EXPLORING ECONOMIC STRUCTURE IN THE U.S. POTATO MARKET

A Thesis

by

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ABSTRACT

Most research regarding the potato market fails to make a clear distinction between processing and fresh markets. The processing market includes potatoes destined for frying, dehydrating and grinding, whereas the fresh market encompasses those potatoes marketed for table consumption. While there exist many similarities, fundamental differences between the two markets point to the potential presence of economic structure, or in other words, a relationship in which the price of potatoes in one market leads the other. This paper opts to separate these two markets and investigate the existence of such relationship using theoretically ordered vector auto-regressions and impulse response functions. The robustness of the relationship is examined by utilizing data sets with different frequencies, monthly and annual.

Secondary to the objective of identifying economic structure between the two markets is the evaluation of sources of risk and volatility. By decomposing the forecast error variance of each vector auto-regression, definite amounts of future variation are attributed to the variables included in the model.

The research results indicate not only the existence of structure over both monthly and annual time periods but also that 1) over monthly periods shocks in the processing market precipitate responses in the fresh market and 2) over annual periods this relationship is reversed, with the processing market responding to fresh market shocks. Additional investigation suggests that the monthly economic structure is driven by differences in seasonality between the two markets, the availability of market information, and substitution of fresh market potatoes for

processing by major processors. Whereas, annual structure is more appropriately explained by the transparency and availability of transactional information.

Furthermore, the research shows that overall a very small proportion of future variance in the monthly data is driven by impulses in the individual price series, fresh or processing. However, the annual model with the inclusion of a production variable illustrates the fact that future volatility in the fresh market may be attributed to changes in processing prices and to an even larger extent, the annual production of potatoes.

DEDICATION

To Papa Rod and Braden…some of the best potato farmers I know.

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1. INTRODUCTION

Treatment of the U.S. potato market in past research has focused primarily on the market as a single, homogenous entity, with little distinction between the fresh and processing markets. The fresh potato market concerns itself primarily with the packing and marketing of potatoes for fresh consumption whereas the processing market includes those potatoes destined for frying, dehydrating, and grinding. It is true that there are many similarities between the two. For example, both types of potatoes are grown using nearly identical agronomic practices, many varieties are shared between markets, storage technologies developed over the course of time are dually applicable and geographical production regions overlap. Yet even with many similarities there is also a significant number of differences between the markets for fresh and processing potatoes. It is these differences which motivate this paper, which purpose is to fundamentally examine the relationship between fresh and processing potato markets using vector auto-regressions, forecast error variance decomposition, and impulse response functions. This paper will also examine other variables which account in large part for volatility in both markets, namely production levels and seasonality.

More specifically, we aim to empirically establish which market leads, or in other words from whence does price discovery flow. The idea of market leaders and followers is well-known within the field of agricultural economics. This relationship is characterized by the transmission of price signals between two markets, in which one market responds to changes in the other. The market which responds to changes is referred to as the follower, while the other is called the leader. While the leader/follower concept is readily accepted as a suitable method for describing the structure between two markets, it has not yet been applied specifically to the potato industry. In this study, the econometric models are evaluated using both annual and monthly data. The intent in evaluating data with different frequencies is to learn whether the relationship between the two markets is stable across time. Stability of the relationship would allow the conclusions from this research to be applied to short-term price movements in either market, as well as longer-term market activity spanning different crop years. Ideally, an enhanced understanding of this structure will help market participants make more informed decisions in regards to production allocation, transaction timing, and the apportionment of resources to market monitoring. It also sets the stage for further research by potentially uncovering interesting phenomena that merit additional attention.

Lastly, the use of vector auto-regressions in this study conveniently allows for the extension of the model to other economic questions. Ancillary to the question of structure between the two markets, is the attribution of error variance in future periods to certain variables within the model. This is an initial step toward comprehension of the source(s) of risk in potato markets. By decomposing the error variance of the model variables, we are able to confirm or repudiate those same variables as major sources of variability in the markets over time. The result of this portion of the analysis is agnostic as to the result. If not confirmed as chief sources of volatility, future researchers will be able to avoid dedicating time and resources to addressing the possibility of risk stemming from the variables treated here. The results from this evaluation will provide a basic starting point for additional research carried out on the topic of risk and risk management specifically within the U.S. potato industry. In these ways, the research at hand fills a necessary and neglected void within the literature using a well-established and reliable methodology.

2. BACKGROUND

2.1 Overview of Potato Crop

Potatoes are an integral crop in the United States food system. Despite major grains and oilseeds consistently outranking the potato in terms of acreage and value of production, it is among the most important vegetables grown in the United States and world (IPC 2018). The significance of the potato may be derived from two primary sources: 1) its esteemed place in the American and global diet and 2) the economic significance for producers, processors, packers, and retailers who participate in its marketing throughout the value chain.

Statistically, these claims of importance may be substantiated by reviewing a few key metrics regarding both potato consumption and production. In the United States, consumption is around 48.3 pounds per capita. This surpasses the next most popular vegetable in the United States, the tomato, by a factor of nearly two (Bentley 2017). Furthermore, the popularity of the crop is not confined solely to the U.S. Globally, the potato is considered the "third most important food crop in the world after wheat and rice, in terms of human consumption", and its influence continues to grow each year (IPC 2018). The likely reasons for its predominance in diets and agricultural production systems can be traced to the crop's overall efficiency in utilizing limited inputs. No other crop produces as much caloric value per unit of land and water than the potato. In fact, an acre of potatoes can yield anywhere from two to four times the food quantity of grain crops, making it an ideal food for efficient use of resources (FAO 2008).

2.1.1 Economic Importance of the Potato

An entire economic value chain has developed which supports both domestic and global demand for the starchy vegetable. In the U.S., around 15,000 farmers in thirty different states grow potatoes commercially (Minor and Bond 2016). Of these potato-producing states, Idaho and Washington are by far the most dominant. They account for over half of U.S. production, and consistently rank amongst some of the most efficient production areas in the world. During the 2016 crop year, U.S. production included over one-million acres planted, resulting in production valued at 3.9 billion dollars, with approximately 44 billion pounds of potatoes harvested (NASS 2017). Globally, the U.S. consistently wields substantial market influence, likely due to its demonstrated preeminence in the field of potato processing. Technologies developed in the 1920s and 60s in the Western United States introduced the dehydrated potato and the frozen French fry to the world. Both have been major contributors to growth in demand for the potato since.

2.1.2 Trade and Potatoes

These factors have ensured the United States' fairly consistent status as a net exporter of potatoes and potato products. However, the U.S. does import potatoes from a number of trading partners; foremost among these countries is Canada. By value, potato imports from Canada account for approximately 80 to 90 percent of total potato imports in the U.S. (NASS 2017). Of these imports the vast majority are frozen, processed potato products (NASS 2017). Close geographical proximity to the U.S. and the North American Free Trade Agreement (NAFTA) are likely factors which drive the high level of imports from Canada. Additionally, two of the world's largest French fry processors are headquartered in Canada. While trade patterns may have some bearing on the relationship between fresh and processing markets in the U.S. and their volatility, the effect is likely muted considering the degree to which the two markets are integrated.

