volatilities.

Missing Data

This report is about estimating the missing GPM values at which soybean processors commit their processing resources and about evaluating the ability of the estimates to explain the quantity of soybeans actually processed. The actual GPM values at which processors commit their processing resources are missing because they are proprietary data. Unfortunately, the number of futures contracts for soybeans, soybean oil, and soybean meal that are traded is not sufficient for estimating a GPM for each month to correspond with the monthly quantity of soybeans processed which is collected by the U.S. Bureau of the Census. At most, GPMs can be estimated for 5 months each year. Seven months remain missing and, consequently, cannot help in explaining the monthly quantity of soybeans processed.

Missing data in regression analysis has a long history in the statistical literature and is currently an active research area (Meng). Meng emphasizes that missing data occur in most applied statistical analyses and that much of the recent research is about estimating missing values for use in regression analysis. This research is stimulated by the development and availability of more sophisticated models of data generation processes and economic behaviors. This report relied on a recently developed option pricing model to estimate missing GPM values. Evaluating estimates provided by a model implies joint testing of both the model and the underlying economic behavior asserted by the model.

Unfortunately, there are also missing monthly values for the quantity of soybeans processed in 1991. Due to budget problems, the U.S. Census did not collect these data in 1991.

As previously explained, the option pricing model and the procedures used to estimate the GPM variance sometimes failed to estimate a GPM at which soybean processors no longer have an incentive to wait for a larger GPM. It might be possible to get estimates for these missing GPMs by using another option pricing model. Earlier it was explained that one might be able to obtain better estimates of GPM variance by using an option pricing model to estimate the individual soybean, soybean meal, and soybean oil variances and then combining them to form an estimate of GPM variance. Possibly, these variance estimates could be used in an option pricing model to estimate more missing GPM values. These are interesting avenues for future research.

When data are missing, the efficiency of estimated regression coefficients is reduced, making it more difficult to detect statistically significant effects (Green, p. 428). In this report, missing data made it more difficult to detect significant effects of GPM on the quantity of soybeans processed. This is the only consequence if the data used to make the estimates can be treated as a random subsample of a sample that also includes the missing data (Meng; Green, p. 428). If the missing data come from a different sample, then estimates based on available data do not apply for the missing data. As explained later based on the available GPM estimates, GPM has a different effect on quantity processed in months in which there is little excess processing capacity. One should, therefore, be careful about assuming that the estimates of the effect of GPM on quantity processed apply to the 7 months each year for which we do not have futures-price data for making GPM estimates.

Missing data within a time series sample imply that corresponding regression error terms are also missing. If there are no data for the i^{th} month, then there will also be no error term for the i^{th} month. Consequently, procedures that use information on serial correlation and/or heteroscedasticity among the regression errors to improve the efficiency of regression-coefficient estimates cannot be used. These procedures require all the error terms to be present.

When errors are missing, we cannot test the null hypothesis of no serial correlation and/or heteroscedasticity.

The efficiency of the regression coefficients measuring the effects of GPM on the amount processed could be improved if a complete set of GPM estimates were available. The improved efficiency might enable one to detect statistically significant effects of GPM on the amount processed in the months when there is considerable excess processing capacity. A complete set of GPM estimates would better enable us to assess whether the effects of GPM on the amount processed is different between months with little and months with considerable excess processing capacity.

Testing for Unit Roots

Monthly soybean crush and spot GPMs were examined for unit roots using the augmented Dickey Fuller test before examining the relationship between crush and price. It was not possible to examine the GPMs chosen by the option pricing model for unit roots because of the missing monthly observations. There are two reasons for the missing observations. One is there are a maximum of seven GPM estimates per year that correspond with seven monthly soybean crushes. The other, as just discussed, is that the option-pricing model did not choose GPMs for the some of the futures contract combinations examined. As argued later, unit root testing for the chosen GPMs, if possible, would likely have the same results as for crush or for the difference between crush and processing capacity.

Figure 3 shows monthly soybean crush from January 1989 through May 2000, except for 1991. Unit root testing was done on the 149 crush observations from January 1992 through May 2000. The figure suggests an upward trend and seasonal variation. Franses (p. 84) and Enders (p. 258) suggest including a deterministic trend term in the augmented Dickey Fuller test when the data show an upward or downward trending pattern. Seasonal variation may be stationary (deterministic) or may be nonstationary due to a seasonal unit root or due to two or more seasonal unit roots. Deterministic seasonality implies some variation in seasonal pattern from year to year but no persistent change in seasonal pattern, whereas unit-root seasonality implies a continuously changing seasonal pattern (Harris, p. 42). Market relationships for soybean crush suggest deterministic seasonality. Soybean price generally rises from one harvest to the next, reflecting storage cost, while the demand for meal is largest in the months after harvest. These market forces result in a monthly pattern of decreasing GPMs and crush from harvest to harvest.

