Journal of Econometrics 157 (2010) 205–219

Contents lists available at ScienceDirect

Journal of Econometrics

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

Econometric modeling of technical change

Hui Jin, Dale W. Jorgenson *

Harvard University, United States

ARTICLE INFO

Article history:
Received 23 August 2008
Received in revised form
9 July 2009
Accepted 7 December 2009
Available online 29 December 2009

JEL classification:
C32
C51
D24

Keywords:
Technical change
Rate and bias
Substitution

ABSTRACT

The purpose of this paper is to present a new approach to econometric modeling of substitution and technical change. Substitution is determined by observable variables, such as prices of output and inputs and shares of inputs in the value of output. Our principal innovation is to represent the rate and biases of technical change by unobservable or latent variables. This representation is considerably more flexible than the constant time trends employed in the previous literature. An added advantage of the new representation is that the latent variables can be projected into the future, so that the rate and bias of technical change can be incorporated into econometric projections.

1. Introduction

The index number approach to productivity measurement has been the work horse of empirical research on the rate of technical change for half a century.[1] This salient concept has generated a vast literature on productivity measurement, recently surveyed by Jorgenson (2005). The key idea is to treat the level of technology as an unobservable or latent variable in a neo-classical production function. Under appropriate assumptions the rate of technical change is the residual between the growth rate of output and the growth rate of inputs. Using index numbers for these growth rates, the level of technology can be recovered without estimating the unknown parameters of the production function.

Recently, attention has shifted to the biases of technical change.[2] This shift is motivated by a wide range of applications, such as changes in the distribution of income, emphasized in the survey by Acemoglu (2002b), and determinants of energy conservation, highlighted in the survey by Jaffe et al. (2003). However, biases of technical change are not directly observable. In this paper we present a new econometric approach to measuring both the rate and the biases of technical change. Our key contribution is to represent the rate and biases by unobservable or latent variables.

The standard econometric approach to modeling the rate and biases of technical change was introduced by Binswanger (1974a,b) and described in the surveys by Binswanger and Ruttan (1978), Jorgenson (1986), and Ruttan (2001). Binswanger's approach is to represent price effects by the translog function of the input prices introduced by Christensen et al. (1973). He represents the rate and biases of technical change by constant time trends and fits the unknown parameters by econometric methods. This approach to modeling technical change is widely employed, for example, by Jorgenson and Fraumeni (1983), Jorgenson et al. (1987, Ch. 7), and, more recently, by Feng and Serletis (2008).

Binswanger's approach exploits the fact that price effects depend on observable variables, such as the prices of output and inputs and the shares of inputs in the value of output. The key to modeling these effects is to choose a flexible functional form that admits a variety of substitution patterns.[3] Our model of substitution, like Binswanger's, is based on the translog price function, giving the price of output as a function of the prices of inputs. The measures of substitution are unknown parameters that can be estimated from observable data on prices and value shares.

* Corresponding address: Harvard University, Department of Economics, 122 Littauer Center, 02138 Cambridge, MA, United States. Tel.: +1 617 495 4661; fax: +1 617 495 4660.

E-mail address: djorgenson@harvard.edu (D.W. Jorgenson).

1 For details see Diewert and Morrison (1986).

2 Acemoglu (2002a) presents models of biased technical change and reviews applications to macroeconomics, development economics, labor economics and international trade. Acemoglu (2007) surveys more recent developments in the literature and presents detailed results on relative and absolute biases of technical change.

3 Additional details are given by Jorgenson (1986). Barnett and Serletis (2008) provide a detailed survey of flexible functional forms used in modeling consumer demand, including parametric, semi-parametric, and non-parametric approaches.

0304-4076/$ – see front matter
doi:10.1016/j.jeconom.2009.12.002

Our novel contribution is to replace the constant time trends that describe the rate and biases of technical change in Binswanger's model by latent or unobservable variables. An important advantage of the translog price function in this setting is that the resulting model is linear in the latent variables. We recover these variables by applying the Kalman (1960, 1963) filter, a standard statistical technique in macroeconomics and finance, as well as many areas of engineering.

An important feature of the Kalman filter is that latent variables representing the rate and biases of technical change can be recovered for the sample period. A second and decisive advantage of the Kalman filter is that the latent variables can be projected into the future, so that the rate and biases of technical change can be incorporated into econometric projections.[4] The rate of technical change captures trends in productivity, while biases of technical change describe changes in the structure of production.

We implement our new approach for modeling substitution and technical change for the post-war US economy, 1960–2005. This period includes substantial changes in the prices of fossil fuels and the wage rate. Energy crisis periods with dramatic increases in energy prices alternating with periods of energy price collapse are particularly valuable for our purposes. By modeling substitution and technical change econometrically, we are able to decompose changes in the price of output and the input value shares between price effects and the effects of technical change. Empirically, these two sets of effects are comparable in magnitude.