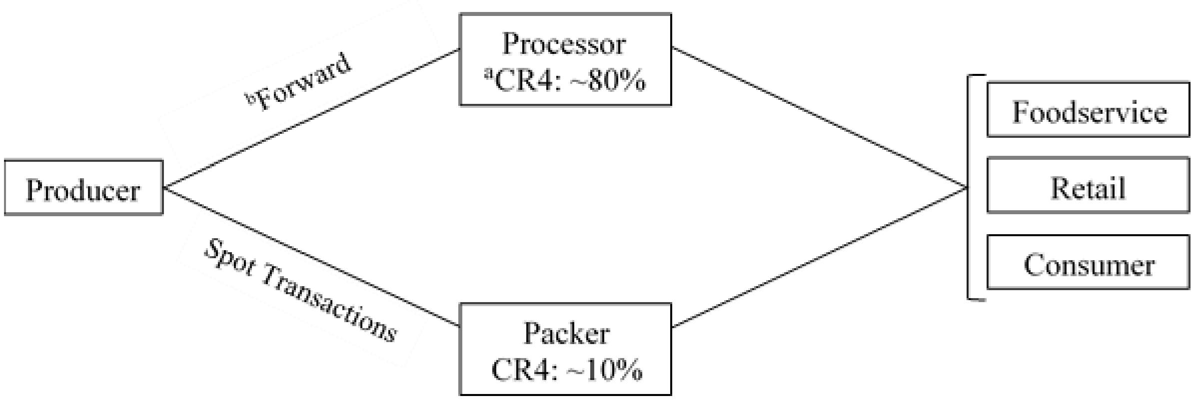
2.1.3 Usages and Substitutability of Potatoes

While similar in some characteristics, potatoes produced in the U.S. are actually quite heterogenous as a result of their varied uses. There are three primary uses for potatoes: processing, fresh-consumption, and seed. The majority (~60%) of the potatoes produced domestically are ultimately destined for the processing sector which transforms the potato into value-added products such as French fries, dehydrated powders, and chips. Historically, the processing sector has grown steadily, displacing an increasing amount of the fresh market. At present, it appears the growth in processing versus fresh potatoes has stabilized. The remaining balance of the crop is divided principally between fresh-markets (~30%) and retained tubers for the following crop year's seed stock (~10%) (NPC 2017). Each of these markets demands specific traits unique to their industry and exchange between them occurs, albeit infrequently. Notwithstanding the heterogeneity of the marketplace, potatoes grown for processing or packing are oftentimes substituted into other markets. While the substitution of processing potatoes for packing and packing potatoes for processing may not be ideal, given the right circumstances, this practice does occur. The exchange of potatoes between the two markets has also likely been aided by the development of new, more versatile varieties, principally the Russet and its descendants. The Idaho Potato Commission maintains a list of "most popular varieties" of which many are classified as dual usage.

2.2 Key Differences and Similarities Between Fresh and Processing Markets

The producer is the primary link between the various markets. While later stages in the value chain have little room to alter the composition of their inputs, potato farmers, especially those in the foremost growing areas, regularly substitute the production of processing potatoes for that of fresh-pack potatoes and vice versa.[1] Despite the linkage of the two markets at the farm level, the value chain from that point forward diverges. For this reason, the research at hand focuses primarily on the hypothesized connection of the two markets post-production.

Figure 1. Illustration of Potato Value Chain



[a]CR4 denotes the four-firm market concentration ratio or in other words the percent of market share controlled by the four largest companies in the industry.

[b]While the majority of transactions in the processing sector occur on a forward contracting basis, there are instances in which processors utilize the spot market for fresh potatoes. See section 6.1.1 for additional information.

[1] Agronomic constraints such as pest and disease control limit geographically the production of seed potatoes. Additionally, the majority of seed potatoes are grown in certified seed-growing areas, further limiting the practicality of substituting their production for that of processing or fresh-pack potatoes.

Figure 1 illustrates some key differences, including industry concentration and market transaction types between processing and fresh sectors within the potato industry. Typically, potatoes grown for fresh consumption are sold by the farmer to a packer. These potato packers are normally confined to regional operations with limited processing capacity. They receive potatoes from farmers and then pack the potatoes under private label and packer-owned brands, which are then marketed to retail and foodservice entities and end-consumers. There are hundreds of independent packers scattered throughout the U.S. Accordingly, the sector has a low concentration ratio of 10 percent. Oftentimes, they are owned or operated by potato producers in a cooperative or proprietary type business model. First priority is given to potatoes grown by members of the growing association or the owner's own crop. Excess capacity is then filled by purchases made on the local or regional spot market. The spot market for fresh potatoes is both active and relatively transparent. Currently, the main source of price information regarding the fresh potato market is the USDA Agricultural Marketing Service's weekly "Potato and Onion Report". All information contained in the report reflects recent transactions on the spot market for fresh potatoes and is obtained via voluntary submissions from packers and other potato handlers across the U.S.

This model stands in contrast with that of the processing sector. The processing industry may be appropriately categorized as oligopolistic when compared to the fresh sector. Four-firm concentration ratios of the frozen potato and potato chip markets are between 60 and 80 percent respectively, well within the range of concentration exhibited by oligopolistic markets (Katchova et al. 2005). Given the highly concentrated market structure, the potato processing industry may be considered an oligopsony. A handful of firms dominate not only the sale and distribution of processed potato products, but also the purchase of raw potatoes.[2] Forward contracts at prices and terms favorable to the processors are largely dictated to the farmer, with some allowance for collective bargaining carried out by grower groups. However, processors have recently shown less inclination to negotiate with such groups (O'Connell 2017). Unlike the fresh sector, there is no formal medium for price discovery, nor is there an active spot market for processing potatoes. Rather, price is largely determined via forward contracts on an individual basis, where pertinent information regarding price movements may or may not be accessible or transparent. Transactions involving processing potatoes are often carried out in an informational vacuum, where the only reliable information regarding recent price movements is sourced from the spot market for fresh potatoes.

Apart from these fundamental differences, there are some shared similarities between the two markets. One such commonality is the fact that the potato, though widely consumed, is a perishable crop. Unlike wheat, rice, and corn, whose storability extends into years under appropriate conditions, the potato, under ideal circumstances generally has a storage life of less than one year. Even then, the storage can be prohibitively expensive for producers to use. The issue of storability affects the processing and fresh sectors equally. While processed potato products may be stored for extended periods of time, the cost of this type of storage exceeds that of storing potatoes themselves. It is therefore in the processors' best financial interest to store adequate quantities of raw potatoes in order to satisfy demand for processed potato products throughout the year.

[2] Recent research indicates Frito-Lay controls approximately 60 percent of the U.S. potato chip market, while the frozen and dehydrated business is dominated by Lamb-Weston, McCain Foods, Simplot and Cavendish.

Another shared characteristic of both the fresh and processing sectors is the seasonality of production. As previously cited, the two largest potato producing states, Idaho and Washington, both have similar climates that allow for little deviation from an established growing season. The highly concentrated production in these two states prevents other regions of the country from satisfying consumer demand during counter-cyclical seasons. Thus the seasonality of production in tandem with the limited storability of the fresh potato creates a market frequently punctuated by volatility for both the processing and fresh sectors.

3. LITERATURE REVIEW

Vector auto-regression (VAR) has long been an acceptable and useful method for empirically studying financial and economic data. VAR was originally developed and popularized by Sims' (1980) seminal work on the use of lagged regression models to characterize the effect of a shock in certain right-hand-side variables. From the beginning, VAR attracted significant attention from the academic community, primarily because of its ability to reflect the actual structure of economic phenomena. True economic structure was particularly elusive and many econometricians and economists alike hoped that by not forcing models to conform to *a priori* expectations, valuable information could be teased from the data. Apart from assisting researchers in identifying true structure, Cooley and Leroy (1985) also suggest other alternative, yet effective uses of VAR, including: forecasting, causality testing, theoretical evaluation, assessment of policy, data characterization, and postulation of hypotheses. Undoubtedly, this versatility has contributed substantially to the attractiveness of VAR among academicians and practitioners alike.

VAR alone are difficult to interpret, as the coefficient results from a VAR model often reflect both complex contemporaneous and delayed interactions among selected variable(s). Therefore, any analysis employing the method is generally accompanied by impulse response functions (IRF) and/or forecast error variance decompositions (FEVD). IRF calculated via mathematical transformation illustrate the reaction of variable to a one-time shock in the error term. The process by which the shock is transmitted forward in temporal space is not without criticism. Cooley and Leroy (1985) together with others (Friedman 1981, Fischer 1981, and

Goldfeld 1982) have expressed concern that IRF are inappropriately associated with causal interpretations. They argue that while IRF are useful for the evaluation of models in which shocks are performed on variables with truly exogenous, uncorrelated error terms, economic models generally lack this basic characteristic and are therefore unable to be interpreted causally using IRF. Much of the literature, while cautious of deriving directional causal relationships from observing IRF, opts instead for the interpretation of Granger-causality from the functions (Lutkepohl 1990). Another frequent critique of IRF is its susceptibility to the dilemma of omitted variable bias. Naturally, economic and financial systems and markets are complicated. It is difficult to ascertain with a high degree of certainty that the variables included in any IRF analysis are unaffected by other variables not included within the model (Lutkepohl 1990).