The procedure used for handling the seasonal variation is to first estimate an OLS equation with crush as the dependent variable and with monthly dummy variables as independent variables and then examine the OLS residuals for a unit root (Enders, p. 229). The augmented Dickey Fuller test with a deterministic time trend was used to test for a unit root in the residuals. The results shown in table 3, using the Shazam econometric program, rejected the null of hypothesis of a unit root at the 5-percent level. This program selects the length of lag in the Dickey Fuller test based on the highest significant lag order in the autocorrelation or partial autocorrelation of the first difference series (Shazam, p. 168). The null hypothesis of monthly crush having a unit root could not be rejected at the 10-percent level when the deterministic time trend variable was excluded from the Dickey Fuller test. This inconsistency produces uncertainty about whether or not monthly crush contains a unit root.

Two modifications of the monthly crush data were considered. One was to subtract monthly crush from monthly capacity. This variable is unused capacity. The other modification was to divide monthly crush by monthly capacity and convert the proportion to a percentage. This variable is percent capacity used.[20] Capacity is the level of sustainable maximum output (crush) (Corrado and Mattey). Each modification provides an opportunity to explicitly consider the effect of capacity constraint on the soybean-processing decision. Each also offers the possibility of correcting for a unit root in the amount crushed.

Capacity unused will not have a unit root if capacity and crush are cointegrated. The logarithm of percent capacity used will not have a unit root if the logarithm of crush minus the logarithm of capacity are cointegrated. Capacity minus crush and the logarithm of crush minus the logarithm of capacity may be cointegrated if the soybean-crushing industry increases capacity when scarce and decreases it when in excess. If this is the case, then capacity minus crush and the logarithm of crush minus the logarithm of capacity are measures of excess supply and excess demand, respectively, for processing resources. The excess supply and excess demand in this case influence investment and abandonment decisions. In this context, capacity measures the supply of and crush measures the demand for processing resources.

Investment and abandonment decisions may result in capacity minus crush and in log of crush minus log of capacity being stationary. In addition, if the futures GPMs at which processors commit processing resources determine unused processing capacity and percent capacity used, then these futures GPMs may also likely be stationary.

Figures 4 and 5 show monthly percent capacity used and unused capacity. Unlike for the amount of crush, neither figure shows a trend. Increase in capacity from January 1989 through May 2000 offset the increase in the amount crushed over this period. Figures 4 and 5 do show seasonal variation for percent capacity used and for unused capacity. As was done with the amount crushed, an OLS equation with monthly dummy variables was estimated for percent capacity and for unused capacity and then the OLS residuals were examined by the augmented Dickey Fuller test for unit roots. Unlike for the amount crushed, a time trend variable was not included in the Dickey Fuller test, because neither figure 4 nor 5 suggests a time trend. The Dickey Fuller test shown in table 3 rejected a unit root at the 5-percent level both for percent capacity used and for unused capacity.

The spot GPM shown in figure 6 was also examined for a unit root.[21] The same procedure

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[20] Soybean capacity data were taken from the U.S. Bureau of the Census report *Survey of Plant Capacity*.

[21] The spot GPM was taken from the *Oil Crops Situation and Outlook Yearbook*. The meal and oil prices used to calculate the GPM are Decatur, IL, prices and the soybean price is the Illinois processor price.

described for percent capacity and unused capacity was used to examine the spot price for a unit root. The Dickey Fuller test also rejected the null hypothesis that the spot GPM contains a unit root at the 5-percent level (table 3). Alternative explanations can be given for rejecting the null hypothesis. One is that the spot GPM determines the percent capacity used and unused capacity for which unit roots were rejected. The other is that spot price is a meaningless economic variable with no theory to predict whether or not it has a unit root. The alternative explanations are examined in the next section.

Examining the Effect of GPM on Soybean Crush

OLS was used to examine the effect of GPM on monthly crush, on capacity not used, and on percent capacity used. GPM is the dependent variable because it is the decision variable used by processors to make processing commitments. The effect of GPM on capacity not used and on percent capacity used can be thought of as the effect on crush holding capacity constant, because capacity is known when the decision to process is made. The effect on crush may vary as capacity is approached, but capacity is held constant. Capacity is not held constant for the OLS equations with monthly crush as the dependent variable.

The curve showing the effect of GPM on crush likely becomes flatter as capacity committed approaches 100 percent, indicating that each increment in capacity used requires larger GPM increases. One explanation for the flattening of the curve is that as capacity becomes scarcer, it earns higher rents (Corrado and Mattey, pp. 164-5). The higher rents allocate the scarce capacity among those demanding processing services.

The option pricing model does not consider capacity directly in determining the option premium or the time value of waiting. Capacity is not an independent variable. However, both the size of the GPM offered by the market and the GPM variability may be related to the amount of unused capacity, and both do affect option premiums and time values and the choice of the GPM for committing processing resources.

