Part 2. Analyzing Environmental Policies with IGEM

Chapter 3. The Supply Side of the U.S. Economy

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In this chapter we discuss the specification of the supply side of IGEM, the construction of the industry output and input data, and the estimation of the production models described in Section 1.1. In Section 3.1 we give a summary description of the historical performance of U.S. industries, including the sources of industry growth. In Sections 3.2 and 3.3 we present the estimation results for the production models for domestic output. The total supply of any commodity is the sum of domestic output and imports. In section 3.4 we describe the estimation of the import demand and total supply functions introduced in Section 1.5.

In Section 1.1 we have specified a production model with industry output as a function of capital, labor, intermediate inputs and technology (1.1):

(3.1) $QI_j = f(KD_j, LD_j, QP_1^j, QP_2^j, ...QP_m^j, t)$, j=1,2,...35

Capital input incorporates information on 62 distinct asset types, ranging from computers to single-family structures. Appendix D discusses how to aggregate these assets, using annual rental rates as weights. Simple sums of the stocks of the various assets would fail to capture the substitution among different types of capital.

The labor input index presented in Appendix C is an aggregate of hours worked, cross-classified by characteristics of individual workers, such as age and educational attainment. This explicitly recognizes the differences in productivity among workers, as reflected in their wage rates. Sums of hours worked by the many different types of workers would fail to capture the substitution among the different types of labor input.

Finally, output and intermediate input are based on a time series of input-output tables, allowing us to distinguish, for example, between computers, treated as a capital input, and semiconductors, an intermediate input into the Machinery industry. This is described in Appendix B. We also distinguish between the refined petroleum products that most users buy and the crude oil sold by the Petroleum Mining industry to the Petroleum Refining industry.

In IGEM the production function is replaced by its dual, a price function giving the price of output as a function of the prices of inputs.[1] The production model is expressed as a hierarchical tier structure of price functions, where the top tier has technology represented by latent variables in a Kalman filter, as discussed below. The estimation of the unknown

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[1] 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).

parameters of this model is reported in section 3.2. The remaining tiers represent technology at the level of intermediate inputs, consisting of energy and non-energy materials. The estimation of the unknown parameters of these models is reported in Section 3.3. Before discussing estimation, we first consider historical trends of output growth by industry in Section 3.1, using growth accounting measures of the growth of inputs and productivity growth. This historical behavior drives our projections.

3.1 U.S. economic performance at the industry level 1960-2005

The list of the industries included in our model is given in Table 3.1. Industries 7-27 comprise manufacturing, while Industries 28-35 make up services. The remaining industries are agriculture, the four mining sectors, and construction. Two additional sectors, households and general government, do not produce marketed goods but employ capital and labor. There are five energy-related industries – Coal Mining, Petroleum and Gas Mining, Petroleum Refining, Electric Utilities and Gas Utilities. Table 3.1 gives output, intermediate input, capital input and the number of workers employed for all 37 sectors in the year 2005. Households and general government have no intermediate inputs, so that output is equal to value added.

The largest market industries in terms of gross output or value added are Services, Finance, Insurance, and Real Estate (FIRE) and Trade. Among the manufacturing industries the largest in terms of output are Food, Industrial Machinery, which includes computers, and Electrical Machinery, which includes semi-conductors. In terms of value added, the largest manufacturing industries are Industrial Machinery, Electrical Machinery and Chemicals. The energy group is a small share of the U.S. economy; it produced gross output valued at $1,154 billions in 2005, compared to $18,535 billions of total business output. The value added in the energy group was equal to 4.4% of GDP in 2005.

Table 3.2 gives growth rates of output, intermediate input and value added for all 37 sectors for the period 1960-2005. Output growth is most rapid for the information technology (IT) and high-tech industries – Industrial Machinery, Electrical Machinery, and Communications. In this period GDP was growing at 3.3% per annum and these industries were growing in excess of 5.6%. Growth of intermediate input is also most rapid for these sectors. Instruments, Rubber and Plastics, FIRE, Services and Trade comprise the next echelon of four industries in terms of output growth, all in excess of 3.7% per year. These are also leaders in value added growth.

The exceptional performance of the IT-producing industries – Industrial Machinery and Electrical Machinery – is discussed in detail by Jorgenson, Ho and Stiroh (2005, henceforward JHS). There we show that the IT-producing industries not only grew the fastest during the entire period 1977-2000, but had the greatest growth acceleration during the 1995-2000 information technology investment boom. In Appendix B we compare 1960-73, 1973-95, and 1995-2005 sub-periods in order to show how the various industries recovered from the low-growth period that followed the oil shocks of the 1970s and how growth accelerated after 1995.

We next describe the sources of economic growth at the industry level. Our methodology for measuring productivity at the industry level begins with an industry production function:

(3.2) $$QI_j = f(KD_j, LD_j, X_j, t)$$

where Q is industry output, K is capital input, L is labor input, X is intermediate input, and t is an indicator of the level of technology, all for industry j. The variables KD, LD, and X are index numbers with many components and the production function (3.1) is separable in these components. For example, the index of intermediate input X_{jt} is defined as a translog index of the intermediate inputs, where the QP_i^j 's are quantities and the PS_i 's are prices:

(3.3) $$\Delta \ln X_j = \sum_i \bar{v}_{ij} \Delta \ln QP_i^j \qquad v_{ijt} = \frac{PS_{it} QP_{it}^j}{\sum_i PS_{it} QP_{it}^j}; \quad \bar{v}_{ij} = \tfrac{1}{2}(v_{ijt} + v_{ij,t-1})$$

Let PI_j, $PKD_{,j}$, $PLD_{,j}$, and $PX_{,j}$ denote the prices of industry output and the three inputs, respectively. Under the assumptions of constant returns to scale and competitive markets, a translog index of productivity is:

(3.4) $$v_{t,j} \equiv \Delta \ln QI_j - \bar{v}_{K,j} \Delta \ln KD_j - \bar{v}_{L,j} \Delta \ln LD_j - \bar{v}_{X,j} \Delta \ln X_j$$

where $\bar{v}$ is the two-period average share of the input in the value of output. Note that the assumptions imply that value of output is equal to the sum of values of the inputs:

$$PO_{jt} QI_{jt} = PKD_{jt} KD_{jt} + PLD_{jt} LD_{jt} + PX_{jt} X_{jt}$$

and the value shares sum to unity.

Table 3.3 presents the sources of growth for each industry based on (3.4), where the growth of output is the sum of the contributions of capital, labor, intermediate inputs and productivity growth. For example, the contribution of capital is the weighted growth rate

$\overline{v}_{K,j} \Delta \ln KD_j$, averaged over the sample period. The considerable impact of intermediate inputs on the growth of industry output is strikingly apparent in Table 3.3. Intermediate input is the key contributor to industry growth in most of the manufacturing industries, including Petroleum Refining. However, it makes a negative contribution in Petroleum and Gas Mining and Textiles.

Investments in tangible assets and human capital are very important contributors to the growth of output. The contributions of capital input are positive for every industry. The market sectors where capital input is particularly significant are Petroleum and Gas Mining, Electric Utilities, Gas Utilities, Communications, and FIRE. We should mention that in JHS (2005) capital is broken into IT capital and non-IT capital, and all industries had rapid growth of IT capital input, including those with low or negative output growth. This is discussed in greater detail in Appendix D.

Labor input makes large positive contributions to Services, Construction, and Trade. It is not an important contributor to growth in the energy industries. Many industries had negative contributions of labor input, including Agriculture, Metal Mining, Coal Mining, Leather, Textiles and Apparel. Since labor input is an important source of aggregate economic growth, these negative contributions are outweighed by positive contributions from the other industries. When we divide labor input into less and more highly educated components (JHS (2005, Chapter 6)), we see that rapid growth of college-educated workers characterizes almost all industries. However, growth of college-educated labor input for the economy as a whole is concentrated in trade, finance, and service industries – which have high levels of employment.

The final contributor to the growth of output identified in Table 3.3 is productivity. Electrical Machinery has the most dramatic contribution of productivity growth, 3.8 percentage points out of 6.5% for output, followed by the other IT-producing industry, Industrial Machinery, 2.6 percentage points out of 5.9%. Productivity growth is also relatively important in Agriculture, Coal Mining, Textiles, Apparel, Instruments and Communications.

In the energy group, productivity contributed 0.68 percentage points of the 3.58% per year growth in output in Electric Utilities. For Coal Mining, productivity accounted for 1.17 percentage points out of growth of 2.21%; for Petroleum Refining, productivity was only 0.08% of growth of 1.63%. Petroleum and Gas Mining and Gas Utilities had negative productivity growth. A total of eight industries had negative productivity growth for the period 1960-2005, including Construction and Services. The perplexing phenomenon of negative productivity growth at the industry level is widely discussed and is an important factor in our projections.