There is a method for reflecting the possibility of correlation among error terms. Frequently, a shock in the error term of one endogenous variable is accompanied by a shock in another one of the variables included in the model. By orthogonalizing the shocks in the matrix used to then trace the shocks throughout future periods, the representation of the error term is uncorrelated. Despite arguments against and the apparent deficiencies of the tool, IRF are utilized extensively throughout the literature and are widely accepted as an efficient quantitative tool to better understand economic structure.

FEVD are in many ways similar to IRF, however, rather than describing the effect of a shock in future periods, they describe the percentage of forecast error attributable to an exogenous shock in each variable in the system. Numerous pieces of research have applied FEVD to the field of risk analysis. Campbell (1990) uses the variance decompositions to evaluate the source and magnitude of variation in unexpected stock returns coming from two exogenous components. Campbell et al. (2009) employs a slightly adapted version of this methodology to consider movements within the U.S. housing market.

Sims (1980, 1981) originally advocated for models of VAR class as an alternative to traditional econometric models. This argument was founded upon the belief that traditional econometric models failed as a result of the lack of specification provided by inadequate or at least incomplete economic theory. VAR at the time provided a highly flexible, open-ended approach to absence of *a priori* beliefs. However, as time progressed many sought the structure afforded by traditional econometric modeling while still allowing for some remnant of adaptability within the model, thus leading to the development of the structural vector auto-regression (SVAR). In many ways the movement towards SVAR is ironic, especially considering that the original intent of VAR was to purposefully exclude any structure so as to better understand economic form as it really exists. However, despite the irony, the generally accepted methodology of today tends toward an approach that starts with a broadly specified (VAR) and then seeks to introduce structure (SVAR) as a way of more conclusively confirming the reality of economic theory. Blanchard and Watson (1984), Sims (1986) and Bernanke (1986) pioneered the practice of including structure derived from economic theory in VAR estimation and subsequent IRF and FEVD analysis. The structure is imposed using restrictions on SVAR such that the system is identified and therefore contains a unique solution. By explicitly defining the model, IRF and FEVD results demonstrate clearly, unlike the traditional VAR, whether the underlying theory is confirmed or repudiated or if in some way the constructed model does not possess the correct specification needed to achieve the former.

Another key difference between VAR and SVAR is the technique used to estimate parameters. Zellner (1962) established that if an auto-regressive system is composed of multiple equations, and each equation contains exactly the same right-hand-side variable, then the best, linear, unbiased estimate of the parameters is obtained through ordinary least squares. In the case of SVAR, the requirement for identical right-hand-side variables throughout is not satisfied. Consequently, additional estimation procedures must be used to obtain the appropriate structural parameter estimates. Sims (1986) achieves estimates using maximum likelihood, yet others have added other possibilities which realize the same end. These include Bernanke (1986) who obtained structural estimates by employing Hansen (1982) method-of-moments and Blanchard and Watson (1986) who combine the maximum likelihood method with instrumental variables.

There also exists the possibility of imposing the same type of structure present in SVAR while still relying on the relative simplicity of obtaining parameters estimates via OLS. By orthogonalizing the shocks in the error term of a traditional VAR, and then ordering the variables so that the contemporaneous effects are recursive, a model can achieve structure. This method is likely preferable in systems involving a low number of variables and where clear theory supporting a specific ordering of the variables is present (Becketti 2013).

While there have been studies that approach the topic of volatility in potato markets, most have been confined to a single particular source of risk. For example, Muthusamy et al. (2008) evaluated the effect of potato supply management carried out by the grower cooperative, United Potato Growers of Idaho, on overall price levels and volatility. Older work done by Gray (1963), Sooy and Branch (1980) and Paul et al. (1979) focused exclusively on the interaction between risk and futures trading for potato markets. Notably, none of these more prominent studies surrounding volatility in potato markets leveraged FEVD analysis to account for sources of risk.

There exists, however, other industry specific literature in the broader field of agricultural economics which uses a similar framework to the one contained within this research. The literature establishes clearly the combined use of the suite of VAR related tools, including IRF and FEVD. In this way much of the literature generally tends towards a two-stage analysis in which the subject of economic structure is broached via the VAR and IRF and then volatility is examined using the complementary FEVD.

Examples of recent, well-implemented studies utilizing this econometric framework include Hausman et al. (2012) and Zhang et al. (2007). Both studies examine difference aspects of the bio-fuels market through the lens of SVAR and accompanying IRF and FEVD. Hausman et al. (2012) gives a treatment of the response of U.S. crop prices to shocks in acreage of both the crop itself as well as others, whereas, Zhang et al. (2007) investigates causal relationships amongst various fuel additives as well as the corn market. In both cases a SVAR was selected for its ability to impose accepted economic theory on the models as well as to take advantage of the characteristic timing observed in agricultural markets.

A broader, more comprehensive use of the VAR class of models was used by Rezitis (2014) in which relationships between thirty commodities, oil prices, and exchange rates are explored. This study is an ideal example of the application of VAR to the existence of connections between seemingly unrelated markets. The study opts for VAR due to its flexibility and propensity for identifying interesting relationships.

Finally, Musunuru (2017) considers the dynamic interaction among meat and grain prices and exchange rates in the U.S. IRF produced from the results of a VAR in the paper demonstrate clear linkages between prices of agricultural commodities and shocks in other markets. The argument is made that understanding these links will assist producers in designing and implementing hedging programs, adapting market strategies and also minimizing risk exposure.

4. DATA

Data[3] for the study comes primarily from figures gathered by two agencies within the USDA. The National Agricultural Statistics Service (NASS), compiles a variety of information on the potato industry including production, consumption, and usage data together with price reporting from across major potato producing regions in the U.S. This data is found in the *Annual Potato Summary*, which has been published yearly since 1986. Other supplemental figures were obtained through the Economic Research Service (ERS), which maintains a comprehensive database of statistics not covered by NASS, including seasonal potato storage numbers, and annualized production, consumption, and price data extending from 1949 until present. All price data utilized throughout the study is inflation adjusted to 2016 U.S. dollar equivalent using the U.S. Federal Reserves' Consumer Price Index for food items.

Table 1. Summary Statistics of Annual Fresh and Processed Potatoes 1986-2016

		Number of Observations	Minimum	Maximum	Mean	Standard Deviation	Coefficient of Variation
Monthly	Fresh	372	4.779	31.057	11.828	4.080	0.345
	Processed	372	5.522	12.316	7.806	1.161	0.149
Annual	Fresh	31	7.415	20.631	11.820	2.867	0.243
	Processed	31	6.342	9.724	7.735	0.895	0.116
	Production[a]	31	356,438	513,544	436,396	36,273	0.083

[a]Production in 1,000 hundred weight (cwt).

[3] The data is presented prior to the methodology in order to provide the reader with adequate context for comprehension of the variables involved in the research models.

Two main time series are leveraged for the analysis portion of this study. The first is bivariate and consists of monthly price observations from January 1986 to December 2016 for both the fresh and processing potato markets. 1986 was the first year the USDA began reporting the two prices separately and is therefore the selected starting point for our research. The second data set is comprised of trivariate annual frequency data, also from 1986 to 2016. Observations here also include two separate price series for fresh and processing potatoes, but add additional figures on total annual production of potatoes in the U.S. Prices in all cases are reported in U.S. dollars per hundredweight (cwt).

Table 2. Unit Root Tests for Model Variables

	Dickey-Fuller Test	
	Test Statistic	p value
Annual		
ΔFresh Price[a]	-7.582	< 0.01
ΔProcessing Price	-6.688	< 0.01
ΔProduction	-9.221	< 0.01
Monthly		
Fresh Price	-4.044	< 0.01
Processing Price	-3.479	0.04

[a]Statistics accompanied by Δ indicate first differences.

The validity of a VAR is contingent on the stationarity of the data. Prior to the estimation of our VAR model and subsequent analysis, each series was evaluated using the Dickey-Fuller unit root test. Initial testing of non-differenced data, indicated the presence of non-stationarity in the annual data. Resultantly, the annual series were transformed to represent first differences in each variable. The Dickey-Fuller test was then re-administered and the data was confirmed as stationary. The monthly data was found to be stationary in its present state and was accordingly left untransformed. All data, following the adjustments, is found to be stationary at the 1 percent level, with the exception of monthly processing price which is significant at the 5 percent level. All results from the Dickey-Fuller tests are summarized in Table 2.