Initial examination of the effect of GPM on crush led to considering the possibility that the chosen futures GPMs may better estimate the GPMs at which processors commit production resources when the industry is operating close to full capacity. In this situation, buyers of product have an incentive to get their purchase orders in early to ensure product purchase. There is less incentive to do so when the industry is operating at much less than full capacity. Consequently, commitments to purchase product may be made over a longer period of time, reducing the precision of the chosen GPMs. In addition, when the industry is operating at much less than full capacity, processors have an incentive to commit additional production resources if the GPM rises significantly after the initial resource commitment, that is, after commitments made when option time values first declined to zero. Committing additional resources if the GPM increases after the initial resource commitment is less of an option when the industry is operating close to full capacity. This restriction may make the chosen GPMs more precise estimates of the GPMs used by processors to commit processing resources when the industry is operating at close to full capacity.

The seasonal nature of soybean processing, discussed earlier, enables the selection of processing periods with capacity sometimes approaching 100 percent and other periods when capacity is always well below 100 percent. Table 4 shows the average percent capacity used for the 7 months in which the futures contract combinations expire. The percentages decrease monotonically from one harvest completion to the next.

Based on the results in table 4, the observations on GPM, crush, and capacity data were separated into two groups and examined individually. One group contains the data for November, January, and March—high-capacity months. The other group contains the data for May, July, August, and September—low-capacity months. Table 5 shows information on percent processing capacity for each group. Average percent capacity differs by over 12 percent between the two groups. Also, all the observations on GPM, crush, and capacity data were examined together—all months.

Table 6 shows the results from using the chosen GPMs to explain the amount of soybeans crushed for the three high-capacity months, for the four low-capacity months, and for all seven months. Monthly crush, percent capacity used, and capacity not used were alternative dependent variables. Linear, log-log, and Spillman equations were estimated using OLS.

The t-values of the estimated GPM coefficients are identified at the 10-, 5-, and 1-percent significance levels and the equations are examined for economic meaning. The estimated equations are later compared with a similar set using spot GPM as the dependent variable.

Equations 1 through 9 in table 6 are the OLS linear equations. The hypotheses examined here are that the GPM coefficients for crush and percent capacity used are greater than zero and the coefficient for capacity not used is less than zero. None of the GPM coefficients for low-capacity months were significant at the 10-percent level—the lowest of the three chosen significant levels. The GPM coefficients for percent capacity used and capacity not used were significant at the 5-percent level for the high-capacity months. The corresponding coefficient for crush was not significant. This difference may have been due to not considering the effect of changing capacity levels in the crush equation. The GPM coefficients for crush and percent capacity used were significant for all months at the 5- and 10-percent levels, but not significant for capacity not used.

The results for the linear equations support the hypothesis that the chosen GPMs affect the level of crush for the high-capacity months and indicate that it is important to control for changing capacity levels. The results for the linear equations do not support the hypothesis that the chosen GPMs affect the level of crush for the low-capacity months. Reasons for this result were discussed earlier.

Equations 10 through 18 in table 6 are the OLS log-log equation estimates. The GPM coefficients for these equations are elasticities. The results for high-capacity months for percent capacity used and capacity not used, like the corresponding linear equations, are statistically significant. The significance levels for the log-log equations are switched with those for the linear equations. A 1-percent GPM increase was estimated to reduce capacity not used by just over 1 percent and to increase the percent of capacity used slightly less then one-tenth of 1 percent.[22] The all-months result for crush, like the result for the corresponding linear equation, was statistically significant. A 1-percent GPM increase was estimated to increase the crush by slightly more than one-fifth of 1 percent.

The curve showing the estimated relationship between capacity not used and GPM based on the estimated log-log equation for capacity not used (equation 16) becomes flatter and approaches zero as GPM increases. This result is consistent with the notion, discussed earlier, that the curve of the relationship between GPM and crush becomes flatter as the capacity limit is approached.

A similar result is not observed for the log-log equation for percent capacity used (equation 13). Here the upper limit is 100 percent of capacity. The log-log equation increases and becomes flatter as GPM increases. However, there is no upward limit to this equation.

A Spillman equation was estimated for percent capacity used for the high-capacity months, low-capacity months, and all months (equations 19, 20, and 21). The purpose was to estimate an equation that imposes an upper capacity limit. The Spillman equation is

$$Y = B_1 - B_2 (B_3)^x$$

X here is the futures GPM and Y is the percent capacity used. B_1 is the capacity limit and is set equal to 100 percent. One hundred is subtracted from both sides, both sides are multiplied by minus 1 and logs of both sides are taken. The resulting equation, shown below, is estimated using OLS.

$$\log(100 - Y) = \log(B_2) + \log(B_3)X$$

OLS estimates of $\log(B_2)$ and of $\log(B_3)$ may be either positive or negative. However, the antilog transformation to B_2 and B_3 results in positive values only. If $\log(B_3)$ is less than zero, then B_3 will be less than 1 and positive. If $\log(B_3)$ is greater than zero, then B_3 will be greater than 1. A value of B_3 less than 1 and positive implies that percent capacity used will increase from increases in GPM. A value of B_3 greater than 1 implies that percent capacity used will decrease from increases in GPM. Consequently, the t-test on the OLS coefficient $\log(B_3)$ in equations 19, 20, and 21 is a one-tail test for less than zero.