We also decompose the rate of technical change between an autonomous part, unaffected by price changes, and an induced part, responsive to price changes. The rate of induced technical change links the rate and biases of technical change through the correlation between the input prices and the latent variables representing biases. Efforts to economize on an input that has become more expensive or to increase the utilization of an input that has become cheaper will affect the rate of technical change. Although modest in size, rates of induced technical change are generally opposite in sign to rates of autonomous technical change.

In Section 2 we present our econometric model of substitution and technical change. We augment the translog price function by introducing latent variables that represent the rate and biases of technical change. In Section 3 we apply an extension of the Kalman filter to estimate the unknown parameters of the model and generate the latent variables. In Section 4 we extend the standard framework for the Kalman filter to include endogenous prices by introducing instrumental variables. We propose a two-step procedure based on two-step Maximum Likelihood Estimation and derive two diagnostic tests for the validity of the instruments.

In Section 5 we present our empirical results. We find that substitution and technical change are both important in representing changes in patterns of production. In particular, biases of technical change are quantitatively significant for all inputs. The rates of technical change decompose neatly between a negative rate of induced technical change and a positive rate of autonomous technical change, which generally predominates. This implies that biased technical change, a change in technology directed to a particular input, reduces the rate of technical change. Section 6 concludes.

[4] A detailed projection of US economic growth, incorporating projections of the rate and biases of technical change based on the Kalman filter, is presented by Jorgenson et al. (2008). The intertemporal general equilibrium model underlying these projections also incorporates the dynamics of capital accumulation and asset pricing, so that we do not include these dynamics in the specification of our models of production.

2. Econometric model

In our data set, production is disaggregated into 35 separate commodities produced by one or more of the 35 industries making up the US economy and listed in Table 1. The industries generally match two-digit sectors in the North American Industry Classification System (NAICS). Industries produce a primary product and may produce one or more secondary products. Each industry is modeled by a system of equations that represents possible substitutions among the inputs of capital, labor, energy and materials and the rate and biases of technical change.

Our focus on the US economy is motivated by the availability of a new data set constructed by Jorgenson et al. (2007a). On June 30, 2008, the European Union released similar data sets for the 25 member states prior to the enlargement to include Bulgaria and Romania on January 1, 2007.[5] The Research Institute for Economy, Trade and Industry in Japan has developed data sets of this type for mainland China, Japan, Korea, and Taiwan.[6] Our new methods for modeling substitution and technical change can be applied to these economies and others with similar data sets.

The production function expresses output as a function of capital, labor, m intermediate inputs, non-competing imports (X_N) and technology (t); for industry j:

$$Q_j = f(K_j, L_j, X_{1,j}, X_{2,j}, \ldots, X_{m,j}, X_{Nj}, t), \quad j = 1, 2, \ldots, 35. \tag{1}$$

At the first stage the value of each industry's output is allocated to four input groups—capital, labor, energy, and non-energy materials:

$$Q_j = f(K_j, L_j, E_j, M_j, t). \tag{2}$$

The second stage allocates the energy and non-energy material groups to the individual intermediate commodities. This stage is not discussed further in this paper.[7]

Assuming constant returns to scale and calculating the cost of capital as the residual that exhausts the value of output, the value of output is equal to the value of the four inputs:

$$P_{Qjt}Q_{jt} = P_{Kjt}K_{jt} + P_{Ljt}L_{jt} + P_{Ejt}E_{jt} + P_{Mjt}M_{jt}. \tag{3}$$

In representing substitution and technical change, it is more convenient to work with the dual price function instead of the production function in (2).[8]The price function expresses the unit output price as a function of all the input prices and technology, $P_{Qj} = p(P_{Kj}, P_{Lj}, P_{Ej}, P_{Mj}, t)$.

Dropping the industry subscript j for simplicity, we assume that the price function has the *translog* form:

$$\begin{aligned} \ln P_{Qt} &= \alpha_0 + \sum_{i=1}^{n} \alpha_i \ln P_{it} + \frac{1}{2}\sum_{i,k} \beta_{ik} \ln P_{it} \ln P_{kt} \\ &\quad + \sum_{i=1}^{n} \ln P_{it} f_{it} + f_{pt} \quad i, k = \{K, L, E, M\}. \end{aligned} \tag{4}$$

We refer to the translog price function (4) as the *state-space model of producer behavior*. The parameters α_0, α_i and β_{ik} are estimated separately for each industry. The latent variables f_{it} and f_{pt} are also estimated separately for each industry, using the Kalman filter

[5] See van Ark et al. (2008).

[6] See Jorgenson et al. (2007b).

[7] In the data set constructed by Jorgenson et al. (2007a) the energy and non-energy aggregates in (2) are assumed to be homothetically separable within the production function (1). More details are given by Jorgenson et al. (2005).

[8] The dual price function is equivalent to the primal production function in that all the information expressed in one is recoverable from the other. Further details are given by Jorgenson (2000).