International Journal of Industrial Organization 28 (2010) 434–440

Contents lists available at ScienceDirect

International Journal of Industrial Organization

journal homepage: www.elsevier.com/locate/ijio

Firm market value and production technology ☆

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ARTICLE INFO

Article history:
Received 8 March 2007
Received in revised form 14 October 2009
Accepted 20 October 2009
Available online 29 October 2009

JEL classification:
D24
L63
L86

Keywords:
Empirical industrial organization
Production functions
Computer industry

ABSTRACT

This paper estimates the production technology of the U.S. computer industry using firm market value to control for the correlation between inputs and unobservable productivity shocks. We show that firm market value can serve as a proxy for unobservable productivity shocks. We also show that firm market value is robust as a proxy when firm faces uncertainties and capital market imperfections. Empirical results suggest that our firm market value proxy works well for the computer industry.

1. Introduction

Empirical work depends on observables. Production technology is affected by a mix of observable factors, such as expenditures on capital and labor, and unobserved productivity shocks, such as how capably managers deploy these resources. Consequently, economists who study technology must isolate echoes of unobserved productivity shock in available data.

We use firm market value to control for such unobservable characteristics in an analysis of the U.S. computer industry. We build on Olley and Pakes (1996) and Levinsohn and Petrin (2003). In their model, firms have heterogeneous marginal products of factor inputs. Economists cannot observe this heterogeneity directly, but by inverting the relationship between investment or intermediate inputs and firm heterogeneity, they can control for it. We show that firm market value provides an additional means to distinguish among heterogenous firms.

We apply our method to the U.S. computer industry. The computer industry is characterized by rapid change, and thus provides an appropriate subject of study for estimating technologies that permit time-varying firm effects. We use a unique data set from the merger of Compustat data and establishment-level information based on Dun and Bradstreet's archives.

This paper is organized as follows. In Section 2, we review methods of estimating production functions. In Section 3, we prove that firm market value, like investment, can be a proxy for unobservable productivity shocks. We describe our data set in Section 4. In Section 5, we apply our proxy to the U.S. computer industry, and compare the results of the value proxy to estimates generated using fixed effects and the investment proxy. Section 6 discusses the limitations of our approach and concludes.

2. Estimating production functions

A wide variety of information affects firms' production decisions. Some information, such as change in inventory, can be summarized by a number. Other characteristics, such as the hiring of a new manager or the launch of a new product with great potential, cannot be easily quantified by economists. For example, in September 2005, Hewlett–Packard spent approximately $600 million to acquire two data management software companies, Peregrine Systems and AppIQ.[1] The effect these acquisitions had on Hewlett–Packard's business may depend on a variety of qualitative factors, including how many key personnel remain in Peregrine and AppIQ after acquisition and how capably Hewlett–Packard integrates these firms' products into its overall marketing strategy. Presumably, HP analyzes the effects of

☆ A first draft of this paper was a chapter of Firestone's dissertation at the Haas School of Business, UC Berkeley. We are grateful for the support of the Haas School's Fisher Center for Real Estate and Urban Economics. Thanks to the editor, two anonymous referees. Emek Basker, Tom Davidoff, Greg Duffee, Jeffrey Perloff, John Quigley, Jacob Sagi, Hugo Salgado, Richard Stanton, Nancy Wallace, Donald W. Walls, and Catherine Wolfram. All remaining errors are our own.

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[1] The Wall Street Journal, Sept. 20, 2005, page C4.

0167-7187/$ – see front matter
doi:10.1016/j.ijindorg.2009.10.007

these business decisions both prior to and after its strategic move. However, its analysis is neither observable nor easily summarized by outsiders such as economists. Ignoring these unobservable productivity shocks creates biased estimation of production functions, as they affect the firm's choice of inputs.

A general form of a firm's production function takes the form: $y_{it}=f(x_{it}, \mu_{it}; \beta)$, where x_{it} is the set of inputs, μ_{it} is a productivity shock and β is a vector of parameters. To illustrate the analysis, we assume that the firm has a Cobb–Douglas production function with two major inputs, capital and labor. After taking the logarithm of both sides, the production function is:

$$y_{it} = \beta_k k_{it} + \beta_l l_{it} + \omega_{it} + \epsilon_{it} \tag{1}$$

where y_{it} is log sales, k_{it} is log capital, and l_{it} is log labor. The unobserved part in the production function consists of two exogenous processes. ω_{it} is the Hicks neutral productivity shock, which is known to the firm at the time when variable inputs are selected. ϵ_{it} is a random error with zero mean in the production process, which is unpredictable by the firm. Unlike capital, the labor input is likely to be correlated with the Hicks neutral productivity shock. That is to say, firms can adjust their employment level contemporaneously when they observe the productivity shock. OLS gives biased and inconsistent estimates due to this simultaneity problem. Levinsohn and Petrin (2003) discuss the OLS bias using the same production function. They show that the actual bias can go either direction depending on how labor responds to the shock and how capital is correlated with labor. A natural alternative to OLS is to instrument labor with some variables which are correlated with the labor input but not with the productivity shock. However, for many applications of production economics, it is very difficult to find appropriate instruments, such as firm-level input prices.