The t-tests on GPM (B_3 above) for equations 19 and 21 (low-capacity and all months) were significant at the 1- and 5-percent levels. The t-test on GPM for equation 20 (low-capacity months) was not significant.

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[22] The log-log coefficient for percent capital used is the percent change in a percent. It may be easier to think of this coefficient as the percent change in the ratio of crush to capacity.

The curve of equation 19 becomes flatter as GPM increases and approaches the upper limit of 100 percent asymptotically. These results support the notion that the curve showing the relationship between crush and GPM becomes flatter as the capacity limit is approached. The corrected R-square was 0.10 for equation 21 and 0.23 for equation 19. The lower R-square for equation 19 was due to combining the low- with the high-capacity months.

Table 7 shows average GPMs for the high- and low-capacity months. The average spot GPM is 12 cents per bushel lower for the high-capacity months. The expectation is for the GPM to be higher for the high-capacity months. This result suggests that processors do not commit processing resources using spot GPMs. As expected, the average futures GPM is higher for the high-capacity months.

The hypothesis testing shown in table 6 is repeated in table 8 using spot GPMs instead of the chosen futures GPMs. There are important differences in hypothesis testing outcomes.

The chosen futures GPMs for the linear and log-log equations and high-capacity months had statistically significant effects on percent capacity used and capacity not used. The corresponding results for the spot GPMs were all statistically insignificant. In addition, none of the GPMs for the other linear and log-log equations passed the one-tail hypothesis tests discussed previously.

Surprisingly, the t-test on the Spillman GPM coefficient for the high-capacity months is significant at the 10-percent level. This is the only statistically significant result for the effect of spot GPM on the amount crushed.

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Figure 1. Histogram of chosen gross processing margins