5. METHODOLOGY

5.1 Introduction to Methodology

The empirical portion of this study is divided into three segments. The first involves the additive decomposition of the monthly prices in order to discuss the observation of seasonality between the two series. Second, is the construction of two VAR using ordering motivated by theory to include structure in the models. The third utilizes IRF and FEVD derived from the VAR as aids to interpret the structure of the potato market and then measure the effect on volatility over subsequent periods.

In the second segment, separate VAR are constructed, one using monthly data and the other using annual data in order to analyze the stability of the relationship between the processing and fresh markets over different periods of time. We hypothesize that 1) a leader/follower type relationship does exist between the two markets and 2) the same economic structure across months may not hold when considered across crop years.

Besides the need to consider the stability of economic structure over different lengths of time, the study was also initially constrained by the very nature of dealing with agricultural data. While price information is available on both a monthly and yearly basis, production data is not. Furthermore, previous research has established the relative inelasticity of potatoes in regards to demand (Richards and Kaiser 2017). This contributes additional motivation to include the annual model together with its production variable. This is, in effect, an amalgamation of the two factors that hypothetically weigh most heavily on potato price levels and volatility: yield and acreage. The desire to evaluate the effect of production levels on the two markets in regards to volatility and structure ultimately contributed to the decision to also construct the annual VAR.

Both the monthly and annual data models are presented in tandem throughout the methodology section, due to the fact that identical mathematical procedures were used in arriving at the results and to clearly state the ordering of both models. Thereafter, a discussion of the monthly results and their implications is treated prior to and apart from the annual results.

5.2 Additive Decomposition of Monthly Prices

The observed values of each time series are broken into three distinct components, trend, seasonal, and random contributions to the original price observation.

$$y_t = Trend_t + Seasonal_t + Random_t$$

After finding the trend using a centered moving average calculation and subtracting it from the series, the seasonal component is identified by averaging the effect for each given month over the entire de-trended data by including a dummy variable in the model for each month. The remaining statistical noise, or residual errors, are considered the random component of the decomposition as they capture all those factors not related to the general trend of the series or its predictable monthly behavior.

5.3 Construction of Vector Auto Regressive Models

The most basic representation of the two VAR constructed are as follows:

$$y_{t_{monthly}} = \begin{bmatrix} fresh\ prices_t \\ processed\ prices_t \end{bmatrix} \qquad y_{t_{annual}} = \begin{bmatrix} annual\ production_t \\ processed\ prices_t \\ fresh\ prices_t \end{bmatrix}$$

There may exist some criticism of the relatively small number of variables included in the models. However, as previously stated little meaningful potato industry data with monthly frequency exists. While the possibility of some interpolation exists, this may distract from the robustness of the results and detract from the clarity of the findings. Additionally, the very nature of VAR implies that a small number of initial variables can quickly become many depending on the lag structure dictated by information criterion. Given the relatively small sample size of the annual data, any addition of superfluous variables would certainly jeopardize the statistical power of the results and reduce the chances of identifying true and dependable relationships. Schwarz-loss criterion was used to determine the appropriate lag length. For both the monthly and the annual data lag order was one. Accordingly, the contemporaneous observation, y_t, and the same observation lagged one period, y_{t-1}, were included in the final VAR equation for the monthly and annual data for each of the variables.

The general reduced form for a vector auto-regression can be summarized by the following:

$$y_t = A_1 y_{t-1} + A_2 y_{t-2} + \cdots + A_k y_{t-k} + C x_t + u_t$$

By multiplying throughout by A^{-1} the reduced form of the VAR is subsequently expressed structurally.

$$A^{-1} y_t = A^{-1} A_1 y_{t-1} + A^{-1} A_2 y_{t-2} + \cdots + A^{-1} A_k y_{t-k} + A^{-1} C x_t + A^{-1} u_t$$

The key here is that now the reduced form error term u_t may be re-designated $v_t = A^{-1} u_t$ which follows a random process, or in other words any shocks administered to the system are now orthogonalized and uncorrelated. Matrix A in the above example serves as the connection between the reduced form and structural representation of the model and is obtained by decomposing the correlation matrix Σ into two separate elements, the lower triangular matrix A and it's accompanying transpose A'.

$$\Sigma = AA'$$

$$A^{-1}A'^{-1}\Sigma = I$$

$$\mathrm{E}[u_t A^{-1}(u_t A^{-1})'] \Rightarrow E[u_t u_t']A^{-1}A'^{-1} \Rightarrow A^{-1}A'^{-1}\Sigma = I$$

The mathematics are quite elegant and allow us to successfully convert the original correlated error terms to the orthogonalized, uncorrelated shocks:

$$v_t = A^{-1}u_t$$

5.4 Model Variable Ordering

This property, while satisfying the need to isolate shocks, is still not sufficient for causal interpretation of the results generated from the model. Additional identifying assumptions are generally necessary to make definitive statements about what is happening within the economic system. We adopt the Sims (1980) method which advocates for the use of recursive ordering within the VAR, where the position within the system of a particular variable is determined not arbitrarily. The orthogonalized arrangement of the error term shocks per the above mathematical transformation make evident the fact that by re-ordering variables the resulting impacts may change. An illustration applicable to the model considered in this study is useful for understanding such ordering.

$$v_{t_{monthly}} \equiv \begin{bmatrix} v_t^{fresh\ prices} \\ v_t^{processed\ prices} \end{bmatrix} = \begin{bmatrix} \alpha_{11} & 0 \\ \alpha_{12} & \alpha_{22} \end{bmatrix} \cdot \begin{bmatrix} u_t^{shock\ in\ fresh} \\ u_t^{shock\ in\ processed} \end{bmatrix}$$

and

$$v_{t_{annual}} \equiv \begin{bmatrix} v_t^{annual\ production} \\ v_t^{processed\ prices} \\ v_t^{fresh\ prices} \end{bmatrix} = \begin{bmatrix} \alpha_{11} & 0 & 0 \\ \alpha_{12} & \alpha_{22} & 0 \\ \alpha_{13} & \alpha_{23} & \alpha_{33} \end{bmatrix} \cdot \begin{bmatrix} u_t^{shock\ in\ production} \\ u_t^{shock\ in\ processed} \\ u_t^{shock\ in\ fresh} \end{bmatrix}$$

Here the theoretical restrictions from ordering are illustrated. Not all variables respond to shocks in all variables, rather only to those explicitly specified. In the case of the annual data, a contemporaneous shock in production affects shocks in the ensuing variables of both processed and fresh price. Conversely, a contemporaneous shock in fresh price affects processed price in the monthly data. The whole purpose of first orthogonalizing the shocks and then determining variable ordering according to theory is to simplify the interpretation of the subsequently formed IRF by clarifying and isolating the influence among variables. Nonetheless, simplification comes at a cost. The curse of recursiveness is its requirement that order be forced upon the system.

Justification for the above ordering of variables in the annual model is derived from Nerlovian thinking, that price is generally viewed as a function of production. Additionally, the efficient market hypothesis indicates that prices should instantaneously incorporate all relevant information, including production (Staff 2016). Based on this economic intuition, production should be ordered first, followed by processed price, and then finally fresh price. Fresh price is ordered last because price discovery in that market occurs in a more liquid, active and transparent spot-type environment. This stands in contrast with the market for processing potatoes, which is constrained by forward contracts. It would be inappropriate to place processed price last, owing to the fact that it would be unable to react contemporaneously to changes in the fresh market prices.

Unlike the annual model, the approach used in the case of the monthly data is atheoretical. Moreover, there is some evidence from previous research that indicates in bivariate vector auto-regression, ordering and structure are less concerning as the robustness of the results can simply be determined by easily altering the order of the two variables (Becketti 2013). It remains important, however, to utilize orthogonalized shocks in the error term in order to clearly attribute changes in one series to the other, thereby aiding in the interpretation of results.

5.5 Impulse Response Functions and Forecast Error Variance Decomposition

The purpose of constructing VAR is to evaluate the relationship between the included variables using IRF. IRF trace the effects across the system of a one-unit shock in the standard deviation of a particular variable. The general form of the previously summarized VAR may be re-written in moving average form:

$$y_t = \mu + \sum_{i=1}^{\infty} \Phi_i \, u_{t-i}$$

Per this representation, IRF are calculated by following each component of Φ_i throughout successive time periods after a shock is applied to u_{t-i} at time period $i = 0$. The primary IRF is contained within a confidence interval, derived from bootstrapping this process repeatedly.