Measures of average performance over the period 1960-2005 conceal changes over time. Table 3.4 provides growth rates of productivity for the 35 industries for the entire period and for the sub-periods 1960-1973, 1973-1995, and 1995-2005. On average, productivity growth was highest during 1960-73, decelerated dramatically during 1973-95, and revived substantially during 1995-2005. However, the two industries that supplied hardware for what JHS (2005) calls the Information Age had accelerating productivity growth. Industrial Machinery, including computers, accelerated from 1.29% during 1960-73 to an unprecedented 5.0% during 1995-2005 while Electrical Machinery, including semi-conductors, accelerated from 2.62% to 5.8% per year.

The industries in the energy group have exhibited a wide variety of behavior. Coal Mining had accelerating productivity growth, reaching 2.58% per year during 1995-2005. Electric Utilities followed the national average with a sharp deceleration to -0.48% per year during 1973-95 followed by a revival to 0.40% during 1995-05. Productivity growth in Petroleum Refining accelerated from 0.36% in 1960-73 to 0.79% in 1973-95 and then fell sharply to -1.87%. Petroleum and Gas Mining, and Gas Utilities were the poor performers; both had negative productivity growth after 1973, with a less negative growth after 1995. This poor performance may reflect tighter environmental regulations and is an important topic for research.

We conclude from this brief discussion that capital, labor, and intermediate inputs stand out as the most important sources of growth at the industry level. Growth in productivity is an important source of growth, but far less significant in economic terms than growth of inputs. The restructuring of the American economy in response to the progress of information technology has been massive and continuous. The structure of output is shifting toward the IT-producing industries, but even more substantially toward the IT-using service industries. This shift has left the energy sectors growing more slowly than average. Finally, the composition of the work force is shifting toward more college-educated workers with rising investments in higher education.

3.2 Implementing the production model, top tier

The industry production function (3.1) expresses output as a function of capital, labor, the 35 intermediate commodities, non-competing imports and technology. This is implemented as a hierarchical tier structure of price functions given in Table 1.2. Industry output is a function of capital, labor, energy intermediates, and non-energy materials, as expressed in (1.2). In the lower tiers the materials aggregate is allocated to the individual commodities. In this section we focus on the top tier. The lower tiers are described in section 3.3 below.

3.2.1 A state-space industry price function

As explained in Chapter 1, our production model is based on the dual price function rather than the production function (1.2). The price function expresses the price of output as a function of the prices of the four inputs and technology. We impose constant returns to scale on the production function and calculate the cost of capital as the residual that exhausts the value of output, so that:

$$(3.5) \quad PO_{jt} QI_{jt} = PKD_{jt} K_{jt} + PLD_{jt} L_{jt} + P_{Ejt} E_{jt} + P_{Mjt} M_{jt}$$

Under this assumption the output price is a homogeneous function of degree one of the four input prices:

$$PO_j = p(PKD_j, PLD_j, P_{Ej}, P_{Mj}, t) .$$

In modeling production we use a *state-space model of producer behavior* and employ the translog form of the price function. This specification is given as (1.4) and (1.5):

$$(3.6) \quad \ln PO_{jt} = \alpha_0^j + \sum_i \alpha_i^{Pj} \ln p_{it} + \tfrac{1}{2} \sum_{i,k} \beta_{ik}^{Pj} \ln p_{it} \ln p_{kt} + \sum_i \ln p_{it} f_{it}^{Pj} + f_t^j$$

$$p_i, p_k = \{PKD_j, PLD_j, P_{Ej}, P_{Mj}\}$$

$$(3.7) \quad \xi_t^j = F^j \xi_{t-1}^j + \varepsilon_t$$

$$\xi_t = (1, f_{Kt}^p, f_{Lt}^p, f_{Et}^p, f_{Mt}^p, \Delta f_t)'$$

where p_i denotes the price of the *ith* input, the latent variables f_{it}^P represent biases of technical change, and the latent variable f_t the level of technology. The parameters α_0, α_i^P and β_{ik}^P are estimated separately for each industry and the superscript P denotes parameters of the price function, as distinguished from parameters of the investment and import functions. We drop the j superscript for the jth industry for simplicity.

The state-space model of producer behavior (3.6) and (3.7) includes both the substitution parameters β_{ik}^P and the latent technology variables, f_{it} and f_t. This makes possible to separate changes in the input demands resulting from price-induced substitution from those reflecting changes in technology. The latent variables describing the state of technology at each point of time are estimated separately for each industry using the Kalman filter discussed below. This permits a very flexible representation of technical change in the sample period, as well as a highly tractable methodology for projecting technical change in the forecast period.

The state-space specification of the price function has a far more flexible representation of technical change than the parametric specifications of time trends used in previous models of production. For example, in previous versions of our model[2], the price function is written in a parametric form:

$$(3.8) \qquad \ln P_{Qt} = \alpha_0 + \sum_{i=1}^{n} \alpha_i \ln P_{it} + \tfrac{1}{2} \sum_{i,k} \beta_{ik} \ln P_{it} \ln P_{kt} + \sum_{i=1}^{n} \beta_{it} \ln P_{it} g(t) + \alpha_t g(t) + \tfrac{1}{2} \beta_{tt} g(t)^2$$

where g(t) is a logistic function of time. An important advantage of the state-space specification is that no explicit parametric form is required for the changes in technology. However, note that the autoregressive scheme (3.7) involves unknown parameters that we estimate as part of the Kalman filter.

The application of translog price functions in general equilibrium models is described in detail by Jorgenson (1998). We summarize the key features here. An important advantage of the translog form is that it is sufficiently rich to encompass arbitrary patterns of substitutability among the inputs, but generates linear input demand functions useful in implementing the Kalman filter. Differentiating (3.6) with respect to the log of input prices, we obtain the input share equations. For example, the demand for capital is:

$$(3.9) \qquad v_K = \frac{PKD_t KD_t}{PO_t QI_t} = \alpha_K^P + \sum_k \beta_{Kk}^P \ln p_k + f_{Kt}^P$$

The input value share is a linear function of the logarithms of the input prices and a latent variable representing biases of technical change. The parameters β_{ik} capture the price responsiveness of demands for inputs for a given state of technology. These parameters are called *share elasticities* and capture the degree of substitutability among inputs. For example, a lower price of capital leads to greater demand for capital input. This may lead to a higher or lower share of capital input, depending on the substitutability of other inputs for capital; this

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[2] See Jorgenson (1998).

substitutability is captured by the share elasticity for capital input. Share elasticities may be positive or negative, so that the share of capital may increase or decrease with the price of capital input. When all share elasticities β_{ik} are zero, the price function reduces to the Cobb-Douglas or linear logarithmic form and the shares are independent of input prices.

The latent variables f_{it}'s represent the *biases of technical change*. For example, if the capital term f_{Kt} is increasing with time for a given set of input prices, technical change is *capital-using*. Alternatively, if f_{Kt} is decreasing, technical change is *capital-saving*.

In estimating the unknown parameters, restrictions derived from production theory must be imposed on (3.6). In describing these restrictions it is more convenient to use a more concise vector and matrix notation. The price function and input share equations are written as:

(3.10) $\ln PO_t = \alpha_0 + \boldsymbol{\alpha}^{P}{}'\ln \mathbf{p}_t + \tfrac{1}{2}\ln \mathbf{p}_t{}'\mathbf{B}^P \ln \mathbf{p}_t + \ln \mathbf{p}_t{}'\mathbf{f}_t^P + f_t + \varepsilon_t^p$

(3.11) $\mathbf{v}_t = \boldsymbol{\alpha}^P + \mathbf{B}^P \ln \mathbf{p}_t + \mathbf{f}_t^P + \boldsymbol{\varepsilon}_t^v$

where:

$$\mathbf{p} = (PKD, PLD, P_E, P_M)'; \qquad \mathbf{v} = (v_K, v_L, v_E, v_M)';$$

$$\mathbf{f}_t^p = (f_{Kt}^p, f_{Lt}^p, f_{Et}^p, f_{Mt}^p)'; \qquad \mathbf{B}^P = [\beta_{ik}].$$

We have added disturbance terms, ε_t^p and $\boldsymbol{\varepsilon}_t^v$, that are random variables with mean zero and represent shocks to producer behavior for a given state of technology.