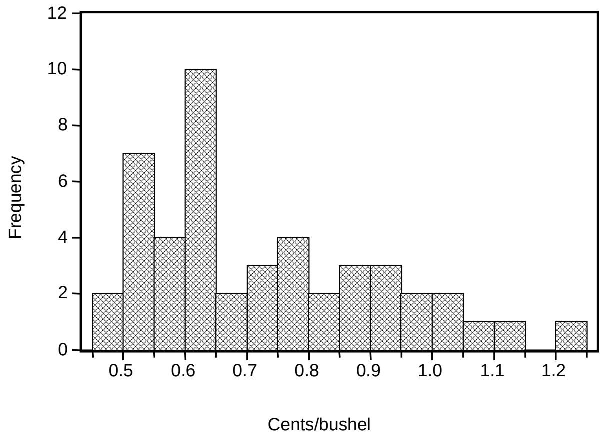

Figure 2. Time line of chosen futures gross processing margins

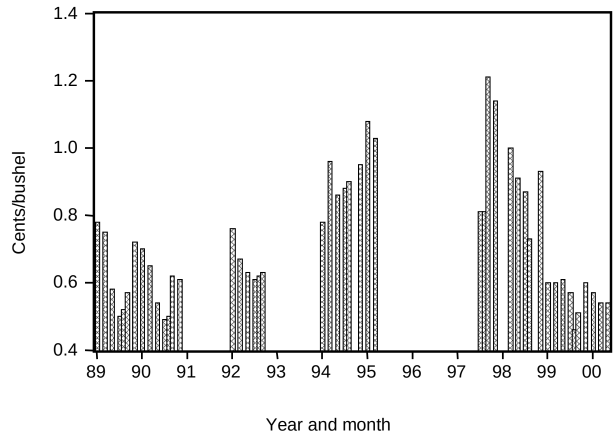

Figure 3. Soybeans crushed

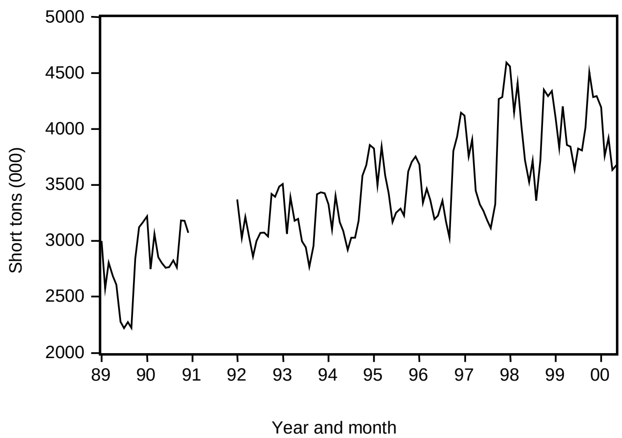

Figure 4. Percent crushing capacity used

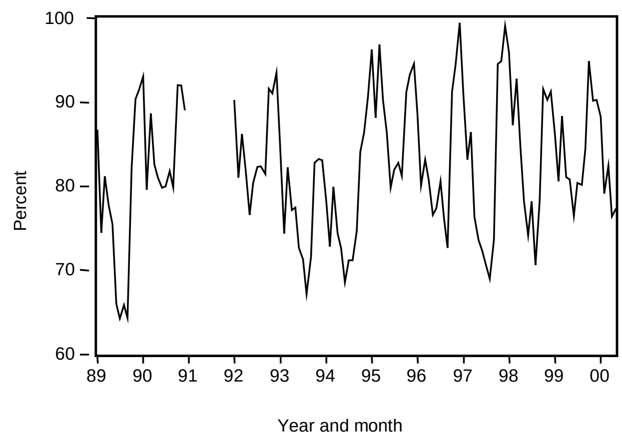

Figure 5. Capacity minus crush

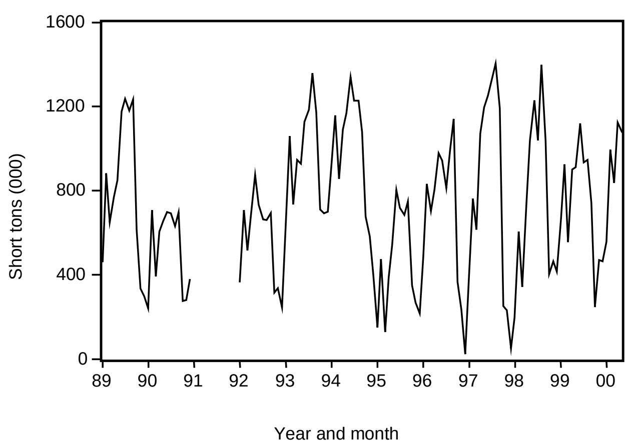

Figure 6. Spot gross processing margin

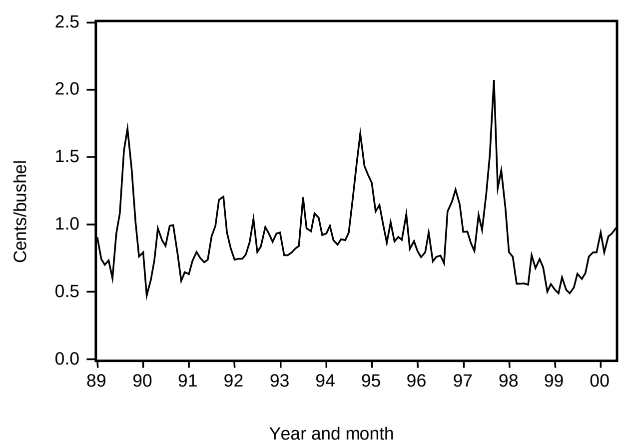

Table 1—Price movement combinations of asset 1 and asset 2 for up to four price moves

M = 0

(0,1,1)

M = 1

(1,1,1) dD	(1,1,2) dC
(1,2,1) uB	(1,2,2) uA

M= 2

(2,1,1) d^2D^2	(2,1,2) d^2DC	(2,1,3) d^2C^2
(2,2,1) $duDB$	(2,2,2) $duDA$ or $duCB$	(2,2,3) $duAC$
(2,3,1) u^2B^2	(2,3,2) u^2AB	(2,3,3) u^2A^2

M = 3

(3,1,1) d^3D^3	(3,1,2) d^3D^2C	(3,1,3) d^3DC^2	(3,1,4) d^3C^3
(3,2,1) d^2uD^2B	(3,2,2) d^2uD^2A $d^2uD(CB)$	(3,2,3) d^2uC^2B or $d^2uC(DA)$	(3,2,4) d^2uC^2A
(3,3,1) du^2DB^2	(3,3,2) du^2CB^2 $du^2B(DA)$	(3,3,3) du^2DA^2 $du^2A(CB)$	(3,3,4) du^2CA^2
(3,4,1) u^3B^3	(3,4,2) u^3B^2A	(3,4,3) u^3BA^2	(3,4,4) u^3A^3

M = 4

(4,1,1) d^4D^4	(4,1,2) d^4D^3C	(4,1,3) $d^4D^2C^2$	(4,1,4) d^4DC^3	(4,1,5) d^4C^4
(4,2,1) d^3uD^3B	(4,2,2) d^3uD^3A or d^3uD^2CB	(4,2,3) $d^3u\,D^2AC$ d^3uC^2DB	(4,2,4) d^3uC^3B d^3uC^2DA	(4,2,5) d^3uC^2A
(4,3,1) $d^2u^2D^2B^2$	(4,3,2) $d^2u^2D^2BA$ $d^2u^2B^2DC$	(4,3,3) $d^2u^2D^2A^2$ or $d^2u^2B^2C^2$ d^3u	(4,3,4) $d^2u^2C^2BA$ $d^2u^2A^2CA$	(4,4,5) $d^2u^2C^2A^2$
(4,4,1) du^3DB^3	(4,4,2) du^3B^3C du^3B^2AD	(4,4,3) du^3B^2AC du^3A^2DB	(4,4,4) du^3DA^3 du^3A^2CB	(4,4,5) du^3CA^3
(4,5,1) u^4B^4	(4,5,2) u^4B^3A	(4,5,3) $u^4B^2A^2$	(4,5,4) u^4BA^3	(4,5,5) u^4A^4

Table 2—Equations for calculating call option prices on the price difference between asset 1 and asset 2