Despite some shortcomings, VAR remain popular for their exceptional predictive power. In time series analysis, it is theorized that all relevant information necessary to determine future changes in a variable is self-contained within past observations of that same variable. By utilizing FEVD, our analysis can be extended to attribute variance within the prediction to specific variables within the model. Lütkepohl (1991) describes the procedure by which this is accomplished:

$$y_{t+h} - \hat{y}_{t+h} = \sum_{i=0}^{h-1} \Phi_i \, u_{t-i+h}$$

Where $y_{t+h} - \hat{y}_{t+h}$ represents the actual observation of element j at some future period $t + h$

minus the predicted value of the same element. By utilizing the orthogonalized error matrix previously derived, $v_t = A^{-1}u_t$, in place of error term u_{t-i+h} , and imposing the same type of ordering restrictions, we are able to economically associate a percentage figure of the error term at period h with a given variable.

6. RESULTS

6.1 Seasonality

Figure 2. Seasonality of Potato Prices

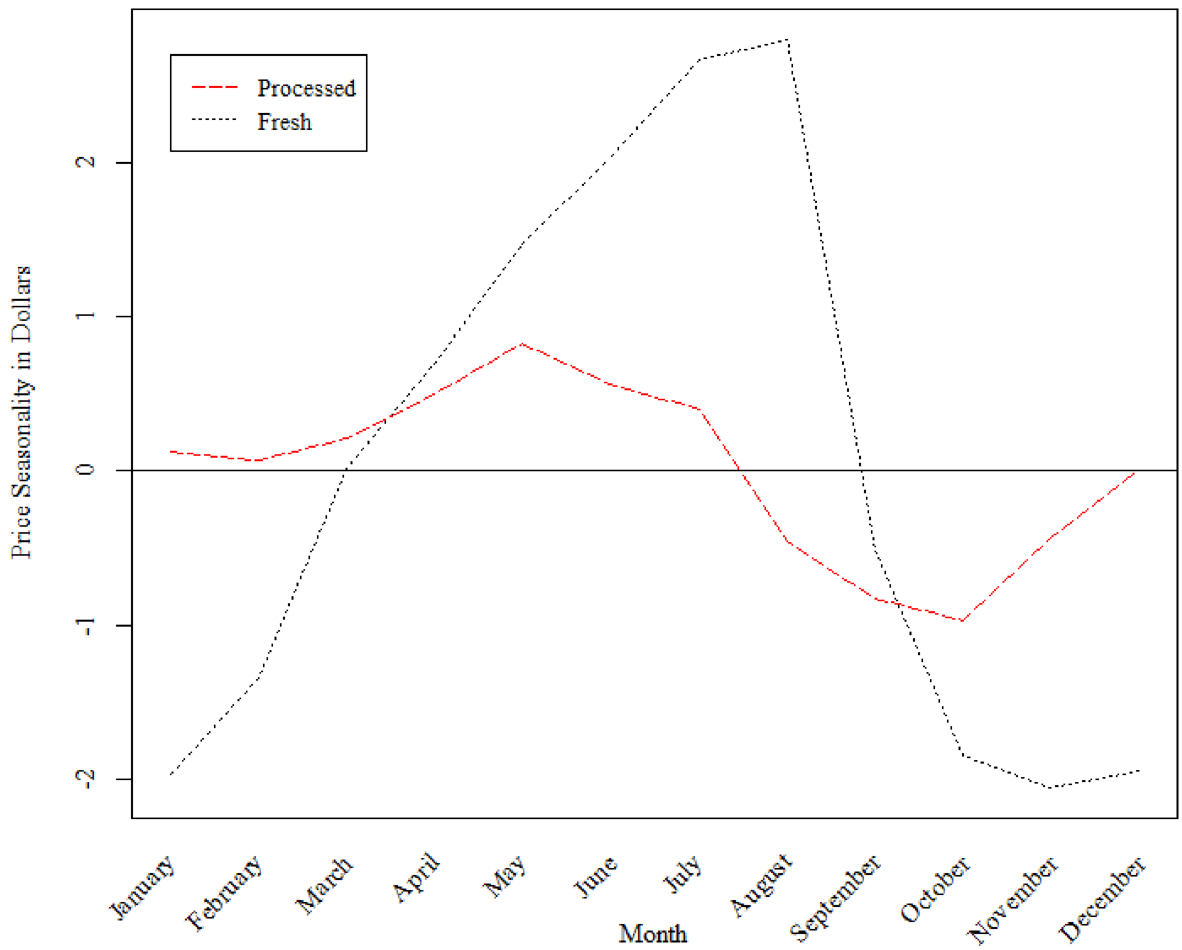


Figure 2 represents the seasonal component of the additive decomposition of both fresh and processing potato prices over time. Each series clearly exhibits a pronounced seasonal effect. The decomposition indicates that for processing prices the seasonal effect is strongest during the month of May. In other words, on average processing potato prices are approximately one dollar higher in May relative to the other months. Fresh price seasonal effect peaks in August, or on average fresh potato prices are approximately three dollars higher in August, relative to the other months. Processing and fresh potatoes are grown under similar agronomic conditions, are produced and harvested during approximately the same periods, and are stored using the same technologies. Therefore, any difference in seasonal trends must be introduced from other factors.

6.1.1 Market Information

One such factor may be the timing and availability of information within both markets. Processors store to satisfy their needs, yet the presence of storage shrinkage and decay makes completely accurate forecasts implausible. As the storage season, which typically begins in October and ends in July, nears the final months it becomes evident to the major processors whether the stocks in storage will be adequate to satisfy their needs until the new crop of potatoes begins in July. As previously discussed, the processing market is highly concentrated. In this sense the processing market possesses the advantage of being able to limit the dissemination of information regarding potato stocks. It is possible that there is an informational delay between the time in which a major processor begins fresh market purchases and when the fresh market becomes cognizant of said purchases. An opposite effect is not possible because of the differences in market structure. That is, if the fresh market discovers a shortage in supply, during the storage season or otherwise, fresh packing sheds are confined to making purchases solely on the fresh market because processing potatoes are, at that point in time, committed under contract.

6.1.2 Storage and Supply

The timing of supply may also affect the seasonality of prices. Supply in potato markets is fundamentally tied to storage. Major progress has been made in the area of potato storage. The introduction of Chlorpropham (CIPC), a chemical sprout suppressant, in the late 1950s, advances in mechanical and electronic controls for temperature and airflow in the 1980s and 90s, and improvements in genetic storage traits all contributed to a decrease in the portion of the crop lost to shrinkage and decay as well as the extension of marketing periods for the crop. However, even with the advent of more effective storage technology, there are still periods of time in which potatoes are relatively scarce. The period in which storage stocks are dwindling and new crop potatoes have not yet begun to enter the marketplace often coincides with warmer summer months. As temperatures increase, the cost of operating the cooling and humidifying equipment in storage facilities rapidly rises. The corresponding price series seem to reflect both the rise in storage costs and the relative scarcity of potato supply for both the fresh and processing markets prior to new crop.

6.1.3 Differing Demands

Another important factor in explaining differences in seasonality between the two markets is the demand experienced in each market. While it is difficult to identify what the primary differences in demand may be, we know that these differences are accounted for in the prices observed in both the processing and fresh potato markets. Such differences may be associated with consumer preferences. For example, U.S. consumers may have a stronger tendency to consume French fries and other processed potato products earlier in the summer, while fresh potato consumption peaks later in the season.

6.1.4 Forward Contracting's Smoothing Effect

The final result that is shown clearly via the results of the decomposition is the smoothing effect of forward contracts on price variability. While both series demonstrate seasonality to one degree or another, fresh potato price consistently exhibits larger and longer fluctuations. This aligns well with to the theory of risk trade-off. Producers are willing to forgo opportunities for periods of high prices in order to avoid similar periods of low prices. This is further supported by the summary statistics previously presented that indicate the overall price level and volatility of the processing market for potatoes are considerably lower than the fresh market.

6.2 Discussion of Monthly Results

IRF reveal the relationship between the two markets for potatoes. In addition to treating the direct result of IRF, additional depth is added to the analysis by considering forward contracting as the primary factor which may be imposing structure between the two markets. Then FEVD is examined to determine whether shocks in either market are a significant source of volatility in the other.

