INDUCED ENERGY-SAVING INNOVATION IN INDUSTRIAL DURABLE GOODS

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INTRODUCTION

The project has built on the theoretical framework and econometric approach developed by Newell (1997) and Newell, Jaffe, and Stavins (1999) and applied these techniques to investigate innovation in durable goods used for industrial end uses. They developed a theoretical and empirical framework for estimating the price-sensitivity of changes in product characteristic resulting from *innovation*, and applied the framework to improvements in the energy efficiency of residential/commercial heating and cooling equipment. They examined how the menu of available energy-using capital goods has changed over time, and the extent to which those changes appear to be related to the relative price of energy and other plausible factors, including regulation. For those products the evidence suggests: (i) the *rate* of overall innovation was independent of energy prices and regulations, (ii) the *direction* of innovation was responsive to energy price changes for some products but not for others, (iii) energy price changes induced changes in the subset of technically feasible models that were offered for sale, (iv) this responsiveness increased substantially during the period after energy-efficiency product labeling was required, and (v) nonetheless, a sizeable portion of efficiency improvements were autonomous.

The current project extended that research to investigate innovation in durable goods used for industrial end uses. For the case of farm tractors, we found additional support for the induced innovation hypothesis at a product characteristics level. We found that periods of rising real energy prices were associated with faster improvements along the energy efficiency dimension, while real wage increases were associated with faster improvements in tractor size (horsepower). In addition, we found support for the existence of a "learning curve" in tractor production, as represented by a strong positive relationship between product cost reductions and cumulative output. In fact, cumulative output proved to bear a clearer relationship to product cost reductions than did time, which is typically employed in analyses of technological change. This project report is divided into three sections covering (1) the method used, (2) the data employed, and (3) the results obtained.

METHOD

The project has had several parts. First, we employed data on the product characteristics of models of available on the market at different points in time to econometrically estimate a series of *characteristics transformation surfaces*. Each surface summarizes the technologically feasible combinations of characteristics at a point in time. For example, one can make a very energy-efficient, powerful farm tractor, or one can make a very inexpensive one, but it is not technically feasible to make a unit that is both very cheap and very efficient and powerful. At any point in time, the transformation surface summarizes the technical tradeoffs among energy efficiency, production cost, and other attributes; over time, the transformation surface shifts.

The investigation has focused on an econometric analysis of innovation in farm tractors, for which there is an exceptionally rich array of data that spans over 80 years and across thousands of different product models and dozens of manufacturers. Newell (1997) and Newell, Jaffe, and

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Stavins (1999) and found that the key information requirements for an investigation of induced energy-saving product innovation are data on product characteristics (e.g., horsepower and energy efficiency), purchase price, production costs, product output, and characteristics "prices" such as the price of energy (for energy efficiency) and the wage rate (for horsepower).

We investigate technological change by estimating the parameters of the transformation surfaces, and simultaneously estimating how these parameters change over time. Newell (1997) showed that "overall" improvements in technology are associated primarily with changes in the constant term of the estimated function, while "directional" technological change relative to energy efficiency is associated with changes in the slope parameters. We introduce induced technological change by allowing the relevant parameters to vary as functions of the relative price of energy (for the fuel use characteristic) and the relative farm wage (for the horsepower characteristic). In addition, we allowed the constant term to vary as a function of cumulative output in order to represent learning-by-doing as a source of product cost reductions.

EMPIRICAL APPLICATION

For the case of farm tractors, we constructed a database on product characteristics from the *Nebraska Tractor Test Data* reports (1920–1996), which have been conducted by the University of Nebraska for virtually every tractor model sold in the U.S. since 1920. The dataset contains 1,631 different models of wheel tractors from seven major manufacturers (Allis Chalmers, Case, Deere, Ford, International Harvester, Massie Ferguson, and White) and several other minor manufacturers spanning 78 years (1918–1995). The full dataset has 5,724 complete observations, with information on each tractor's test number, year tested, make, model, fuel type, energy efficiency, horsepower, and whether the tractor had a cab or four-wheel drive. We also employed data on the cost of tractor production, product output, energy prices, and farm wages. To facilitate interpretation of the parameter estimates of the characteristic transformation surfaces, we normalized the time variable so that 1975 equals zero and all other time-series variables (i.e., energy prices, wages, annual output, and cumulative output) so that they equal unity in 1975, or zero after taking natural logarithms. We normalized all other variables so that their normalized means equal unity, or zero after taking natural logarithms.

Energy Efficiency

Our measure of energy efficiency is horsepower-hours per gallon, which measures the work done per gallon of fuel during the power-take-off (PTO) horsepower test at the rated engine speed. For a small number of observations, the Nebraska Test Lab did not perform this test, but rather tested the drawbar horsepower of the tractor, which measures the work done per gallon of fuel during the 10-hour run at 75% drawbar load.

Product Cost

We deflated the nominal unit price of each product model by an input cost index to derive a measure of the real capital cost of each model. The derivation of the input cost index is described below. The nominal unit prices for new and used tractors were found in the *Used Tractor Price Guide, 1945-1997* (1998), *National Farm Tractor and Implement Blue Book* (1939-1992), the *Red Tractor Book* (1916-1960), the *Official Guide, Tractors and Farm Equipment* (1969-1994), and other related publications which have been published by private

companies and trade associations since at least 1916. Generally we use the retail price of a one-year-old tractor, although we occasionally employ the "as-is" price (which does not include dealer reconditioning costs) or the list price. We determined the years of production for each tractor using the *Used Tractor Price Guide, Farm Tractors: 1950-1975* (Larsen 1981), and *Farm Tractors: 1975-1995* (Gay 1995).