Since the price function is homogeneous of degree one, doubling of all input prices doubles the output price. This implies the restrictions:

(3.12) $\alpha_K + \alpha_L + \alpha_E + \alpha_M = 1$

$$\sum_i \beta_{ik} = 0 \quad \text{for each } k$$

$$\sum_i f_{it} = 0$$

The price function is symmetric $\left(\dfrac{\partial^2 PO}{\partial p_i \partial p_k} = \dfrac{\partial^2 PO}{\partial p_k \partial p_i}\right)$, so that matrix of share elasticities must be symmetric:

(3.13) $\beta_{ik} = \beta_{ki}$

Finally, the price function must be concave. We require only that the price function is *locally concave,* that is, concave when evaluated at the prices observed in the sample period, not necessarily concave at all possible prices or *globally concave*. Concavity involves restrictions on the Hessian matrix of second-order derivatives of the price function, $\mathbf{H} = \left[\frac{\partial^2 PO}{\partial \mathbf{p} \partial \mathbf{p}'} \right]$.

The Hessian matrix takes the form:

$$(3.14) \quad \frac{1}{PO_t} \mathbf{N}_t \mathbf{H}_t \mathbf{N}_t = \mathbf{B} + \mathbf{v}_t \mathbf{v}_t ' - \mathbf{V}_t \equiv \tilde{\mathbf{H}}_t$$

where **N** is a diagonal matrix with the input prices along the diagonal and $\mathbf{V}_t$ is a diagonal matrix with the input value shares. The local concavity condition requires that the matrix $\tilde{\mathbf{H}}_t$ be non-positive definite for each observation in the sample period. To implement this condition the matrix is decomposed to its Cholesky factors, $\tilde{\mathbf{H}} = \mathbf{LDL}'$, where **L** is a unit lower triangular matrix and **D** is a diagonal matrix. The condition that $\tilde{\mathbf{H}}_t$ is non-positive definite is equivalent to the diagonal elements of $\mathbf{D_t}$ being non-positive:

$$(3.15) \quad D_{ii,t} \leq 0$$

Turning to the latent variables describing the state of technology, productivity growth translates into a fall in output price for given input prices. The price dual to equation (3.4) is expressed as:

$$(3.16) \quad -v_t = \Delta \ln \frac{PO_t}{PO_{t-1}} - \Delta \sum_{i=KLEM} \bar{v}_{it} \ln \frac{p_{it}}{p_{i,t-1}}$$

Productivity change between *t-1* and *t* is:

$$(3.17) \quad \Delta T_t = -\sum_{i=1}^{n} \ln P_{it} (f_{it} - f_{i,t-1}) - (f_t - f_{t-1})$$

As technology progresses for a given set of input prices, the price of output falls. The first term in (3.17) depends on the prices and the biases of technical change. We refer to this as the rate of *induced* technical change. When the latent variable f_{Kt} is rising, technical change is capital-using and a higher price for capital input will reduce the rate of productivity growth in (3.17). When technical change is capital-saving, a higher price for capital will increase the rate of productivity growth. It is important to emphasize that the flexible specification of the latent variables implies that technical change may be capital-using at one point of time and capital-saving at another. The second term in (3.17) depends only on changes in the level of technology f_t, so that we refer to this as the rate of *autonomous* technical change.

The rate of technical change (3.17) is the sum of induced and autonomous rates of technical change. Ordinarily, the autonomous rate of technical change would be positive, while the induced rate of technical change could be positive or negative. The rate of induced technical change is simply the negative of the covariance between the logarithms of the input prices and the biases of technical change. If lower input prices are correlated with higher biases of technical change, then the rate of induced technical change is positive.

Since the shares for all four inputs sum to unity, the biases of technical change f_{it} must sum to zero, as in (3.12). Similarly, the shocks to producer behavior for a given state of technology $\boldsymbol{\varepsilon}_t^v$ sum to zero. We can solve out these constraints on the shocks, as well as the homogeneity constraints (3.12), by expressing the model (3.10) and (3.11) in terms of relative prices, dropping one of the share equations and one of the biases of technical change. The system that is estimated is:

(3.18) $\ln PO_t = \alpha_0 + \tilde{\boldsymbol{\alpha}}^P{}' \ln \mathbf{p}_t + \frac{1}{2} \ln \mathbf{p}_t{}' \tilde{\mathbf{B}}^P \ln \mathbf{p}_t + \ln \mathbf{p}_t{}' \mathbf{f}_t^P + f_t + \varepsilon_t^p$

(3.19) $\mathbf{v}_t = \tilde{\boldsymbol{\alpha}}^P + \tilde{\mathbf{B}}^P \ln \mathbf{p}_t + \mathbf{f}_t^P + \boldsymbol{\varepsilon}_t^v$

where:

$$\mathbf{p} = (PKD / P_M, PLD / P_M, P_E / P_M)'; \quad \mathbf{v} = (v_K, v_L, v_E)'; \qquad \mathbf{f}_t^p = (f_{Kt}^p, f_{Lt}^p, f_{Et}^p)'.$$

We impose the restrictions:

$\tilde{\mathbf{B}} = \tilde{\mathbf{B}}'$;

$\tilde{\mathbf{B}} + \mathbf{v}_t \mathbf{v}_t{}' - \mathbf{V}_t$ is locally concave.

We assume that the biases of technical change f_{it} are stationary. We assume, further, that the level of technology is non-stationary but the first difference, $\Delta f_t = f_t - f_{t-1}$, is stationary, so that technology evolves in accord with a stochastic trend or unit root. This implies that in the long run after the initial conditions die down, the rate of growth of productivity is a constant, and the bias terms are constant.

To implement a model of production based on the price function (3.17), we express the technology state variables as a vector auto-regressive scheme (VAR). Denote the vector of stationary state variables by:

(3.20) $\tilde{\xi}_t = (1, f_{Kt}^p, f_{Lt}^p, f_{Et}^p, \Delta f_t)'$

The transition equations are written as a first-order VAR:

(3.21) $\tilde{\xi}_t = \tilde{F}\tilde{\xi}_{t-1} + \varepsilon_t$,

where ε_t is a random vector with mean zero representing technology shocks and $\tilde{F}$ is a matrix of unknown parameters. Given the values of these latent variables estimated during the sample period and estimates of the coefficient matrix $\tilde{F}$, the transition equations are also useful for projecting the technology state variables.

The state-space specification of producer behavior allows for a very flexible representation of technical change in the sample period, as well as a highly tractable methodology for projecting technical change in the forecast period. For example, the productivity growth rate in Electronic and Electrical Equipment, the industry that makes semi-conductors, is very high, as shown in Jorgenson, Ho and Stiroh (2005). The VAR for this industry with estimated coefficient matrix $\mathbf{\Phi}$ extrapolates this growth into the future. Other industries have lower projected productivity growth rates, leading to a rapid and sustained fall in the relative price of Electronic and Electric Equipment products. In turn this generates continued rapid diffusion of information technology based on semiconductors, as in the sample period.

3.2.2. The Two-Step Kalman Filter

The econometric technique for identifying the latent opportunities for technological innovation is a straightforward extension of the Kalman filter described in detail by Hamilton (1994, Chapter 13). In the empirical research described in the following section, the Kalman filter is used to model production in each of the 35 sectors of IGEM. The latent variables in the state-space specification of the price function (3.17) determine current and future patterns of production along with relative prices, which are the covariates of the Kalman filter. The prices are determined by the balance of demand and supply, so that they are endogenous as well.

The estimation procedure for the state-space model of producer behavior is described in detail in Jin and Jorgenson (2009). Here we summarize the key elements. We first review the standard Kalman filter, following Hamilton (1994), and then discuss extensions to deal with our endogenous explanatory variables. Let ξ_t, t=0,1,2,…T, denote the vector of unobserved latent variables and y_t, t=1,2,…T be the vector of observations on the dependent variables. The vector y_t is determined by ξ_t and x_t, the vector of observations on the explanatory variables.

The state-space model is written as:

(3.22) $\underset{(r\times 1)}{\xi_t} = \underset{(r\times r)}{F}\,\underset{(r\times 1)}{\xi_{t-1}} + \underset{(r\times 1)}{\varepsilon_t}$, (3.23) $\underset{(n\times1)}{y_t} = \underset{(n\times k)}{A'}\underset{(k\times1)}{x_t} + \underset{(n\times r)}{H'}\underset{(r\times1)}{\xi_t} + \underset{(n\times1)}{w_t}$,

where the shocks u_t and w_t are assumed uncorrelated at all lags and:

(3.24) $E(\varepsilon_t\varepsilon_\tau') = \begin{cases} \underset{(r\times r)}{Q} & t=\tau \\ 0 & otherwise \end{cases}$

$E(w_t w_\tau') = \begin{cases} \underset{(n\times n)}{R} & t=\tau \\ 0 & otherwise \end{cases}$

The *state equation* is (3.22) and the *observation equation* is (3.23), where x_t is exogenous, that is, uncorrelated with the disturbance w_t. The matrices Q and R are the covariance matrices for disturbances. The matrices A, H, F, R, and Q include unknown parameters, but some of their elements are known. For simplicity we denote the unknown components of the matrices {A,H,F,R,Q} by the parameter vector θ.