Figure 3. Monthly Impulse Response Functions

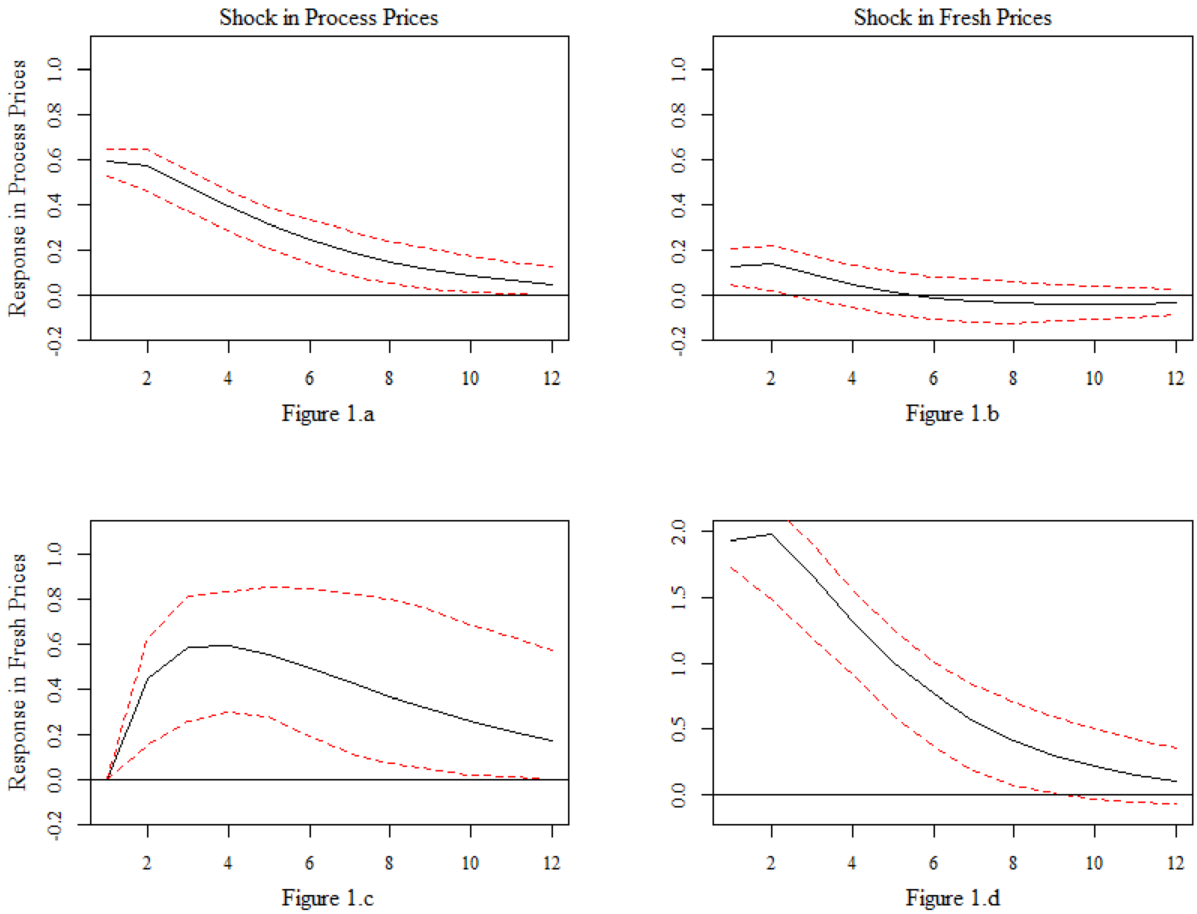


Figure 2 contains the results from generating IRF for the monthly data. The underlying VAR was ordered such that a contemporaneous shock in fresh prices would affect processing prices, but a processing price shock would not affect fresh prices. Interestingly, the relationship between the two market sectors does not seem to follow general economic intuition. The following discussion, serves as a plausible explanation of both expected behavior as well as the drivers behind the counterintuitive result.

The variable ordering and economic theory surrounding price discovery would seemingly point to processing prices responding to a shock in the fresh price. Price discovery is the process of determining the price of a good or service through interactions between buyers and sellers in the marketplace (Ward 2018). Discovery of price is only possible in the presence of transparent, observable transactions, typically occurring in a market where participants have access to information and the frequency of transactions reflects economic expectations or realities. Given the known differences between the fresh and the processing sectors, the expectation would be that price discovery in the potato industry as a whole would occur primarily in the fresh market, where nearly all transactions take place on a spot basis and are more visible than those carried out by their processing counterparts. It is reasonable, to expect that producers of processing potatoes and processors themselves would observe price movements in the fresh market and adjust their own negotiations accordingly. The results of the monthly IRF analysis indicate otherwise. A shock in fresh prices produces little to no response in processing prices. Conversely, a shock in the processing market produces a large and persistent response in fresh prices which reaches its climax at three to five months following the shock. An explanation of this fascinating phenomena requires additional scrutiny.

One of the basic narratives in the industry as a whole is the relatively nonexistent growth in total potato consumption over the past century. However, this narrative does not hold true for all forms of potatoes consumed. Prior to 1970, fresh potatoes were consumed at a much higher rate than at present. With the advent of frozen and dehydrated potato products and the significant rise in disposable income during the 1960s and 70s, consumers moved increasingly away from the consumption of fresh potatoes towards the greater ease and convenience of processed potato products. As greater volumes of potatoes were designated for processing, a likely structural shift occurred in the marketplace, in that potato producers and others took their price signaling from the processing side of the market instead of the fresh spot market. Unfortunately, establishing empirically such a structural shift is difficult. Not for lack of statistical or econometric procedures, but primarily due to the fact that potato prices were not reported separately until 1986, nearly two decades after the volume of U.S. potatoes destined for processing surpassed fresh potato volume.

In addition to structural changes driven by the evolution of consumptive patterns, there may be a more likely mechanism that helps explain this seemingly exceptional relationship between the fresh and processing potato markets in which the processing market price leads and fresh prices follow. As previously explained, the vast majority of processing potatoes are grown under forward contract. Prior to the planting season, processors award contracts to farmers to grow a set acreage at a largely pre-determined price. Largely pre-determined, because the majority of potato forward contracts have premiums based on quality characteristics, volume produced, and fresh market price levels at time of delivery. These contracts impose a constraint on the interaction of the processing market with the fresh market. For example, if fresh packers experience unforeseen demand, they are unable to purchase additional supply in the processing market because those potatoes are already committed. Correspondingly, if processors also experience increased demand they must make their purchases on the fresh spot market. The forward contracts act as a filter allowing potatoes and price information to flow in a single direction, from the processing market to the fresh market but not vice versa.

6.2.1 Implications from Monthly Findings

There are numerous implications from this finding. Perhaps the most salient is the relationship between risk in the fresh market and structural connections to the processing market. The fresh market is not only exposed to effects from endogenous factors unique to the fresh market, but also to those factors which affect the processing market and subsequently the fresh market. One example of this is changes in consumptive patterns based on dietary trends. French fries, a processed product, and baked potatoes, a fresh product, have dramatically different nutritional qualities and characteristics. If there is a negative shock to processed potato prices from a health claim that French fries increase the odds of contracting heart disease, even though the baked potato is seemingly unrelated, the results of our analysis indicate fresh potato prices will also suffer as a result. This is a highly generalized example and additional investigation is necessary to explore and confirm the hypothesis, but it serves to illustrate the fact that the fresh potato market's exposure to factors that introduce uncertainty is greater than that of the processing market because of seemingly asymmetric transmission of price shock.

The opportunity for producers to fully capitalize on a shortage in the processing market hinges upon information. This poses a considerable challenge. Three of the five largest potato processors in the U.S. are privately held companies. This facilitates the tight control of market information. Naturally, it remains in the processor's best interest to quietly approach the fresh market to purchase potatoes, with the hope that word spreads slowly that there is additional demand in the market. As there is no formal exchange for potato transactions, and most negotiations are carried out on a person-to-person basis, the informational delay is appreciable. Moreover, the timing of information is not the only barrier to taking advantage of increased demand from the processing market. The lack of an effective mechanism to disseminate said information is also problematic. It is not enough for a few select producers to know that processors are short supply. In this case, there is little foundation for bargaining as processors confronted with a demand for higher prices would simply engage a different producer. Rather, the entire market, or at least the majority of producers must have the information as to eliminate alternatives and introduce some semblance of efficiency into the market.