M = 0

$$\text{Call}(0,1,1) = \text{Max}\{(S_1 - S_2 - K),\ 1/4[\text{Call}(1,1,1) + \text{Call}(1,1,2) + \text{Call}(1,2,1) + \text{Call}(1,2,2)]\}$$
(dD) (dC) (uB) (uA)

M = 1

$$\text{Call}(1,1,1) = \text{Max}\{(dS_1 - DS_2 - K),\ 1/4[[\text{Call}(2,1,1) + \text{Call}(2,1,2) + \text{Call}(2,2,1) + \text{Call}(2,2,2]\}$$
(dD) (d^2D^2) (d^2DC) (duDB) (duDA)

$$\text{Call}(1,1,2) = \text{Max}\{(dS_1 - CS_2 - K),\ 1/4[\text{Call}(2,1,2) + \text{Call}(2,1,3) + \text{Call}(2,2,2) + \text{Call}(2,2,3)]\}$$
(dC) (d^2DC) (d^2C^2) (duDA) (duAC)

$$\text{Call}(1,2,1) = \text{Max}\{(uS_1 - BS_2 - K),\ 1/4[\text{Call}(2,2,1) + \text{Call}(2,2,2) + \text{Call}(2,3,1) + \text{Call}(2,3,2)]\}$$
(uB) (duDB) (duCB) (u^2B^2) (u^2AB)

$$\text{Call}(1,2,2) = \text{Max}\{(uS_1 - AS_2 - K),\ 1/4[\text{Call}(2,2,2) + \text{Call}(2,2,3) + \text{Call}(2,3,2) + \text{Call}(2,3,3)]\}$$
(uA) (duDA) (duAC) (u^2AB) (u^2A^2)

M = 2

$$\text{Call}(2,1,1) = \text{Max}\{(d^2S_1 - D^2S_2 - K), 1/4[\text{Call}(3,1,1) + \text{Call}(3,1,2) + \text{Call}(3,2,1) + \text{Call}(3,2,2)]\}$$
d^3D^3 d^3D^2C d^2uD^2B d^2uD^2A

$$\text{Call}(2,1,2) = \text{Max}\{(d^2S_1 - DCS_2 - K), 1/4[\text{Call}(3,1,2) + \text{Call}(3,1,3) + \text{Call}(3,2,2) + \text{Call}(3,2,3)]\}$$
d^3D^2C d^3DC^2 d^2uD^2A d^2uC^2B

$$\text{Call}(2,1,3) = \text{Max}\{(d^2S_1 - C^2S_2 - K), 1/4[\text{Call}(3,1,3) + \text{Call}(3,1,4) + \text{Call}(3,2,3) + \text{Call}(3,2,4)]\}$$
d^3DC^2 d^3C^3 d^2uC^2B d^2uC^2A

$$\text{Call}(2,2,1) = \text{Max}\{(duS_1 - DBS_2 - K), 1/4[\text{Call}(3,2,1) + \text{Call}(3,2,2) + \text{Call}(3,3,1) + \text{Call}(3,3,2]\}$$
du^2D^2B du^2D^2A du^2DB^2 du^2CB^2

$$\text{Call}(2,2,2) = \text{Max}\{(duS_1 - DAS_2 - K), 1/4[\text{Call}(3,2,2) + \text{Call}(3,2,3) + \text{Call}(3,3,2) + \text{Call}(3,3,3)]\}$$
d^2uD^2A d^2uC^2B du^2CB^2 du^2DA^2

$$\text{Call}(2,2,3) = \text{Max}\{(duS_1 - ACS_2 - K), 1/4[\text{Call}(3,2,3) + \text{Call}(3,2,4) + \text{Call}(3,3,3) + \text{Call}(3,3,4)]\}$$
d^2uC^2B d^2uC^2A du^2DA^2 du^2CA^2

$$\text{Call}(2,3,1) = \text{Max}\{(u^2S_1 - B^2S_2 - K), 1/4[\text{Call}(3,3,1) + \text{Call}(3,3,2) + \text{Call}(3,4,1) + \text{Call}(3,4,2)]\}$$
du^2DB^2 du^2CB^2 u^3B^3 u^3B^2A

$$\text{Call}(2,3,2) = \text{Max}\{(u^2S_1 - ABS_2 - K), 1/4[\text{Call}(3,3,2) + \text{Call}(3,3,3) + \text{Call}(3,4,2) + \text{Call}(3,4,3)]\}$$
du^2CB^2 du^2DA^2 u^3B^2A u^3BA^2

$$\text{Call}(2,3,3) = \text{Max}\{(u^2S_1 - A^2S_2 - K), 1/4[\text{Call}(3,3,3) + \text{Call}(3,3,4) + \text{Call}(3,4,3) + \text{Call}(3,4,4)]\}$$
du^2DA^2 du^2CA^2 u^3BA^2 u^3A^3

M = 3

Call(3,1,1) = Max[0, (d^3S_1 - D^3S_2 - K)]