Estimation of the Kalman filter involves two procedures, *filtering* and *smoothing*. In filtering we use the Maximum Likelihood Estimator (MLE) of the unknown parameter θ. The log-likelihood function, based on the normal distribution, is computed by the forward recursion described by Hamilton (1994):

(3.25) $\max_\theta l(\theta \mid Y_T) = \max_\theta \sum_{t=1}^{T} \log N(y_t \mid \hat{y}_{t|t-1}, V_{t|t-1})$,

where the matrix,

$Y_t = (y_t', y_{t-1}', \ldots y_1', x_t', x_{t-1}', \ldots x_1')'$,

consists of the observations up to time t. The mean and variance:

(3.26) $\hat{y}_{t|t-1} = E(y_t \mid Y_{t-1})$; $V_{t|t-1} = E[(y_t - \hat{y}_{t|t-1})(y_t - \hat{y}_{t|t-1})']$

are functions of θ and the data, and are calculated in the forward recursion. We use numerical methods to calculate the covariance matrix of the maximum likelihood estimator $\hat{\theta}$. In smoothing, we estimate the latent vector ξ_t, given $\hat{\theta}$, using the backward recursion.

The econometric model we have presented in Section 3.2.1 above can be expressed in the form (3.22-23) required by the Kalman filter with the following definitions:

$$y_t = \begin{bmatrix} v_{Kt} \\ v_{Lt} \\ v_{Et} \\ \ln \frac{P_{Qt}}{P_{Mt}} \end{bmatrix}; \quad x_t = \begin{bmatrix} 1 \\ \ln \frac{P_{Kt}}{P_{Mt}} \\ \ln \frac{P_{Lt}}{P_{Mt}} \\ \ln \frac{P_{Et}}{P_{Mt}} \\ \frac{1}{2}(\ln \frac{P_{Kt}}{P_{Mt}})^2 \\ \frac{1}{2}(\ln \frac{P_{Lt}}{P_{Mt}})^2 \\ \frac{1}{2}(\ln \frac{P_{Et}}{P_{Mt}})^2 \\ \ln \frac{P_{Kt}}{P_{Mt}} \ln \frac{P_{Lt}}{P_{Mt}} \\ \ln \frac{P_{Kt}}{P_{Mt}} \ln \frac{P_{Et}}{P_{Mt}} \\ \ln \frac{P_{Lt}}{P_{Mt}} \ln \frac{P_{Et}}{P_{Mt}} \end{bmatrix}; \quad \xi_t = \begin{bmatrix} 1 \\ f_{Kt} \\ f_{Lt} \\ f_{Et} \\ f_{pt} \\ f_{pt-1} \end{bmatrix}; \quad w_t = \begin{bmatrix} \varepsilon_{Kt}^v \\ \varepsilon_{Lt}^v \\ \varepsilon_{Et}^v \\ \varepsilon_t^p \end{bmatrix}; \quad \varepsilon_t = \begin{bmatrix} 0 \\ \varepsilon_{Kt} \\ \varepsilon_{Lt} \\ \varepsilon_{Et} \\ \varepsilon_{dpt} \\ 0 \end{bmatrix} \tag{3.27}$$

$$A' = \begin{bmatrix} \alpha_K & \beta_{KK} & \beta_{KL} & \beta_{KE} & 0 & 0 & 0 & 0 & 0 & 0 \\ \alpha_L & \beta_{KL} & \beta_{LL} & \beta_{LE} & 0 & 0 & 0 & 0 & 0 & 0 \\ \alpha_E & \beta_{KE} & \beta_{LE} & \beta_{EE} & 0 & 0 & 0 & 0 & 0 & 0 \\ \alpha_0 & \alpha_K & \alpha_L & \alpha_E & \beta_{KK} & \beta_{LL} & \beta_{EE} & \beta_{KL} & \beta_{KE} & \beta_{LE} \end{bmatrix};$$

$$H' = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & \ln \frac{P_{Kt}}{P_{Mt}} & \ln \frac{P_{Lt}}{P_{Mt}} & \ln \frac{P_{Et}}{P_{Mt}} & 1 & 0 \end{bmatrix}, \quad F' = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ \chi_K & \delta_{KK} & \delta_{KL} & \delta_{KE} & \delta_{Kp} & -\delta_{Kp} \\ \chi_L & \delta_{LK} & \delta_{LL} & \delta_{LE} & \delta_{Lp} & -\delta_{Lp} \\ \chi_E & \delta_{EK} & \delta_{EL} & \delta_{EE} & \delta_{Ep} & -\delta_{Ep} \\ \chi_p & \delta_{pK} & \delta_{pL} & \delta_{pE} & \delta_{pp}+1 & -\delta_{pp} \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}$$

We require two modifications of the standard Kalman filter in order to incorporate the concavity constraints, and introduce instrumental variables to deal with the endogeneity of the prices. We impose concavity by adding the constraints in (3.15) to the computation of the MLE. There are a total of 3T constraints (3 share equations times T periods). To introduce the instrumental variables, z_t, we assume that it includes the observations on these variables at time t and satisfies the equation:

(3.28) $$\underset{(k\times 1)}{x_t} = \underset{(k\times m)}{\Pi}\ \underset{(m\times 1)}{z_t} + \underset{(k\times 1)}{\eta_t} \quad ,$$

where z_t is uncorrelated with η_t and w_t, and η_t is correlated with w_t but uncorrelated with v_t.

Combining equation (3.28) with the observation equation (3.23), we construct a new observation equation:

(3.29) $$\begin{bmatrix} y_t \\ x_t \end{bmatrix} = \begin{bmatrix} A'\Pi \\ \Pi \end{bmatrix} z_t + \begin{bmatrix} H' \\ O \end{bmatrix} \xi_t + \begin{bmatrix} A'\eta_t + w_t \\ \eta_t \end{bmatrix} ,$$

or:

(3.30) $$\underset{[(n+k)\times 1]}{\tilde{y}_t} = \underset{[(n+k)\times m]}{\tilde{A}'}\ \underset{(m\times 1)}{\tilde{x}_t} + \underset{[(n+k)\times r]}{\tilde{H}'}\ \underset{(r\times 1)}{\xi_t} + \underset{[(n+k)\times 1]}{\tilde{w}_t} \quad ,$$

The state equation (3.22) is unchanged. The new model satisfies the exogeneity requirement of the Kalman filter. This would be a promising approach if the size of Π were small; however, in our application, this matrix involves 120 unknown parameters.

A more tractable approach is the two-step Kalman filter, obtained by a direct application of the two-step MLE (Wooldridge, 2002, Ch. 13). In the first step we estimate $\hat{\Pi} = XZ'(ZZ')^{-1}$ using OLS, which is a consistent estimator of Π, where X and Z represent the matrices of observations on x_t and z_t, t=1,2,…T. In the second step we replace X in the standard Kalman filter with $\hat{X} = \hat{\Pi}Z$. Wooldridge (2002) shows that the resulting $\hat{\theta}$ is a consistent estimator of θ, and is asymptotically normal with the following approximate covariance:

(3.31) $$\begin{aligned} \sqrt{N}(\hat{\theta}-\theta) &= \frac{A_0^{-1}}{\sqrt{N}}\sum_{i=1}^{N}[-g_i(\theta;\Pi)] + O_p(1) \\ &= -\frac{A_0^{-1}}{\sqrt{N}}\left\{\frac{\partial l(Y,X,Z,\theta,\Pi)}{\partial\theta} + \left[\frac{1}{N}\frac{\partial l(Y,X,Z,\theta,\Pi)}{\partial\theta\partial\Pi}\right]\left[N(Z'Z)^{-1}Z'\eta\right]\right\} + O_p(1) \\ &\approx -\frac{A_0^{-1}}{\sqrt{N}}\left\{\frac{\partial l(Y,X,Z,\hat{\theta},\hat{\Pi})}{\partial\theta} + \frac{\partial l(Y,X,Z,\hat{\theta},\hat{\Pi})}{\partial\theta\partial\Pi}(Z'Z)^{-1}Z'\hat{\eta}\right\} + O_p(1) \end{aligned}$$

where:

$$A_0 = \frac{1}{N}\frac{\partial l^2(Y,X,Z,\theta,\Pi)}{\partial\theta\partial\theta'} \approx \frac{1}{N}\frac{\partial l^2(Y,X,Z,\hat{\theta},\hat{\Pi})}{\partial\theta\partial\theta'}.$$

As described in Jin and Jorgenson (2009, Section 4), the instrumental variables are stationary variables that are determined independently of the variables that describe technology and prices. We include tax rates, the value of the time endowment generated by demographic changes, lagged prices, expressed relative to the price of labor input, lagged full consumption, the U.S. population, and government demand, expressed relative to lagged private national wealth. We have eleven instrumental variables z_t and only nine endogenous explanatory variables x_t, and thus can use the over-identifying restrictions to test for exogeneity of the candidate instrumental variables. The test results presented by Jin and Jorgenson (2009, Table A2) show that the instrumental variables chosen are exogenous for all industries.

