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The role of energy productivity in U.S. agriculture

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ABSTRACT

This paper investigates the role of energy on U.S. agricultural productivity using panel data at the state level for the period 1960–2004. We first provide a historical account of energy use in U.S. agriculture. To do this we rely on the Bennet cost indicator to study how the price and volume components of energy costs have developed over time. We then proceed to analyze the contribution of energy to productivity in U.S. agriculture employing the Bennet–Bowley productivity indicator. An important feature of the Bennet–Bowley indicator is its direct association with the change in (normalized) profits. Thus our study is also able to analyze the link between profitability and productivity. Panel regression estimates indicate that energy prices have a negative effect on profitability in the U.S. agricultural sector. We also find that energy productivity has generally remained below total farm productivity following the 1973–1974 global energy crisis.

1. Introduction

In this study we investigate the role that energy plays in the U.S. agricultural sector, both in terms of its role as a factor of production and its role as a contributor to productivity growth. Our analysis employs a unique data series compiled by the U.S. Department of Agriculture's Economic Research Service (ERS). The data comprise a state-by-year panel, which will allow us to assess the impact of technological advances over the study period as well as the effect of volatile energy prices. Of particular interest are the effects of major energy market shocks (e.g. the oil price shocks of the 1970s) on energy productivity and the profitability of the U.S. agriculture. The data set consists of three outputs and six inputs; the latter include direct energy use in agriculture as well as indirect energy use as, for example, consumption of agricultural chemicals.[1] Both price and quantity data are available. A detailed description of the data set is given in Section 3 below.

First we give an historical accounting of energy consumption in U.S. agriculture. While direct energy consumption in the agricultural sector represents only a very small fraction of the total U.S. energy use, changes in the energy market can have a large impact on costs and, therefore, on profitability of the sector as well as on food prices.[2] The effects of energy costs on profitability may also be greatly exacerbated by changes in fertilizer and pesticide costs, both of which are significant energy users. Here we rely on a Bennet (1920) indicator decomposition of profit into price and volume indicators, which can further be decomposed into changes over time and space. These decompositions are possible due to the additive structure of the Bennet indicator. Such decompositions are not possible with the more familiar Fisher and Törnqvist indexes. Thus our work provides an additional tool for the analysis of the role of energy in agriculture.

Secondly we study the contribution of energy to productivity growth in U.S. agriculture. Again we use an additive measure, namely the

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[1] Energy inputs feature in every stage of agricultural production, from making and applying chemicals to fueling farm machinery used in tillage and harvesting of crops, and to electricity for livestock housing facilities. Such reliance on energy consumption has left farmers vulnerable to high energy costs and volatile energy market fluctuations, thereby highlighting the importance of efficient use of energy for farm profitability and for more sustainable agricultural practices (see Levine, 2012).

[2] For example, Wang and McPhail (2014) report that in addition to global food demand, energy shocks also play an important role in explaining recent rapid increases in food prices.

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Bennet (1920) productivity indicator.[3] This indicator requires data on both prices and quantities of outputs and inputs, much like the Fisher and Törnqvist indexes. And, like the Fisher and Törnqvist indexes, it can be derived based on a test approach (see Diewert, 2005) or through its dual, the Luenberger productivity indicator (see Chambers, 2002; Chambers et al., 1996). The Bennet (1920) indicator satisfies many desirable properties. In this study, one of the most important is its additive structure which allows for straightforward aggregation and disaggregation. Thus we can aggregate direct energy use to get an overall contribution of energy to productivity growth. We can also aggregate over regions or time periods, again introducing a useful analytical tool.

2. Indicators

The purpose of this section is to provide a short introduction to indicator theory as a means of summarizing economic variables (see Chambers, 2002 or Färe et al., 2008, for more detailed information). We follow Diewert (2005) and refer to summary measures constructed as ratios as indexes and summary measures constructed as differences as indicators. Ratio measures are relatively familiar; price and quantity indexes, as well as productivity indexes, are examples. Yet difference measures have very simple aggregation properties. The 'total' difference is the sum of the sub-aggregates, which makes them useful when summarizing panel data, as we have here.[4] Another advantage of using differences rather than ratios is that they circumvent problems arising from the presence of zeroes in the data.[5] Use of differences is also a convenient tool to analyze the sources of profit change from price and quantity changes or to determine the sources of deviations of actual values from budgeted or optimal values (see Fox, 2006).

We begin with some notation. Let $x^\tau \in R^N_+, \tau = t, t+1$, be a nonnegative vector $x^\tau = (x^\tau_1, \ldots, x^\tau_N)$ of inputs at time τ and let $w^\tau \in R^N_+$, $w^\tau = (w^\tau_1, \ldots, w^\tau_N)$, $\tau = t, t+1$, be its corresponding vector of input prices. Costs at τ are defined as the inner product

$$C^\tau = w^\tau x^\tau = \sum_{n=1}^{N} w^\tau_n x^\tau_n. \tag{1}$$

What we call the Bennet (1920) cost indicator (or cost change indicator) is defined as the cost difference

$$C^{t+1} - C^t \tag{2}$$

which, following Bennet (1920), can be decomposed into two indicators: a price indicator

$$W^{t+1}_t = \frac{1}{2}\left(x^{t+1} + x^t\right)\left(w^{t+1} - w^t\right) \tag{3}$$

and a volume (quantity) indicator

$$X^{t+1}_t = \frac{1}{2}\left(w^{t+1} + w^t\right)\left(x^{t+1} - x^t\right) \tag{4}$$

with the property that

$$C^{t+1} - C^t = W^{t+1}_t + X^{t+1}_t. \tag{5}$$

The price indicator is the additive analog of a price index. Here the simple average of the input quantities serves as the weight for the change in the input prices. Similarly, in the volume indicator, the simple average of the input prices serves as the weight for the change in input quantities. For these indicators to make sense, the prices must be 'deflated' by some general measure (see Balk, 2008, 2010; Chambers, 2001, 2002; Chambers and Färe, 1998).