Call(3,1,2) = Max[0, (d^3S_1 - D^2CS_2 - K)]

Call(3,1,3) = Max[0, (d^3S_1 - DC^2S_2 - K)]

Call(3,1,4) = Max[0, (d^3S_1 - C^3S_2 - K)]

Call(3,2,1) = Max[0, (d^2uS_1 - $D^2B\ S_2$ - K)]

Call(3,2,2) = Max[0, (d^2uS_1 - D^2AS_2 - K)]

Call(3,2,3) = Max[0, (d^2uS_1 - C^2BS_2 - K)]

Call(3,2,4) = Max[0, (d^2uS_1 - C^2AS_2 - K)]

Call(3,3,1) = Max[0, ($d^1u^2S_1$ - DB^2S_2 - K)]

Call(3,3,2) = Max[0, ($d^1u^2S_1$ - CB^2S_2 - K)]

Call(3,3,3) = Max[0, ($d^1u^2S_1$ - $DA^2\ S_2$ - K)]

Call(3,3,4) = Max[0, ($d^1u^2S_1$ - CA^2S_2 - K)]

Call(3,4,1) = Max[0, (u^3S_1 - B^3S_2 - K)]

Call(3,4,2) = Max[0, (u^3S_1 - B^2AS_2 - K)]

Call(3,4,3) = Max[0, (u^3S_1 - BA^2S_2 - K)]

Call(3,4,4) = Max[0, (u^3S_1 - A^3S_2 - K)]

Table 3—Dickey Fuller unit root tests

Variable	**t-value for γ**[1]
Soybean crush	-3.47 [3] **
Soybean crush	-1.91 [2]
Percent capacity used	-3.05 [2] **
Capacity unused	-3.10 [2] **
Spot gross processing margin	-3.11 [2] **

[1] The null hypothesis is γ equal to zero.

[2] indicates t-value for γ is estimated using the following equation: $\Delta y_t = \alpha_0 + \gamma y_{t-1} + \Sigma_{i=2}^{\rho} \beta \Delta y_{t-i+1} + \varepsilon_t$

Critical t-values for this equation and 100 observations are -2.58, -2.89, and -3.51 at the 10, 5, and 1 percent significance levels, respectively.

[3] indicates t-value for γ is estimated using the following equation: $\Delta y_t = \alpha_0 + \alpha_1 t + \gamma y_{t-1} + \Sigma_{i=2}^{\rho} \beta \Delta y_{t-i+1} + \varepsilon_t$

Critical t-values for this equation and 100 observations are -3.15, -3.45, and -4.04 at the 10, 5, and 1 percent significance levels, respectively.

** indicates the 5-percent significance level.

Table 4—Average percent processing capacity used for the months in which the futures contract combinations expire

January	March	May	July	August	September	November
88.3	87.0	77.4	75.2	74.4	76.7	90.6

Table 5—Percent processing capacity used for high- and low-capacity months

Months	Average	Maximum	Minimum	Standard deviation	Skewness	Kurtosis
Nov., Jan., & Mar	88.5	96.8	78.0	5.1	-0.4	2.5
May, July, Aug., & Sept.	75.9	84.4	64.2	6.0	-0.6	2.1

Table 6—Estimated relationships between the chosen futures gross processing margins and soybean crush, percent capacity used, and capacity not used

Equation number	Dependent variable	Equation type	Months	Constant (t-value)	GPM (t-value)	$\bar{R}^2$
1	Crush	Linear	High Cap	1.07E+08 (6.38)	185,512.1 (0.89)	0.04
2	Crush	Linear	Low Cap	91,003.901 (6.99)	195,292.2 (1.04)	0.04
3	Crush	Linear	All	89,583,373 (8.40)	310,641.5 (2.17)**	0.07
4	% Capacity used	Linear	High Cap	80.4 (17.0)	0.103 (1.70)**	0.09
5	% Capacity used	Linear	Low Cap	81.6 (18.6)	-0.085 (-1.31)	0.03
6	% Capacity used	Linear	All	74.5 (15.44)	0.098 (1.5)*	0.03
7	Capacity not used	Linear	High Cap	27,513,470 (3.95)	-148,445.8 (-1.71)*	0.09
8	Capacity not used	Linear	Low Cap	16,942,430 (2.95)	2,381,103 (2.89)	0.23
9	Capacity not used	Linear	All	30676410 (4.49)	-74,055.85 (-0.81)	-0.01
10	Crush	Log-Log	High Cap	18.23 (29.92)	0.087 (0.61)	-0.03
11	Crush	Log-Log	Low Cap	17.76 (31.80)	0.166 (1.24)	0.02
12	Crush	Log-Log	All	17.58 (41.94)	0.221 (2.24)**	0.08
13	% Capacity used	Log-Log	High Cap	4.12 (17.24)	0.082 (1.48)*	0.06
14	% Capacity used	Log-Log	Low Cap	4.65 (17.29)	-0.078 (-1.21)	0.02
15	% Capacity used	Log-Log	All	4.03 (15.46)	0.086 (1.40)*	0.02
16	Capacity not used	Log-Log	High Cap	21.05 (10.20)	-1.06 (-2.23)**	0.17
17	Capacity not used	Log-Log	Low Cap	14.97 (18.91)	0.553 (2.92)	0.23
18	Capacity not used	Log-Log	All	19.49 (13.85)	-0.608 (-1.83)**	0.05