Second, we apply a Likelihood Ratio Test to the hypothesis of zero correlation between endogenous explanatory variables and instrumental variables. The LR test statistic is given in Jin and Jorgenson (2009, section 4) and is asymptotically chi-squared. The results presented there (Table A3) show that the instrumental variables are highly correlated with the endogenous variables. We conclude that both diagnostic tests confirm the validity of our instruments.

3.2.3. Empirical Results

In this Chapter we focus on the essential features of the price function estimates; details are given in Appendix E. The constrained two-step maximum likelihood estimates of the parameters of the observation equation (3.23) for each of the 35 sectors are given in the appendix, Table E1. These estimates correspond to the α_i and β_{ik} parameters assigned to the matrix A', with the standard errors in parentheses. Recall that the β_{ik}'s are share elasticities and represent the responses of the four inputs – capital, labor, energy, and materials – to changes in the input prices for a given state of technology. The share elasticities can be positive or negative, but must satisfy the homogeneity (3.12), symmetry (3.13), and concavity (3.15) constraints. Also, the matrix H' in the definition of the Kalman filter involves the data, but no unknown parameters.

The α_i's are the intercept terms of the share equations and are almost all statistically significant. The share elasticities are well estimated with small standard errors in a majority of cases. For example, in the first industry, Agriculture, of the six β_{ik}'s four are significantly different from zero. For Electric Utilities, five of the six share elasticities are statistically significant. On the other hand, Lumber and Wood has only one significant substitution coefficient.

To illustrate the quality of the fit, we have plotted the actual and fitted value shares for capital and energy inputs for Petroleum Refining (industry 16) and Electric Utilities (30) in Appendix Figures E.1 and E2. The actual and fitted shares for all industries are given in a more condensed format in Figure E3 for energy input, and in Figure E4 for non-energy materials. The fitted shares track the actual data, even when these data change substantially over this period, certainly for Electric Utilities. For Petroleum Refining the errors are slightly larger during the oil shocks and in the most recent period. The fitted values are similar to the actual data in Figures E3 and E4 for almost all industries with the largest errors in Primary Metals and Services. This goodness of fit is to be expected, given the substantial number of parameters for the sample period of 1960-2005.

Bias in technical change

Estimates of the parameters of the state equation (3.22) for each of the 35 sectors in Table E1 are the coefficients of the stationary VAR (3.7), used to represent the evolution of technology during the sample period 1960-2005. We use this VAR to extrapolate the rate and biases of technical change in the state-space specification of producer behavior (3.6) into the future. In Figure 3.1 we present the latent variables (f_{Kt} , f_{Lt} , f_{Et}) representing the state of technology at each point of time for one industry, Petroleum Refining, to illustrate the results. These are plotted for the sample period 1960-2005 with projections for 2006-2025. First note that the absolute level of each line is unimportant, since the average level of each share is determined by the α coefficient. We are mainly interested in changes in the latent variable over time.

The latent variable for energy input rises during the 1970s oil shocks, reflecting a rise in the energy share that cannot be explained by the rise in oil and other energy prices alone. This latent variable is stable in the 1990s and then rises again after 2000. The latent variable for the capital share is very volatile, compared to the latent variable for labor share, but the projections do not diverge. In Figure 3.2 we plot the f_{Et} latent term for all five energy industries to show the energy-saving bias of technical change.

Coal mining is not an energy-intensive industry and the latent variable for energy does not show as much volatility as for the other industries. This variable is generally falling since the mid-1980s, so that technical change is energy-saving. In the Petroleum and Gas Mining industry, the latent variable for energy input falls fall sharply after 2000 with the sharp rise in oil mining profits. In Electric Utilities the steady fall since the early 1980s reflects energy-saving technical change or changes in the share of energy input that cannot be explained by price movements. A large energy-using change characterizes Gas Utilities between the late 1960s and early 1980s.

To summarize the bias in technical change for all 35 industries, we calculate the change in the latent variables f_{Kt}, f_{Lt}, f_{Et} and f_{Mt} between 1960 and 2005 in Table 3.5. A positive value in the f_{Kt} column, for example, indicates a capital-using bias over this period. Most industries, 29 out of 35, have a capital-using bias in this period, that is, an increase in the use of capital beyond that explained by the fall in the cost of capital. This includes all five industries in the energy group. Two-thirds of the industries had labor-saving technical change, the major exception being the labor-intensive Services and Construction industries.

Eleven of the 35 industries have energy-saving technical change, while 20 industries have material-saving bias. The major energy-intensive industries – Paper, Chemical Products, Electric Utilities and Gas Utilities – have energy-saving technical change, while Petroleum Refining, Stone, Clay and Glass, Primary Metals, and Transportation have energy-using change. These biases of technical change are small in most cases, but there are large changes in Petroleum and Gas Mining, Chemical Products, Petroleum Refining, and Government Enterprises. In the energy group Electric Utilities have labor- and energy-saving technical change, while Petroleum Refining has labor- and material-saving change. Technical change in Gas Utilities is energy-saving, and capital-, labor- and material-using, while change in Coal Mining is capital-using and in Petroleum and Gas Mining is energy-saving.

The total change for 1960-2005 reported in Table 3.5 hides many changes in behavior over this period, as shown in the plots in Figures 3.1-3.2 and Figures E3-E4 in Appendix E, giving trends for all industries. While the bias of technical change is energy-using for 24 industries over the whole period, these industries are mostly energy-using from 1960-1980 and energy-saving from 1980-2000. The turning point is the Second Oil Crisis when energy prices reached postwar peaks in real terms. There is also a noticeable energy-using trend in many industries in the mid-2000s. Similarly, while the capital bias fluctuates, there is a widespread capital-using technical change during the second half of the 1990s, the period of the information technology boom.

The rate of technical change

In the price function (3.6) the latent variable f_t represents the level of technology. A fall in f_t indicates a lower output price for given input prices and an improvement in technology, while a rise in this latent variable indicates a reversion in technology. The change in the level of technology is given for the 35 industries in Table 3.6. This is calculated for the entire 1960-2005 period, the most recent decade 1995-05, and the first twenty years of the projection period 2005-2025. While the majority of industries had falling prices and improving technology, there are nine industries with negative productivity growth over the 1960-2005 period. These poor performers include three energy industries – Petroleum and Gas Mining, Petroleum Refining, and Gas Utilities – and the large labor-intensive industries, Construction and Services. These estimates are consistent with the growth accounting results in Table 3.3.

In Figure 3.3 we plot representative trends in the latent technology variable f_t to illustrate the historical patterns. Some industries have persistent trends, either rising or declining. In Figure 3.3, the rapidly falling trend shows an accelerating rate of productivity growth in Electrical Machinery. Agriculture also shows steady, if not continuous, productivity growth. Services, on the other hand, have a continuously rising latent technology variable f_t, indicating rising costs or falling productivity. For other industries the level of technology rises and falls during different periods. In Figure 3.3 the latent variable for Coal Mining shows rising prices in the 1970s, followed by a long period of positive productivity growth.

Table 3.3 shows rapid productivity growth for Industrial Machinery and Electrical Machinery, which produce computers and semi-conductors; estimates for the price functions confirm this. The latent technology variable f_t for Electrical Machinery falls by 3.75% per year during 1960-2005, while this variable falls by 2.61% for Industrial Machinery. The rate of decline is accelerating for both industries after 1995, as shown in Figure 3.3. The industry with the next largest decline is Textile Mill Products at 1.49% per year, followed by Agriculture. In the most recent period 1995-2005 the industries with the most rapid productivity growth are, in order, Electrical Machinery, Industrial Machinery, Coal Mining, Textiles, and Apparel. At the other end of the performance spectrum Tobacco has the largest fall in productivity at 1.63% per year during 1960-2005. The next poorest performers were Petroleum and Gas Mining and Gas Utilities where productivity falls at 0.8% per year.

3.2.4 Projecting technology trends

We employ the vector auto-regression (3.21) to project the latent variables for IGEM beyond 2005. In the long run the latent variables representing biases of technical change f_{it} converge to constant levels with neither input-using nor input-saving technical change. However, the biases may be positive or negative during the projection period. The VAR (3.21) is not a simple extrapolation of the sample period trends. For example, the widespread trend towards higher capital use after 1995 does not continue unabated. In general, the stationarity requirement implies that there is a reversion to sample averages. The projected values are plotted for 2005-2025 in Figures 3.1-3.2 and the projected bias terms are given in Table 3.7.