We used a Divisia index of input prices to deflate the nominal unit price of a product in order to derive a measure of the real cost or real inputs into production of that product at a given point in time. A Divisia price index has a rate of growth equal to a weighted average of the rates of growth of its component prices. The weights are the relative shares of each component in total value. We developed an index with three components: labor, capital, and materials. To develop a Divisia input price index, the two necessary data components are the nominal input price and input cost share for each input at each point in time. We developed such an index for tractors using data for Standard Industrial Classification (SIC) Code 3523, Farm Machinery and Equipment and for comparable SIC Codes in earlier years (e.g., SIC 3522 for 1958-1971 and SIC 3521 for 1947-1957).

We began by calculating the total value of production in each year as the sum of the value added by manufacture and the cost of materials, as reported for SIC 3523 (or equivalent) in the *Census of Manufactures* (Bureau of the Census 1921-1992). We then decomposed the total value of production into the cost of labor, materials (including energy), and capital.

We calculated total labor cost as the sum of payroll and supplemental labor costs (i.e., Social Security and other legally required payments, and voluntary employer payments), as reported in the *Annual Survey of Manufactures* (ASM) (Bureau of the Census 1955-1994). The total cost of materials is reported directly in the *Census of Manufactures*. We calculated the remaining component, total capital costs, as the difference between the total value added by manufacture and total labor costs. This approach implicitly incorporates an assumption of zero economic profits. Finally, we computed the cost shares as the ratio of the total cost of each of these three inputs to the total value of production. In computing the weights for the Divisia index, we used an average of the cost shares existing in the initial and final year over which price changes occurred.

For growth rates in labor prices, we calculated the price of labor by dividing total labor costs by the total number of employees, as reported in the *Census of Manufactures*. Material and capital prices for 1958-1992 are from a Bureau of Labor Statistics study of productivity changes in the farm equipment industry (Falk and Litz 1991). For materials prices for other years we used the producer price index for intermediate materials for durable manufacturing (Bureau of the Census 1975, Bureau of Labor Statistics 1959, 1992-1993).

For capital for other years, we calculated the price of capital services as the sum of the cost of capital, the current cost of depreciation, and the cost of capital loss on the value of the capital stock, which are based on the price of assets, the rate of return, and the depreciation rate. This is the definition employed by Jorgenson and Wilcoxon (1990) and the Bureau of Labor Statistics. For the price of assets after 1930, we used the implicit price deflator for nonresidential investment in producers' durable equipment (Bureau of the Census 1975, Council of Economic Advisors 1997). We used a value of 0.1072 for the deflation rate, which is the default value for

general industrial equipment suggested by the U.S. Department of Commerce (Fraumeni 1997). For the rate of return we used the annual yield for Moody's AAA corporate bonds (Bureau of the Census 1975, Council of Economic Advisors 1997). The price of assets prior to 1931 is for "producers' goods entering into capital equipment" from Mills (1936).

Energy Prices, Farm Wages, and Product Shipments

We constructed measures of the value to the consumer of energy flow reductions relative to capital cost reductions by dividing the price of fuel by the input cost indices described above. We constructed measures of the value to the consumer of horsepower improvements relative to capital cost reductions by dividing the farm wage rate by the input cost indices described above. The hypothesis is that during periods of rising real wages the importance of labor-saving technological change, in the form of larger tractors per unit cost, will take on increased emphasis.

Data on fuel prices and wages paid by farmers can be found in U.S. Department of Agriculture publications, including *Prices Paid by Farmers for Commodities & Services, United States 1910-1960* (1962) and *Agricultural Prices* (1963-1997). It is interesting to note that tractors have used at least six different types of fuel over the past century (i.e., kerosene, distillate fuel, tractor fuel, diesel fuel, gasoline, and liquid petroleum gas); the transition between engine technologies using these fuels itself represents an interesting case of induced innovation.

Finally, the quantity of shipments (in thousands of units) of wheel farm tractors is from the Bureau of the Census (1921-1995).

SUMMARY OF RESULTS

Overall, the results are consistent with the economic interpretation of the parameters. The estimated elasticities for the various characteristics all have the expected signs and reasonable magnitudes; and the coefficient on cumulative production is negative, indicating positive technological change. The results confirm that the cost of durable goods increases with increasing energy efficiency, capacity, and other desirable characteristics, and that the cost of producing a given bundle of characteristics tends to fall with increased cumulative production experience as a result of technological change in production techniques and product design.

In addition, we found support for induced innovation in the tradeoffs between product cost, energy efficiency, and horsepower. That is, the slope of the technological frontier with respect to fuel efficiency was less negative during periods of higher energy prices, meaning that the elasticity of product cost with respect to energy flow is lower, or, equivalently, that the tradeoff at a point in time between production cost and energy efficiency has shifted so that energy efficiency is less expensive on the margin. The same was found to be true for horsepower with respect to changes in the real farm wage.

Specifically, we found that a 10 percent increase in real energy prices is associated with a statistically significant change in the elasticity of product cost with respect to energy flow of about 0.013. Regarding horsepower improvements, we found that a 10 percent increase in real wages is associated with a statistically significant change in the elasticity of product cost with respect to energy flow of about -0.05.

In addition, we found support for the existence of a "learning curve" in tractor production, as represented by a strong positive relationship between product cost reductions and cumulative output. Specifically, a 10 percent increase in cumulative production was associated with about a 7 percent decrease in quality-adjusted product cost. In fact, cumulative output proved to bear a clearer relationship to product cost reductions than did time, which is typically employed in analyses of technological change.

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