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Impacts of energy shocks on US agricultural productivity growth and commodity prices—A structural VAR analysis☆

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ABSTRACT

We examine the impacts of energy price shocks on U.S. agricultural productivity growth and commodity prices' volatility by developing a structural VAR model. We use historical annual data of real U.S. gasoline prices, agricultural total factor productivity (TFP), real GDP, real agricultural exports, and real agricultural commodity price from 1948 to 2011 to estimate the model. Our results indicate that an energy price shock has a negative impact on productivity growth in the short run (1 year). An energy price shock and an agricultural productivity shock each account for about 10% of U.S. agricultural commodity price volatility with the productivity shock's contribution slightly higher. However, the impact from energy prices outweighs the contribution of agricultural productivity in the medium term (3 years). With more persistent impacts, energy shocks contribute to most (about 15%) of commodity price's variation in the long run.

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1. Introduction

According to the Food and Agriculture Organization (FAO) of the United Nations (2012), the annual global food price index[1] spiked to a post-1996 high in 2008. That year, the global food price index was more than double its earlier lowest level in 2002. While the price index briefly declined in 2009, it continued to grow and reached 2.5 times its 2002 level in 2011. According to the Economic Research Service (ERS) of the U.S. Department of Agriculture (USDA), the U.S. food grain price increased to 2.5 times its 2000 level in 2008, and the feed grain price doubled its 2000 level over the same time period (USDA, 2013a). In explaining the rise of agricultural commodity prices, most of the attention has focused on demand-side factors, such as growing demand for food in emerging countries (Abbott et al., 2009; Headey and Fan, 2008), or increased use of crops in biofuel production (Zhang et al., 2009; Hertel and Beckman, 2011). However, supply-side factors, such as technical change or energy shocks, have not attracted as much attention. Although some researchers have pointed to a decline in the growth rate of crop yields or a slowing productivity growth as a causal factor behind the rise in agricultural commodity prices (World Bank, 2007; Alston et al., 2009; Abbott et al., 2009), the magnitude of the impacts of agricultural productivity on commodity prices is still unclear.

While agricultural commodity prices may be affected by productivity growth, commodity prices and agricultural productivity could both be influenced by energy prices, such as crude petroleum or gasoline prices. Energy price shocks were found to be a critical determinant of the U.S. economic growth and manufacturing sector's productivity growth during the 1973–1980 period (Jorgenson and Wilcoxen, 1993; Madisson, 1987). Sharply increased energy prices can also push up agricultural commodity prices through higher production costs. Higher crude petroleum prices not only result in higher agricultural chemicals' prices (Gellings and Parmenter, 2004[2]; Hertel and Beckman, 2011),

☆ The views expressed herein are those of the authors, and not necessarily those of the U.S. Department of Agriculture.

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[1] FAO's food price index consists of the average of five commodity group price indices, including meat price index, dairy price index, cereal price index, oil and fat price index, and sugar price index (FAO, 2012). "Food price" has been used as a general term of "agricultural commodity prices" in many studies in recent years.

[2] Gellins and Parmenter (2004) found that energy accounts for 70–80% of the total costs used to manufacture fertilizers. Therefore, the increase of energy price raises the fertilizer manufacturing cost sharply and pushes up the agricultural production cost.

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but can also increase agricultural production cost directly through the rising energy cost from using farm machinery and livestock cooling and heating systems. In addition, high energy prices could also drive farm input use away from its most efficient practice on the production frontier in the short term, and therefore result in greater volatility in the rate of agricultural productivity growth. Skyrocketing energy prices have also contributed to increased biofuel production (Banse et al., 2011). The increased use of agricultural commodities to produce energy has boosted biofuel feedstock prices and pushed up sector-wide food grain and feed grain prices in recent years (Qiu et al., 2012; Zhang et al., 2009; Trostle et al., 2011, among others). The emergence of large scale biofuel production has increased the linkage between agriculture and energy (Ciaian and d'Artis, 2011; McPhail, 2011; Du and McPhail, 2012).

Despite the many studies that have investigated the responses of agricultural commodity prices to energy shocks (Harri et al., 2009; Zhang et al., 2010; Serra, 2011) or productivity shocks (Fuglie, 2008), few have examined these relationships together. While Qiu et al. (2012) found that the fundamental market forces of demand and supply are the main drivers of food price volatility, their study only focuses on the corn market. Furthermore, the magnitude of the impacts of energy prices on U.S. agricultural productivity and commodity prices is still unknown. For example, how much of the volatility in agricultural commodity prices can be attributed to productivity or energy price shocks? Energy shocks and agricultural productivity's contribution to commodity price movement are very important and complex. Also the relationship between energy prices and agricultural productivity requires new examination due to the more integrated nature between agriculture and energy markets. We would like to introduce a new framework to understand this old topic. The purpose of this paper is two-fold: first, to evaluate the impacts of energy price shocks on agricultural productivity growth and commodity price changes; second, to disentangle demand and supply shocks in the U.S. agricultural commodity market and to quantify the contribution of each individual shock to commodity price volatility with a special focus on energy shocks and productivity shocks.