From Table 3.5 we see that most industries have capital-using technical change during the sample period. However, the projected trends have capital-using change for only nine industries, including Tobacco and Other Transportation Equipment. Industries with projections of a capital-saving bias include Petroleum and Gas Mining, Electric Utilities, and Gas Utilities. Similarly, the labor-saving bias of technical change of the sample period is reversed and only 12 of the 35 industries are projected to continue to labor-saving technical change over the period 2005-2025. Industries with large employment are projected to have labor-using technical change, including Services, Trade, and Construction.

We give the projected change over the next twenty years in Table 3.7 to summarize the trends. The changes in the bias of technical change are not always in the same direction. In Petroleum and Gas Mining, technical change is energy-using between 2005 and 2018, and then energy-saving beyond that. Electric Utilities continue the sample period trend of energy-saving change for another five years and then turn energy-using. Note that these changes are eventually required to taper off. Even in the near term of the next 20 years, the biases of technical change for the most industries reflect the small changes in the sample period. Only in Tobacco, Instruments, Gas Utilities and Government Enterprises do we notice substantial changes.

The levels of technology f_t converge to linear trends, both rising and falling, as shown in Figures 3.3 and 3.4 (recall that f_t is the change in output price, so a rising trend indicates falling total factor productivity). The projected change in negative f_t for 2006-2025 is given in the last column of Table 3.6. Electrical Machinery has the largest projected increase in technology, extrapolating the trends established during the sample period; the change in productivity is an astounding 5.2% per year averaged over the next 20 years. Industrial Machinery is next with 3.4%, followed by Agriculture with 3.2%. Twenty-two of the 35 industries have positive projected productivity growth. For the energy group, the outlook is poor; Coal Mining is projected to have productivity falling at 1.9% per year, Petroleum Refining falls at 0.5%, while Electric Utilities is the only one with positive projected productivity growth at 1.3% per year.

3.2.5 Conclusions on modeling production

A unique feature of IGEM is that the parameters of the model are estimated econometrically from historical data spanning the past half century. Future productivity growth is a key element of any long-run economic projection, so that we have focused on the rate of technical change. The diffusion of new technologies often takes place through investments in capital equipment that embody these technologies. These investments are endogenous to the model and are determined through the balance between supply and demand for saving and investment. Other new technologies spread through investments in human capital, accounted for in IGEM in the projections of future labor quality.

3.3 Implementing production functions; sub-tiers

The lower tiers of the industry production model allocate the energy and non-energy materials aggregates among the individual commodities. This is described in (1.9) in Chapter 1, Section 1.1.3. The commodities are the primary products of the 35 sectors, plus noncompetitive imports. Given the long list of commodities, the demands are derived by means of a hierarchical tier structure of price functions. The tier structure is given in Table 1.2. There is a total of 13 nodes, ranging from the top tier – capital, labor, energy, and non-energy materials, the second tier, for example, the energy node with coal, oil and gas, refining, electricity, gas utilities, and so on, down to the 13th tier – motor vehicles, other transportation, and instruments.

As an example, the value of energy input is the sum of the values of five components – coal mining, petroleum and gas mining, petroleum refining, electric utilities, and gas utilities. Denoting the energy industries by I_E={3,4,16,30,31}, the value of energy input is the product of price and quantity for each industry *j*:

$$(3.32) \quad P_{Ejt}E_{jt} = PS_{3t}QP^j_{3t} + PS_{4t}QP^j_{4t} + PS_{16t}QP^j_{16t} + PS_{30t}QP^j_{30t} + PS_{31t}QP^j_{31t}$$

and the price function is (3.10):

(3.33) $\ln P_{Et} = \alpha_0 + \sum_{i \in I_E} \alpha_i^E \ln P_{it}^{P,E} + \frac{1}{2} \sum_{i,k} \beta_{ik}^E \ln P_{it}^{P,E} \ln P_{kt}^{P,E} + \sum_{i \in I_E} f_{it}^E \ln P_{it}^{P,E}$

where the prices $P_i^{P,E} \in \{PS_3, PS_4, PS_{16}, PS_{30}, PS_{31}\}$ and the j superscripts have been dropped.

The input share equations are derived by differentiating the price function (1.11) with respect to the logarithms of prices. In matrix notation the vector of input shares is written as:

(3.34) $v_t^E = \begin{bmatrix} PS_3 QP_3 / P_E E \\ \cdots \\ PS_{31} QP_{31} / P_E E \end{bmatrix} = \alpha^E + B^E \ln P^{P,E} + f_t^E$

A system of equations similar to (3.32-3.34) applies to each node of our hierarchical tier structure of price functions for each industry. The functional form for these price functions is similar to the top tier, except that there is no latent variable for the level of technology. The aggregates for each at each price function, including the energy aggregate E_{jt}, were constructed from the component prices and quantities as in (3.3). For the top tier the industry output price is measured independently of the input prices. The rate of productivity growth is defined as the difference between a weighted average of the growth rates of input prices and the growth rate of the output price. The energy price and quantity, P_{Ejt} and E_{jt}, are aggregates of the components, so that there is no growth in productivity.

The latent variables describing biases of technical change are a novel feature of IGEM. In the historical data we observe changes in the composition of inputs that cannot be explained by price changes. For example, the use of electricity may be rising even though the price of electricity relative to coal prices is rising. The latent variables representing biases of technical change are assumed to follow a first-order VAR for each *node* and each industry j:

(3.35) $\tilde{\xi}_t^{node,j} = F^{node,j} \tilde{\xi}_{t-1}^{node,j} + \varepsilon_t^{node,j}$ $\quad$ $node$=2,…13; j=1,…35

$\tilde{\xi}_t^{node} \equiv (f_{1t}^{node}, ..., f_{nt}^{node})'$

Our econometric method for estimating the input shares (3.34) is identical to that discussed in Section 3.2.2 for the top tier. Homogeneity, symmetry, and concavity restrictions are imposed in a similar way:

(3.36) $\sum_i \alpha_i^E = 1 \qquad \sum_i \beta_{ik}^E = 0$ for each k;

$\beta_{ik}^E = \beta_{ki}^E$;

$$L_t D_t L_t' = \mathbf{B} + \mathbf{v}_t \mathbf{v}_t' - \mathbf{V}_t; \qquad D_{ii,t} < 0$$

As a consequence of these restrictions we estimate only four of the five equations for the input shares in the energy node, and use four relative prices, as in (3.19) for the top tier.

We apply the two-step Kalman filter given in (3.22) and (3.23). For the energy node where we estimate (3.34) with four share equations and the VAR (3.35), this is implemented by making the following assignments:

$$(3.37) \quad y_t = \begin{bmatrix} v_{3t}^E \\ \vdots \\ v_{30t}^E \end{bmatrix}; \quad x_t = \begin{bmatrix} 1 \\ \ln \dfrac{PS_{3t}}{PS_{31t}} \\ \vdots \\ \ln \dfrac{PS_{30t}}{PS_{31t}} \end{bmatrix}; \quad \xi_t = \begin{bmatrix} 1 \\ f_{3t}^E \\ \vdots \\ f_{30t}^E \end{bmatrix}; \quad w_t = \begin{bmatrix} \varepsilon_{3t}^{Ev} \\ \vdots \\ \varepsilon_{30t}^{Ev} \end{bmatrix}; \quad \varepsilon_t = \begin{bmatrix} 0 \\ \varepsilon_{3t}^E \\ \varepsilon_{7t}^E \end{bmatrix}$$

Without the latent variable representing the level of technology the system of equations is simpler than for the top tier in (3.27). The instrumental variables used to deal with the endogeneity of the prices are the same as those used in the top tier.

At some nodes some inputs are zero and this occurs for many industries. For example, the output of Metal Mining is used by only a few industries. For other industries the parameters for Metal Mining are set equal to zero. Where the inputs are very small estimation becomes difficult and we set the relevant β_{ik}'s to zero, imposing a Cobb-Douglas functional form. Ignoring the parameters of the state equation, there are 13 nodes in the sub-tiers, as shown in Table 1.2, yielding a total of 164 parameters, of which 106 are independent after imposing the constraints in (3.36). There is a total 3710 parameters (106x35 industries) to be estimated for the sub-tiers.

It is difficult to summarize the large number of parameters and latent variables representing biases of technical change succinctly, so that we consider only a few of the most important features. To give a sense of the estimates and the issues involved we focus on the Electric Utilities industry. In Table 3.8 we report the estimated coefficients for all 13 sub-tiers of this industry. The structure of this table and abbreviations follow that in Table 1.2. We first note the wide range of estimates for the share elasticities among the intermediate inputs. The most elastic own price term is in the Textile-Apparel node with a coefficient of -0.397, and the most inelastic own price term is in Machinery Materials with a coefficient of 0.225. This implies that the Leontief framework, imposing fixed input-output coefficients, is far too inflexible and imposes an artificially high welfare cost for policy changes. Another set of estimates for the Agriculture industry is given in Appendix E, Table E2. This also show a similar range of substitution elasticities.