Another approach is the fixed effect model. Firm fixed effects control for firm specific stable characteristics, and are appropriate for mature industries where there is little technological change. The estimating equation would be:

$$y_{it} = \beta_k k_{it} + \beta_l l_{it} + \omega_i + \upsilon_{it} \tag{2}$$

where ω_i is a firm fixed effect, and υ_{it} is a random error. The biggest restriction the fixed effect model imposes is that ω_i has to be constant over time. For the computer industry, this restriction is inappropriate and the same problems of bias and inconsistency are still present.

A third method is to use a control function[2] as a proxy for unobservable productivity shocks. This method was introduced to the literature by Olley and Pakes (1996). It controls for unobserved productivity shocks using optimizing agents' decisions. These models permit firm characteristics to evolve over time. This greater generality comes at the expense of some complexity in estimation techniques. Olley and Pakes (1996) use decisions about capital investment and exit to control for the productivity shock, ω_{it}. They derive from their structural model strictly monotonic functions relating productivity, investment, and exit, and exploit these relationships to control for the productivity shock in a three stage estimation method. In their model, output is a function of a plant's marginal product ω_{it}, its age a_{it}, the level of capital stock k_{it}, labor l_{it}, and i.i.d. noise ϵ_{it}:

$$y_{it} = \beta_0 + \beta_a a_{it} + \beta_k k_{it} + \beta_l l_{it} + \omega_{it} + \epsilon_{it} \tag{3}$$

Capital is a state variable with law of motion $k_{it}=(1-e^{\delta})k_{it-1}+i_{it-1}$ where i_{it-1} is investment at time $t-1$ and δ is the rate of exponential depreciation of capital. The underlying economics is that the stock of capital is less flexible and needs time to adjust. To solve the simultaneity problem, Olley and Pakes (1996) show that the firm's investment i_{it} is a strictly increasing and therefore invertible function of its current productivity shock, ω_{it}, any positive level of investment. So the function can be inverted to express the productivity shock:

$$\omega_{it} = f(i_{it}, k_{it}) \tag{4}$$

As a consequence, the productivity shock in the production equation can be replaced by Eq. (4) and the simultaneity problem is addressed. Olley and Pakes (1996) use both capital and a plant's probability of exit as proxies to estimate production functions. Levinsohn and Petrin (2003) show that intermediate inputs such as energy can also be used as a proxy for the productivity shocks. Ackerberg et al. (2006b) explore the critical nature of assumptions related to the timing of input decisions in these methods, and derive crucial principles for achieving identification. We show that, under certain circumstances, firm market value can also be used to obtain identification in production functions.

3. Theoretical model

We show that firm market value is a viable proxy for unobservable productivity shocks. A crucial property for firm market value to be a good proxy is that it must be strictly monotonic with respect to its productivity. Strict monotonicity means that the relationship between firm market value and the unobservable productivity shock can be 'inverted,' and this inverted function can be used to obtain identification. We prove strict monotonicity with a model of firm behavior based on Abel and Eberly (1994).[3] We derive an endogenous investment policy under convex and fixed adjustment costs. As is familiar in the literature, the firm adds to capital when its productivity crosses a certain boundary and liquidates itself when its productivity declines to a second lower boundary. As long as the firm is in operation, its market value is a strictly monotonic, and thus invertible, function of its productivity.

3.1. Description of technology

Suppose that a firm uses only labor and capital to produce a single output. The firm's operating profit function, ignoring the cost of capital for the moment, can be written as

$$\pi(K(t), L(t), \Omega(t)) = \Omega(t)^{\alpha} K(t)^{\alpha} L(t)^{1-\alpha} - P_l * L(t) \tag{5}$$

where $K(t)$ is capital, $L(t)$ is labor, P_l is the wage rate and $\Omega(t)$ is a Hicks neutral productivity shock which evolves continuously according to geometric Brownian motion

$$\frac{d\Omega}{\Omega} = \mu dt + \sigma d\xi \tag{6}$$

where μ is the drift and σ is the variance. Assume that the firm can only change its capital level at discrete annual intervals t_i, while labor is perfectly flexible. For every unit of capital investment, the firm has to pay two kinds of costs: the market price for the investment, and an adjustment cost. There are both fixed and quadratic costs components of the adjustment cost. The firm can buy capital for P_{kb} per unit, and can sell it for P_{ks}, where

$$P_{kb} > P_{ks} > = 0 \tag{7}$$

The price the firm receives for capital is lower that at which it can buy capital. This may be due to customization of capital for the firm's specific purposes or adverse selection in the resale market for capital.

[2] See Ackerberg et al. (2006b) and Wooldridge (2005) for excellent reviews of this method.

[3] See Adda and Cooper (2003) and Caballero (1999) for reviews of the literature on dynamic approaches to investment.