Equation number	Dependent variable	Equation type	Months	Constant (t-value)	GPM (t-value)	$\bar{R}^2$
19	% Capacity used	Spillman	High Cap	3.448 (7.881)	-0.0142 (-2.61)***	0.23
20	% Capacity used	Spillman	Low Cap	2.8747 (16.000)	0.0026 (1.623)	0.06
21	% Capacity used	Spillman	All	3.522 (11.358)	-0.010 (-2.446)**	0.10

t-values are shown in parentheses.

Significance levels for the t-values are shown for the 10, 5, and 1 percent levels as *, **, and ***, respectively.

The t-test on the GPM coefficients is a one-tail test. The t-test is for greater than zero for the linear and log-log equations with crush and % capacity used as dependent variables. It is for less than zero for the linear and log-log equations with capacity not used as the dependent variable. It is also for less than zero for the Spillman equation with % capacity used as the dependent variable.

The slope coefficients for the linear equations for crush and capacity not used are in units of 1 million bushels per 1-cent increase in GPM. The slope coefficients for the linear equations for % capacity used are in units of 1 percent increase in the percent capacity used per 1-cent increase in GPM.

Table 7—Average futures and spot gross processing margins for high- and low-capacity months

	Average gross processing margin	
Months	Chosen futures	Spot
Nov., Jan., & Mar	$0.78	$0.86
May, July, Aug., & Sept.	$0.67	$0.98

Table 8—Estimated relationships between spot gross processing margins and soybean crush, percent capacity used, and capacity not used

Equation number	Dependent variable	Equation type	Months	Constant (t-value)	GPM (t-value)	$\bar{R}^2$
1	Crush	Linear	High Cap	1.19E+08 (9.40)	32162.15 (0.23)	-0.5
2	Crush	Linear	Low Cap	1.25E+08 (14.96)	-21587.1 (-2.69)	0.20
3	Crush	Linear	All	1.29E+08 (16.61)	-182020.8 (-2.35)	0.09
4	% Capacity used	Linear	High Cap	85.32 (23.04)	0.037 (0.90)	-0.01
5	% Capacity used	Linear	Low Cap	85.102 (31.92)	-0.095 (-3.70)	0.33
6	% Capacity used	Linear	All	89.440 (26.38)	-0.086 (-2.49)	0.10
7	Capacity not used	Linear	High Cap	20292517. (3.74)	-51260.19 (-0.85)	
8	Capacity not used	Linear	Low Cap	23278144. (5.44)	99175.12 (2.42)	0.16
9	Capacity not used	Linear	All	16438116. (3.40)	96513.88 (1.96)	0.06
10	Crush	Log-Log	High Cap	18.69 (40.78)	0.001 (-0.05)	-0.05
11	Crush	Log-Log	Low Cap	19.61 (54.24)	-0.257 ((-3.23)	0.27
12	Crush	Log-Log	All	19.38 (61.26)	-0.193 (-2.73)	0.12
13	% Capacity used	Log-Log	High Cap	4.377 (23.56)	0.024 (0.56)	-0.04
14	% Capacity used	Log-Log	Low Cap	4.94 (29.89)	-0.137 (-3.75)	0.34
15	% Capacity used	Log-Log	All	4.893 (25.48)	-0.111 (-2.60)	0.11
16	Capacity not used	Log-Log	High Cap	18.553 (11.25)	-0.476 (-1.27)	0.03
17	Capacity not used	Log-Log	Low Cap	16.028 (24.90)	0.277 (1.95)	0.10
18	Capacity not used	Log-Log	All	16.062 (14.33)	0.190 (0.76)	-0.01

Equation number	Dependent variable	Equation type	Months	Constant (t-value)	GPM (t-value)	$\bar{R}^2$
19	% Capacity used	Spillman	High Cap	2.856 (8.02)	-0.006 (-1.54)*	0.06
20	% Capacity used	Spillman	Low Cap	2.790 (25.64)	0.004 (3.59)	0.32
21	% Capacity used	Spillman	All	2.522 (10.61)	0.029 (1.19)	0.01

t-values are shown in parentheses.

The significance level for the t-values are shown for the 1-percent level as *.

The t-test on the GPM coefficients is a one-tail test. The t-test is for greater than zero for the linear and log-log equations with crush and % capacity used as dependent variables. It is for less than zero for the linear and log-log equations with capacity not used as the dependent variable. It is also for less than zero for the Spillman equation with % capacity used as the dependent variable.

The slope coefficients for the linear equations for crush and capacity not used are in units of 1 million bushels per 1-cent increase in GPM. The slope coefficients for the linear equations for % capacity used are in units of 1 percent increase in the percent capacity used per 1-cent increase in GPM.