To visualize the role played by the latent variables f_{it}^{node} in tracking changes in demands not due to price effects, the last column in Table 3.8 gives the change in these terms between 1960 and 2005. The value shares in (3.34) are additive in the latent variables f_{it}^{node}. The contribution of the bias of technical change is sizable in most cases. In the particular example of the Electric Utilities industry in Table 3.8, the node for Service Materials (MS) has five inputs – transportation, trade, FIRE, services and Other Services (OS). The shares of these five inputs in 1996 were 23%, 13%, 22%, 37% and 45% respectively. The latent variable f_{it}^{NI} for transportation fell by 0.274 over this period, while FIRE rose by 0.052 and Services rose by 0.244. Intermediate input demand has shifted towards financial and other services at the expense of transportation, communications and government enterprises; this resulted in a 27 percentage point fall in the share of transportation between 1960 and 2005. As another example, Other Services (OS) is made up of three inputs – communications, government enterprises and non-competitive imports. The latent variable f_{it}^{OS} for communications fell by 0.07 during 1960-2005, a seven percentage point fall in the value share, which stood at 60% in 1996.

The latent variables are projected for the simulation period, using the VAR (3.35). To illustrate the projection Figure 3.5 plots the latent variables f_{it}^{MS} for Transportation and Services in the Services Materials node (MS) for the Electric Utilities industry. The plots cover the estimated values during the sample period 1960-2005 and the projected values for 2006-2035. The 27 percentage point fall in the bias term for Transportation is a steady decline through the late 1990s, followed by stable share. The trend for Services is almost the exact opposite, rising substantially in the 1960-1998 period. The other inputs in this node – Trade, FIRE and Other Services – have small changes and are not plotted in Figure 3.5. The complete set of projections of the latent terms in the sub-tiers is given in Appendix E, Table E.3. Recall that the latent variables for the bias terms converge to a constant.

In concluding this sub-section we emphasize the key points. The state-space model of producer behavior is required to capture the changes in patterns of production revealed in the data presented in Section 3.1. Overly simplified formulations like the fixed coefficients of the

Leontief framework would misestimate the cost of policy changes, generating costs that are far too high. Data on the historical time path of production patterns requires latent variables representing biases of technical change to track the changes in inputs that are not explained by price changes. Finally, a latent variable representing the level of technology is needed to capture differences in productivity growth rates across industries and over time.

3.4 Import and total supply functions

In section 1.5 we describe how the total supply of a commodity is an aggregate of the domestic and imported varieties. The total supply and the corresponding demands for domestic and imported goods are modeled like the lower tiers in the production function. There is no independent observation on the total supply price PS_i, since only the domestic and imported prices are observed and these are used to construct the aggregate supply price and quantity as index number. In the same way as the lower tier price functions (1.99) express the aggregate price as a translog function of the price of domestic variety, PC_i, and the price of imports, PM_i in a *state-space* specification. The equation is repeated here:

$$\text{(3.38)} \quad \begin{aligned} \ln PS_{it} &= \alpha_c^{Mi} \ln PC_{it} + \alpha_m^{Mi} \ln PM_{it} + \tfrac{1}{2}(\beta_{cc}^{Mi} \ln^2 PC_{it} + 2\beta_{cm}^{Mi} \ln PC_{it} \ln PM_{it} + \beta_{mm}^{Mi} \ln^2 PM_{it}) \\ &\quad + f_{ct}^{Mi} \ln PC_{it} + f_{mt}^{Mi} \ln PM_{it} \end{aligned}$$

$$\text{(3.39)} \quad f_{mt}^{Mi} = F^{Mi} f_{m,t-1}^{Mi} + \varepsilon_t^i$$

As in the lower tiers of the price functions there is no latent variable for the level of technology and no growth in productivity. The latent variables for the biases of technical change are assumed to follow a first-order VAR, as shown in (3.39). Note that the import price is the U.S. border price in dollars, inclusive of tariffs, just as the domestic price is the producers' price, including sales taxes, but excluding transport and trade margins. The value of total supply is the sum of the domestic and imported commodity values:

$$\text{(3.40)} \quad PS_{it} QS_{it} = PC_{it} QC_{it} + PM_{it} M_{it}$$

The two equations given above generate the total supply QS_i of the commodity.

The share equation for import demand is derived by differentiating the price function:

$$\text{(3.41)} \quad v_{mt}^i = \frac{PM_{it} M_{it}}{PS_{it} QS_{it}} = \alpha_m^{Mi} + \beta_{mm}^{Mi} \ln \frac{PM_{it}}{PS_{it}} + f_{mt}^{Mi}$$

This functional form allows us to track historical changes in imports that cannot be explained by changes in prices. This is important because of the rapid rise in the import share for practically all commodities during the period 1960-2005, a change that occurred for a wide variety of movements in import prices. Models that specify import demands as functions of prices and income yield implausible elasticities.

The share equation (3.41) and VAR (3.39) are estimated for all commodities; however, there are seven commodities with zero imports, so that we estimate only 28 equations. The import shares for 2000 are given in the first column of Table 3.9. The commodity with the largest import share is Leather Products, where imports exceed domestic output. Next is Apparel with 54% and Miscellaneous Manufacturing with 51%. The energy commodities have very high shares too. Petroleum and Gas Mining had a 43% import share and Petroleum Refining had 24%.

The estimated parameters α_m^M and β_{mm}^M are given in the next two columns of Table 3.9. The estimated share elasticities β_{mm}^M's are quite elastic; many are negative, so that the substitution elasticity between imported and domestic goods is greater than unity. The share elasticities for Petroleum Refining and Petroleum and Gas Mining are somewhat inelastic. The reason for this is that petroleum is not a homogenous commodity, say crude oil of a particular grade, but an aggregate of many commodities that have their own price behavior. This leads to estimated elasticities that are much smaller than expected.

To demonstrate the importance of the latent variable representing the bias of technical change f_{mt}^M, we also report the bias in the last column. The rise in the latent variable indicates a rise in the share that cannot be explained by the price term. In the manufacturing industries we see very large increase in import penetration. The largest changes are in Leather Products (0.63), Apparel (0.46), and Miscellaneous Manufacturing (0.44). The energy-intensive industries also see large increases in import shares – Primary Metals (0.28), Stone-Clay-Glass (0.15), and Chemicals (0.13). In the energy group, the large increase in oil imports generated a 0.43 unit change in the latent variable for Petroleum and Gas Mining, and a 0.13 change for Petroleum Refining.

To illustrate the role of the latent variable f_{mt}^M, Figure 3.6 plots this variable for Motor Vehicles for the sample period 1960-2004 and for the projection period 2004-2030. We see a steady rise in the latent variable from the mid-1970s to the mid-1980s, tracking the rise in value shares, followed by a stable period during the 1990s and an increase in the 2000s. The projection of f_{mt}^{M} using (3.38) shows a small rise in the import share going forward. As we noted for the the sub-tiers in section 3.3, these terms converge to a constant.

We conclude this sub-section with noting that the comments for the production sub-tiers apply here as well. The latent variables are necessary to track the historical evolution of U.S. imports. Simpler formulations may be adequate for simulating policy change in a single period. but will be unable to capture historical trends.

Table 3.1 Industry characteristics 2005

		Output ($mil)	Int. input ($mil)	Value added ($mil)	Capital input ($mil)	Workers (mil)
1	Agriculture	424010	240366	183644	103928	3427
2	Metal Mining	25023	15702	9321	6748	32
3	Coal Mining	25507	11180	14327	9764	80
4	Petroleum and Gas	259579	76429	183150	150555	369
5	Nonmetallic Mining	23515	10379	13135	8849	108
6	Construction	1355663	772639	583024	146613	9107
7	Food Products	595414	400716	194698	85394	1635
8	Tobacco Products	30995	22508	8487	4612	31
9	Textile Mill Products	60180	38438	21741	8152	348
10	Apparel and Textiles	35993	20950	15043	1918	364
11	Lumber and Wood	129542	81356	48186	16352	840
12	Furniture and Fixtures	101267	55835	45432	9155	479
13	Paper Products	168010	95537	72473	26854	526
14	Printing and Publishing	229739	87465	142274	51835	1342
15	Chemical Products	521438	288887	232551	141413	940
16	Petroleum Refining	418828	281766	137062	109542	115
17	Rubber and Plastic	187904	103277	84627	24591	858
18	Leather Products	6347	4026	2322	564	42
19	Stone, Clay, and Glass	129354	66340	63015	23549	543
20	Primary Metals	251132	174115	77017	43371	527
21	Fabricated Metals	296458	167543	128915	48235	1353
22	Industrial Machinery and Equip	424034	239807	184227	45841	1561
23	Electronic & Electric Equip	330537	176514	154024	54123	1227
24	Motor Vehicles	442156	355975	86181	26820	856
25	Other Transportation Equip	227460	115185	112275	19787	759
26	Instruments	207399	87887	119511	22883	776
27	Miscellaneous Manufacturing	60531	34852	25679	11470	402
28	Transport and Warehouse	667845	355519	312326	116000	4870
29	Communications	527862	235594	292268	180655	1412
30	Electric Utilities	372987	130236	242751	174264	823
31	Gas Utilities	77393	54422	22971	15597	111
32	Trade	2487860	975584	1512276	468047	32634
33	FIRE	2752265	961589	1790676	1183313	8873
34	Services	4353650	1556446	2797203	551327	49644
35	Goverment Enterprises	327507	111594	215913	98254	1789
36	Private Households	1911067	0	1911067	1911067	0
38	General Government	1572675	0	1572675	364631	22262