Many studies working on assessing the impact of energy price shocks on economic growth or agricultural production have employed general equilibrium modeling techniques (Jorgenson and Wilcoxen, 1993; Gehlhar et al., 2010; Banse et al., 2011; Beckman et al., 2011). The robustness of the results from these studies depends heavily on the numerous assumptions used, such as elasticities. This study relies on historical data and limited assumptions by employing a structural vector autoregression (VAR) model to analyze the impact of energy prices on agricultural productivity and commodity prices. We propose that commodity prices are mainly driven by the following factors: (1) energy shocks; (2) agricultural productivity shocks; (3) domestic demand shocks; (4) global supply and demand shocks; and (5) other shocks in the U.S. agricultural commodity market that are not captured by the shocks listed above. Impulse response is then used to examine the response of commodity prices to relevant demand and supply shocks. Variance decomposition is followed to measure the importance of each shock, particularly an energy price shock, to explain fluctuations in total factor of productivity (TFP) and agricultural commodity prices.

2. Decomposition of the commodity price and the structural VAR model

Studies which only focus on the demand side shock or the supply side shock may exaggerate the impact from either side. Killian (2009), in a study decomposing the real price of oil, suggests employing a structural VAR model to help decompose unpredictable changes in the real price of oil with a structural economic interpretation. Following Killian (2009), this study proposes a comprehensive structural VAR (SVAR) model to decompose unpredictable changes in agricultural commodity prices into mutually orthogonal components with economic theoretical implications that take into account shocks from both supply and demand sides in the agricultural commodity market. Shocks are conceptually defined as changes from individual sources that are not anticipated by the estimated model. For example, an energy shock can be an unexpected change in gasoline prices.

We use a SVAR model with five variables to capture the impacts of an energy shock on U.S. agricultural productivity growth as well as on fluctuations in commodity prices. By doing so, we can also identify the contributions of each shock from the demand side and supply side to commodity price changes. The five annual variables are defined as a vector $\boldsymbol{x}_t = (\Delta P_{Et}, \Delta TFP_t, \Delta X_{At}, \Delta GDP_t, \Delta P_{Ft})'$ where P_E is real U.S. gasoline price index,[3] which is assumed to be affected by demand and supply in the global oil market; *TFP* is the U.S. agricultural total factor productivity index; X_A is real U.S. agricultural export, which represents foreign demand for U.S. agricultural commodities; *GDP* is real U.S. gross domestic product, which is a proxy for U.S. domestic food demand[4]; P_F is real U.S. farm commodity price index; t is the time subscript; Δ denotes the percentage change rate in each series. The SVAR model is represented as:

$$\boldsymbol{A}_0\boldsymbol{x_t} = \boldsymbol{\alpha} + \sum_{i=1}^{p}\boldsymbol{A}_i\boldsymbol{x}_{t-i} + \boldsymbol{\varepsilon}_t \tag{1}$$

where p is the order of lags, $\boldsymbol{\varepsilon}_t$ is the vector of serially and mutually uncorrelated structural innovations, $\boldsymbol{A}_0$, $\boldsymbol{A}_i$, and $\boldsymbol{\alpha}$ are unknown coefficient matrixes and the vector to be estimated. The reduced form of the VAR representation is:

$$\boldsymbol{x}_t = \boldsymbol{A}_0^{-1}\boldsymbol{\alpha} + \sum_{i=1}^{p}\boldsymbol{A}_0^{-1}\boldsymbol{A}_i\boldsymbol{x}_{t-i} + \boldsymbol{e}_t \tag{2}$$

where $\boldsymbol{e}_t$ is the vector of estimated residuals in the reduced form and can be expressed as

$$\boldsymbol{e}_t = \boldsymbol{A}_0^{-1}\boldsymbol{\varepsilon}_t. \tag{3}$$

Following Killian (2009), we impose theoretical restrictions to the recursive structure on $\boldsymbol{A}_0^{-1}$ assuming that variables will not respond to all contemporaneous shocks from variables other than those being specified. It is similar to putting restrictions on a demand or supply curve in the short run. For example, in this study, we assume that U.S. oil refiners are price takers who set the retail price based on their import cost and a specific amount of mark-up in the short-run. Therefore, the U.S. gasoline price shock is not affected by any contemporaneous shocks from other variables in the model but only influenced by the global oil market shocks or other factors that are not included in the model. A U.S. agricultural productivity shock is assumed to respond only to contemporaneous energy shocks and specific agricultural productivity shocks, such as unexpected input or output changes due to unfavorable weather, animal

[3] Agricultural production consumes large amounts of energy, either directly through combustion of fossil fuels, or indirectly through use of energy-intensive inputs, especially fertilizer. Over 2006–10, expenses from direct energy use averaged about 5.7% of total input cost in the U.S. farm sector, while fertilizer expense represented another 5.4%. We use gasoline price as a proxy of energy price as we want to capture the global energy shock effect. U.S. gasoline price has a strong relationship with crude oil price (correlation coefficient is 0.99). In addition, U.S. gasoline refiners act as price taker in the global oil market. Therefore, the variation of U.S. gasoline price over time should capture global energy market shocks.

[4] While food preference changes could play an important role in the demand side for an individual commodity we did not include this variable in our model as this study is based on aggregate data and there is no appropriate index or variable to represent preference changes for aggregate agricultural commodity.