The Bennet indicator in Eq. (5) has been derived by Diewert (2005) using the test approach by solving a functional equation based on tests or axioms. He shows that it is the 'best' indicator in the sense that it satisfies the 'most' axioms or tests including the time reversal test.[6] This indicator has also been derived by Chambers (2002) from the Luenberger input indicator, which provides the theoretical connection to the underlying technology. This connection required invoking the quadratic approximation lemma due to Diewert (1976) and a quadratic functional form for the directional input distance function which represents technology.[7] This yields a price normalized Bennet indicator, which is independent of the unit of measurement.

We follow Chambers (2002) to define the Bennet cost indicator in terms of input prices normalized by the value of the directional vector. In particular, we set the directional vector equal to the sample average of inputs, i.e. we set $g_x = \bar{x}$. The normalized price indicator is then given by:

$$\widetilde{W}^{t+1}_t = \frac{1}{2}\left(x^{t+1} + x^t\right)\left(\frac{w^{t+1}}{w^{t+1}\bar{x}} - \frac{w^t}{w^t\bar{x}}\right) \tag{3'}$$

and the normalized volume (quantity) indicator as:

$$\widetilde{X}^{t+1}_t = \frac{1}{2}\left(\frac{w^{t+1}}{w^{t+1}\bar{x}} + \frac{w^t}{w^t\bar{x}}\right)\left(x^{t+1} - x^t\right) \tag{4'}$$

with the property that

$$\widetilde{C}^{t+1} - \widetilde{C}^t = \widetilde{W}^{t+1}_t + \widetilde{X}^{t+1}_t \tag{5'}$$

where $\bar{x}$ is the sample average input bundle. This normalization comes naturally from the dual relationship between the price-based Bennet indicator with the Luenberger input indicator which uses directional distance functions rather than prices to aggregate inputs.[8]

In this paper we use an expression like that in Eq. (5′) to study how the price and volume components of energy cost have developed over the 1960–2004 period. Since costs are additive, total and partial cost indicators can be readily constructed.

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[3] This indicator is as also known as the Bennet–Bowley productivity indicator based on the work of Bennet (1920) in the context of cost of living and Bowley (1928) in the welfare context. See Chambers (2001, 2002) who shows how exact and superlative productivity indicators can be computed as Bennet–Bowley measures of profit differences. Note that Chambers also refers to the Bennet cost indicator as the Bennet–Bowley cost measure.

[4] As pointed out by Diewert (2005, p. 342) a nice feature of the Bennet indicators of price and volume change is their additive property over commodities which give them 'a big advantage' over their superlative counterparts (e.g. Fisher or Törnqvist) which are inherently non-additive over commodities. The Montgomery (1929, 1937) indicators of price and volume change are also additive over commodities but their axiomatic or test properties are not as attractive as those of the Bennet indicators (see Diewert, 2005, p. 342).

[5] Of course there are ratio measures such as the Fisher index which are well defined irrespective of the signs or values of prices and quantities and difference measures such as the Montgomery indicator, which are not.

[6] Diewert (2005) compares and contrasts the Bennet indicator to other measures of value change, such as the Montgomery–Vartia indicator (see Montgomery, 1929, 1937; Vartia, 1976a, 1976b) which has a structure similar to the Bennet indicator but uses logarithmic averages rather than simple averages as weights. He concludes that from the viewpoint of the axiomatic or test approach to value change, the Bennet indicator is best albeit in practice there may not be much difference between them.

[7] Let T be a technology $T = \{(x, y): x \text{ can produce } y\}$and let $g_x \in R^N_+$, $g_x \neq 0$ be a directional vector. Then the directional input distance function is defined as $\vec{D}(x, y; g_x) = \sup\{\beta : (x - \beta g_x, y) \in T\}$. The Luenberger input indicator is defined as the average of a base period technology Luenberger input indicator $L^o = \vec{D}^o_1(x^o, y^o; g_x) - \vec{D}^o_1(x^1, y^o; g_x)$ and period-1 technology Luenberger input indicator $L^1 = \vec{D}^1(x^o, y^1; g_x) - \vec{D}^1(x^1, y^1; g_x)$, see Chambers (2002, p. 757).

[8] Chambers (2002, p. 757) shows that if the firm minimizes cost, and the directional input distance function is quadratic and satisfies the translation property, the Bennet cost measure is "a superlative input indicator in the sense that it is an exact measure for a second order flexible representation of the technology." In addition, he shows the Bennet cost measure calculated using input prices normalized by the value of the directional vector is "an exact input indicator regardless of whether the technology exhibits constant returns to scale and regardless of whether the entities involved choose outputs optimally." An intuitive choice to use in this normalization would be $g_x = \bar{x}$, which would result in normalizing input prices by the value of the input bundle evaluated at the mean of the input data; i.e. the sample means of capital, land, labor, fertilizers, pesticides and energy use in each state.