6.2.2 Monthly Variance Decomposition and Volatility in Future Periods

The connection between variability in prices and the two markets themselves can be further examined by decomposing the error variances of the VAR. Table 3 shows the dynamic relationship between the two markets and their respective forecast variances.

Table 3. Forecast Error Variance Decomposition (12-periods ahead)

	Impulse in:	Fresh Price		Process Price	
	Response in:	Fresh Price	Process Price	Fresh Price	Process Price
Period	1	100.00	0.00	4.26	95.74
	2	97.47	2.53	4.89	95.11
	3	95.06	4.94	4.62	95.38
	4	93.14	6.86	4.19	95.81
	5	91.64	8.36	3.86	96.14
	6	90.47	9.53	3.69	96.31
	7	89.59	10.41	3.65	96.35
	8	88.94	11.06	3.68	96.32
	9	88.46	11.54	3.76	96.24
	10	88.12	11.88	3.85	96.15
	11	87.88	12.12	3.94	96.06
	12	87.72	12.28	4.02	95.98

Notably, the relationship between a shock in processing prices and the resulting percentage of variance explained by this shock in fresh prices is stable, consistently accounting for around 4 percent of the variation in the fresh price series. The percentage of variation in processing prices explained by that of an impulse in fresh prices interestingly enough, grows over time. Over a period of twelve months the percentage of variation explained by a shock in fresh prices grows from 0 to nearly 12 percent. This suggests the possibility of a changing relationship between the two markets over a longer period of time. Perhaps the processing market requires longer to react to an impulse in the fresh market due to the presence of forward contracting. Regardless, the result advocates the idea that as shocks occur in the fresh market they have little to no impact on short-term volatility in the processing market. However, the same shock when examined into the subsequent crop year does seem to drive variability in processing prices. Simply put, a spike in fresh prices this year may help explain deviations in normal processing price levels in the year to come. FEVD results from the monthly VAR also prompts the critical consideration of sources of risk in both markets. Even though shocks in either series do explain some variation, the percentage accounted for by their companion price series remains relatively small, indicating the majority of variation in the two markets is explained by factors excluded from this particular model.

6.3 Discussion of Annual Results

The previous section primarily concerns itself with the investigation of short-term impacts of shocks in fresh and processing prices. The following section considers similar relationships between fresh and processing prices over longer periods of time and with the inclusion of an additional variable, annual potato production.

6.3.1 Further Justification for Annual Variable Ordering

The addition of another variable to the VAR adds a dimension of difficulty. The recursive nature of the VAR makes the ordering of the three included variables important, not only for the interpretation of results but also for the generation of the results themselves. The chosen ordering was based not only on Nerlovian thinking, as discussed in the methodology section of this paper, but also on a series of individual tests for Granger causality summarized in Table 4.

Table 4. Pairwise Granger Causality Tests

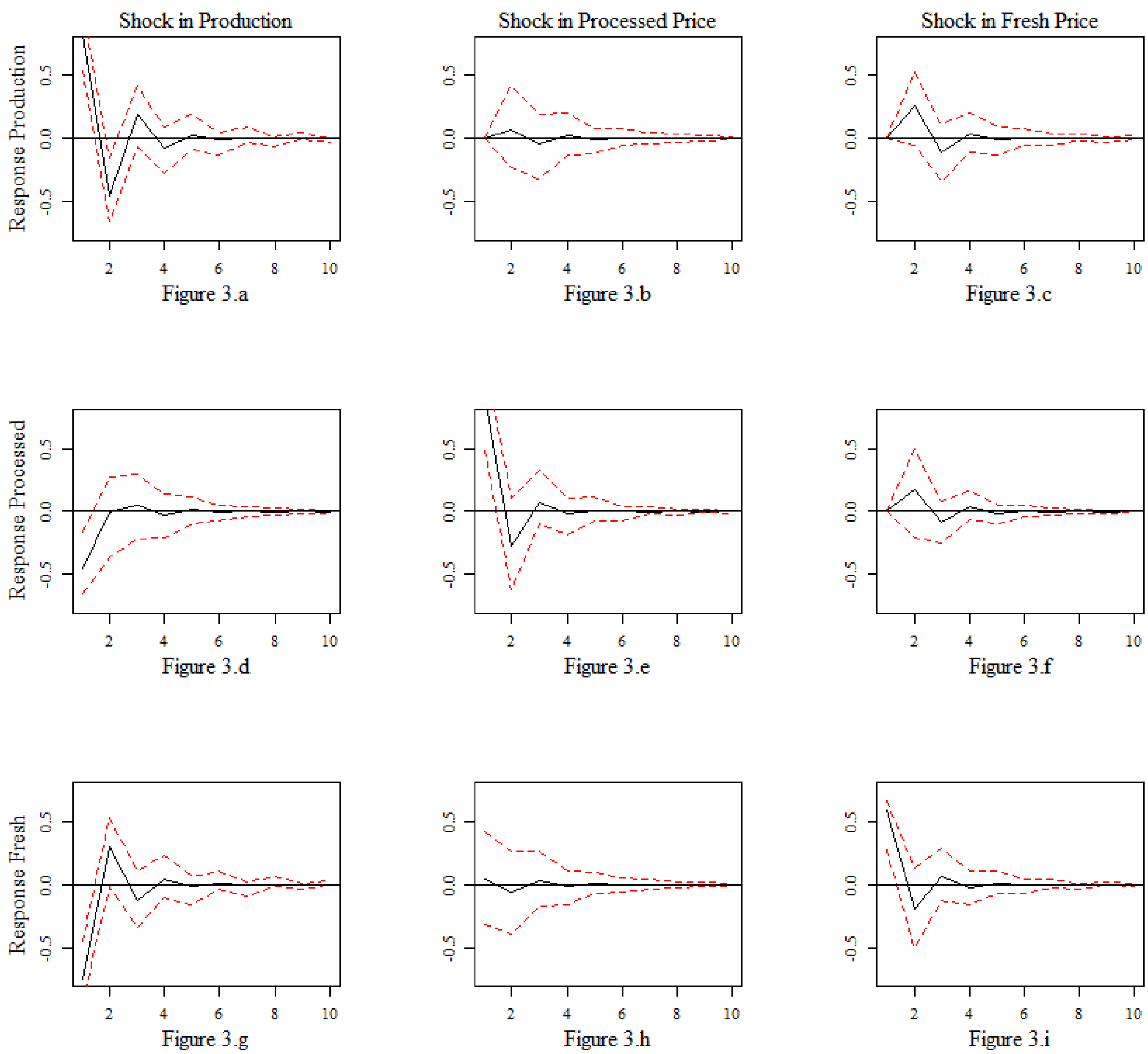
Alternative Hypothesis: H_1	F-Statistic	p-value
Fresh Prices → Production	2.903	0.09[a]
Fresh Prices → Processed Prices	1.298	0.23
Production → Processed Prices	0.544	0.39
Processed Prices → Production	0.299	0.57
Processed Prices → Fresh Prices	0.069	0.77
Production → Fresh Prices	0.033	0.82

[a]A low p-value indicates the rejection of the null hypothesis that the variable x does not Granger cause variable y.

Owing to the relatively small number of observations, critical values for the Granger tests were computed using bootstrapping. The Granger test results are generally supportive of the Nerlovian ordering imposed on the VAR, with the possible exception of production Granger causing processed prices. Despite relatively low powered test statistics from two of the three corresponding Granger tests, we feel confident the ordering imposed in this case is reflective of economic structure in the potato markets over the period and frequency of data used in the analysis.

6.3.2 Annual Impulse Response Function Results

Figure 4. Annual Impulse Response Functions



The impulse responses to shocks in each of the variables are illustrated in Figure 4. It is evident that no shock produces a response that 1) grows with time or 2) has a duration of greater than four periods (years). For example, a shock in the fresh price is not very persistent either in terms of fresh price, processing price or production. We see that following a shock in fresh price, the responding variables are typically only affected for approximately four periods (years). Furthermore, a shock in production typically results in reversals in subsequent periods. This may be interpreted as cobweb movement, or in other words the attempt by producers to adjust production levels based on prices observed in previous periods and vice versa.

The graphs also reveal a reversal of the relationship exhibited between the two markets in the monthly data. The pattern of processed price leading fresh price does not appear to hold over longer periods of time. The annual price of both series is viewed as a measure of the general price level of that market during the 12-month period. The general price level of the processing market responds to shocks in the general price level of the fresh market. The opposite does not hold. This result is economically intuitive and suggests that processors over longer periods of time are forced to reckon with the substitutive possibility of a producer marketing their potatoes on the fresh market instead of the processing market. Producers are not contractually bound across growing seasons and are able to allocate acreage to either fresh or processing potatoes. If processing prices did not respond to longer term movements in fresh prices, processors would be unable to contract sufficient quantities of potatoes to fulfill their needs. While short term decisions merit closer examination of the processing sector, producers looking for guidance regarding the general direction of the market across crop years should direct their attention to the fresh market.

The response in processing prices from a shock in production contrasts with that of fresh prices. Although processing potatoes account for approximately 60 percent of potato acreage on an annual basis, a shock in production elicits a much smaller response in processing prices relative to fresh prices. The lesser response to a shock in production may be explained by the degree to which that segment of the market remains under the monopsonistic control of major processing firms. Just because production is higher at the present does not signify a corresponding adjustment in processed price. Processing firms are intent on maintaining price levels regardless of changes in production levels and this is reflected in the lesser response in processing prices relative to fresh price. The response in processed price, however muted, is clearly negative following a positive shock in production. This seems to indicate that processors are more prone to trim back forward contract prices following an increase in production. The reduction in price following a spike in production may be explained by processing firm's expectation of lower prices in the future or even an effort to artificially lower prices by signaling via the quantity of forward contracts, increased processing potato supply. Moreover, the results from IRF also support the finding from the analysis of seasonality which indicates the presence of a smoothing effect. Processed price does not track precisely with changes in production. This effect is also likely due to the tradeoff producers are willing to make between risk and price. By utilizing forward contracts processing potato producers are not as exposed to shocks in production as their fresh producer counterparts.

Fresh price responds much more intensely to shocks in production. Fresh potatoes are not pre-committed from year-to-year. This allows farmers to rapidly adjust to current market conditions which explains the more dramatic response in fresh price. Similar to the processed price response from production shocks, the period immediately following a shock to production is also negative. This requires a point of clarification. Marketing years in the potato industry overlap the calendar year. This signifies that potatoes grown in the current calendar year are marketed in both the current and subsequent calendar year. A shock in fresh price may occur at a time when production decisions have already been solidified for the following crop year thereby delaying the anticipated increase in production as a response to currently high prices.

6.3.3 Annual Variance Decomposition and Volatility in Future Periods

Table 5. Forecast Error Variance Decomposition (12-periods ahead)

	Impulse in:	Production			Process Price			Fresh Price		
	Response in:	Production	Process Price	Fresh Price	Production	Process Price	Fresh Price	Production	Process Price	Fresh Price
Period	1	1.00	0.00	0.00	20.07	79.93	0.00	61.72	0.17	38.11
	2	92.46	0.52	7.03	18.23	79.02	2.74	62.80	0.42	36.78
	3	91.52	0.71	7.77	18.18	78.47	3.35	62.99	0.52	36.50
	4	91.39	0.77	7.84	18.23	78.31	3.46	63.02	0.54	36.44
	5	91.37	0.78	7.85	18.24	78.28	3.48	63.02	0.54	36.43
	6	91.37	0.78	7.85	18.25	78.27	3.48	63.02	0.55	36.43
	7	91.37	0.78	7.85	18.25	78.27	3.48	63.02	0.55	36.43
	8	91.37	0.78	7.85	18.25	78.27	3.48	63.02	0.55	36.43
	9	91.37	0.78	7.85	18.25	78.27	3.48	63.02	0.55	36.43
	10	91.37	0.78	7.85	18.25	78.27	3.48	63.02	0.55	36.43

The FEVD for the annual data is summarized in Table 4. Several interesting patterns emerge from this information. Perhaps the most interesting result is in regards to the production variable. A shock in production, explains a sizable proportion of variability in fresh price (nearly 7 percent one period after the shock), but the same effect is not observed for processed price. This may serve as supporting evidence for the fact that processing potatoes are more price elastic than fresh potatoes. Due to the inelastic nature of the fresh potato market any shock in production, including ostensibly small ones, will drive significant variability in fresh potato price. This also supports the idea that pricing in the processing market is largely independent of fundamental variables that normally would have an effect. In other words, variation in processed price appears to have little to do with changes in overall potato production. Fresh producers and packers would do well to monitor changes in production levels as this drives a larger share of risk in that market. This is not necessarily the case for the processing market. Production seems to hardly influence volatility in that sector therefore attention should be dedicated to other factors not included in this model.

Also, of note, is the direct interaction between processed and fresh price. An impulse in processed price explains nearly 3 percent of future variability in fresh price, an effect that is remarkably stable over time. Conversely, impulses in fresh price account for less than 1 percent of variability in future processed price. More specific conclusions may be difficult to draw from this result, but it seems to confirm the idea that the two markets remain inextricably connected whether in regards to price transmission or volatility. Yet this connection is one-sided in nature. Furthermore, it categorically identifies events in the processing market as contributors to volatility in the fresh market.

7. CONCLUSION

The relationship between the fresh and processing sectors of the U.S. potato market is complex and fluid. This paper identifies structure both in the short and long term between the two markets. However, the relationship between the two markets is not consistent across all lengths of time.

Monthly data indicates that over the short-term, fresh potato prices respond to shocks in the processing market. This is due in large part to the constraints imposed by forward contracts in the processing market and the effects of purchases made by processors in the fresh market. Comprehension of this structure may help producers, processors, and other value chain participants make more strategically sound decisions. The key recommendation from this study relates to the opportunity for producers to time market transactions based on movements in either the fresh or processing markets. In the short-term, fresh price response to shocks in the processing side of the market are significant and persistent. Therefore, it behooves fresh potato producers to remain attentive to events in the processing market over the short term. Care should be taken to evaluate the supply and demand situations present in the processing market, specifically in the final months of the storage season. The ability to follow this recommendation hinges upon information which per the make-up of the processing market may be difficult to access in a timely manner.

Just the opposite holds true for the annual data. Over longer periods of time the processing market behaves as follower and responds to shocks in the fresh market. Producers and processors alike can monitor the overall price level from previous years in order to anticipate changes in forward contract rates and subsequently processing potato prices. Responses in the processing market from shocks in the fresh market tend toward a duration of three to four years, during which the response alternates from positive to negative as the market re-adjusts to normal price levels. This is particularly useful from a planning perspective and can aid in decision-making regarding the storage of old crop and production decisions for new crops.

Another compelling conclusion drawn from the annual model is in relation to the additional production variable. The result indicates that fresh price is more apt to respond to a shock in production than processing price. This supports the concept, established in previous research, surrounding the price elasticity of fresh versus processing potatoes. We confirm that any drastic change in fresh price is accompanied by some major fluctuation in production, whereas when a similar shock is observed in production the response in processing prices is relatively muted. Acreage destined for processing is largely predetermined and rises incrementally at the direction of processors.

The results from this research also contribute to an improved understanding of the source(s) of variation in both processing and fresh potato prices. There are two major conclusions to be drawn from the results of this portion of the analysis. The first is the clear indication that impulses in either fresh or processing prices, over months or years, do relatively little to explain volatility in future periods for either price series. Indeed, the largest share of future variance which can be attributed to an impulse in one of the price series is that of a shock in the annual processing price, which afterward accounts for around 3 percent of the variance in fresh price. While the same relationship in the monthly data is of a lower magnitude (4 percent), it remains much like the annual results in that the proportion of future variance in fresh price explained by an impulse in processing price remains unchanged over time.

Finally, the annual FEVD demonstrates clearly the linkage between production levels and volatility in fresh prices. This single variable accounts for approximately 7 percent of variance in future periods. When jointly considered from the IRF result concerning the same variables, we can conclusively state that the annual production level is paramount to understanding both the direction of fresh price movements as well as the increase or decrease in observed volatility in the fresh market.

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