Table 3.2: Industry Output, Intermediate Input, and Value-Added Growth, 1960-2005

		Output	Intermediate Input	Value Added
1	Agriculture	2.00	1.30	3.16
2	Metal Mining	0.67	2.17	-1.32
3	Coal Mining	2.21	2.65	2.37
4	Petroleum and Gas	0.40	0.08	0.94
5	Nonmetallic Mining	1.56	1.69	1.48
6	Construction	1.60	2.82	0.08
7	Food Products	2.01	1.56	3.25
8	Tobacco Products	-0.83	0.68	-2.53
9	Textile Mill Products	1.17	-0.12	3.75
10	Apparel and Textiles	-0.28	-0.98	0.79
11	Lumber and Wood	2.03	2.22	1.82
12	Furniture and Fixtures	3.27	3.11	3.47
13	Paper Products	2.04	1.72	2.48
14	Printing and Publishing	1.83	1.77	1.83
15	Chemical Products	2.81	2.55	3.16
16	Petroleum Refining	1.63	1.65	4.56
17	Rubber and Plastic	4.21	3.42	5.24
18	Leather Products	-2.36	-2.29	-2.48
19	Stone, Clay, and Glass	1.90	1.76	2.05
20	Primary Metals	0.84	0.94	0.66
21	Fabricated Metals	1.94	1.97	1.89
22	Industrial Machinery	5.92	4.32	7.97
23	Electronic and Electric Equip	6.50	3.61	9.79
24	Motor Vehicles	3.22	3.36	2.83
25	Other Transportation Equip	1.91	2.27	1.54
26	Instruments	4.32	4.10	4.52
27	Miscellaneous Mfg	2.18	1.83	2.61
28	Transport and Warehouse	3.01	2.79	3.23
29	Communications	5.65	5.36	5.93
30	Electric Utilities	2.94	2.58	3.12
31	Gas Utilities	-0.45	0.13	-4.38
32	Trade	3.72	3.36	3.98
33	FIRE	4.19	4.41	4.08
34	Services	3.93	4.42	3.61
35	Goverment Enterprises	2.43	2.83	2.25
	Private Households	4.09	0.00	4.09
	General Government	1.98	0.00	1.98
	Average	2.33	2.06	2.54

Notes: All figures are average annual growth rates.

Table 3.3: Sources of Growth of Industry Output, 1960-2005

		Input Contributions			Total
	Output	Capital	Labor	Interme-diate	Factor Prdtvty
Agriculture	2.00	0.18	-0.34	0.76	1.40
Metal Mining	0.67	0.48	-0.60	1.40	-0.60
Coal Mining	2.21	0.64	-0.35	0.75	1.17
Petroleum and Gas	0.40	1.05	0.04	-0.11	-0.58
Nonmetallic Mining	1.56	0.82	-0.20	0.67	0.27
Construction	1.60	0.19	0.46	1.55	-0.61
Food Products	2.01	0.19	0.14	1.17	0.52
Tobacco Products	-0.83	0.55	-0.08	0.22	-1.52
Textile Mill Products	1.17	0.09	-0.43	-0.04	1.56
Apparel and Textiles	-0.28	0.17	-0.84	-0.59	0.97
Lumber and Wood	2.03	0.26	0.24	1.38	0.15
Furniture and Fixtures	3.27	0.26	0.63	1.69	0.69
Paper Products	2.04	0.37	0.14	1.06	0.47
Printing and Publishing	1.83	0.63	0.53	0.83	-0.15
Chemical Products	2.81	0.68	0.11	1.46	0.55
Petroleum Refining	1.63	0.15	0.09	1.31	0.08
Rubber and Plastic	4.21	0.45	0.93	1.97	0.87
Leather Products	-2.36	0.00	-1.24	-1.44	0.33
Stone, Clay, and Glass	1.90	0.32	0.15	0.89	0.54
Primary Metals	0.84	0.07	-0.15	0.60	0.32
Fabricated Metals	1.94	0.30	0.06	1.08	0.51
Industrial Machinery	5.92	0.61	0.33	2.34	2.65
Electronic and Electric Equip	6.50	0.76	0.01	1.92	3.81
Motor Vehicles	3.22	0.24	0.13	2.57	0.27
Other Transportation Equip	1.91	0.19	0.25	1.18	0.28
Instruments	4.32	0.53	0.90	1.79	1.10
Miscellaneous Mfg	2.18	0.33	-0.04	1.00	0.88
Transport and Warehouse	3.01	0.36	0.41	1.26	0.99
Communications	5.65	1.88	0.38	2.23	1.16
Electric Utilities	2.94	1.24	0.30	1.10	0.30
Gas Utilities	-0.45	0.43	0.01	-0.03	-0.86
Trade	3.72	0.89	0.73	1.27	0.84
FIRE	4.19	1.42	0.50	1.51	0.77
Services	3.93	0.77	1.69	1.74	-0.27
Goverment Enterprises	2.43	1.02	0.32	0.90	0.19
Private Households	4.09	4.09	0.00	0.00	0.00
General Government	1.98	0.76	1.23	0.00	0.00

Notes: Output and total factor productivity are average annual growth rates. Capital, labor, and intermediate inputs are average annual contributions (share-weighted growth rates).

Table 3.4: Growth of Industry Total Factor Productivity by Subperiod

	1960-2005	1960-1973	1973-1995	1995-2005
Agriculture	1.40	0.03	2.04	1.79
Metal Mining	-0.60	-1.40	0.74	-2.51
Coal Mining	1.17	0.41	0.99	2.58
Petroleum and Gas	-0.58	0.97	-1.49	-0.62
Nonmetallic Mining	0.27	1.26	-0.63	0.96
Construction	-0.61	-0.36	-0.62	-0.90
Food Products	0.52	0.53	0.59	0.37
Tobacco Products	-1.52	0.61	-1.94	-3.36
Textile Mill Products	1.56	1.09	1.55	2.18
Apparel and Textiles	0.97	1.03	0.66	1.58
Lumber and Wood	0.15	0.01	0.09	0.46
Furniture and Fixtures	0.69	0.99	0.17	1.44
Paper Products	0.47	1.12	-0.36	1.45
Printing and Publishing	-0.15	0.54	-1.08	0.97
Chemical Products	0.55	1.93	-0.28	0.55
Petroleum Refining	0.08	0.36	0.79	-1.87
Rubber and Plastic	0.87	1.47	0.39	1.14
Leather Products	0.33	0.17	0.34	0.50
Stone, Clay, and Glass	0.54	1.09	0.16	0.68
Primary Metals	0.32	0.46	-0.21	1.31
Fabricated Metals	0.51	1.06	0.23	0.41
Industrial Machinery and Equipmen	2.65	1.29	2.39	4.98
Electronic and Electric Equipment	3.81	2.62	3.62	5.77
Motor Vehicles	0.27	0.62	-0.15	0.76
Other Transportation Equipment	0.28	0.95	-0.12	0.31
Instruments	1.10	1.70	0.56	1.51
Miscellaneous Manufacturing	0.88	1.35	0.34	1.47
Transport and Warehouse	0.99	1.57	0.56	1.17
Communications	1.16	1.27	1.11	1.12
Electric Utilities	0.30	1.54	-0.48	0.40
Gas Utilities	-0.86	0.67	-1.77	-0.85
Trade	0.84	0.84	0.60	1.36
FIRE	0.77	0.48	0.88	0.90
Services	-0.27	0.23	-0.72	0.05
Goverment Enterprises	0.19	-0.42	0.84	-0.43
Private Households	0.00	0.00	0.00	0.00
General Government	0.00	0.00	0.00	0.00

Notes: All figures are average annual growth rates.

Table 3.5 Changes in the bias of technical change latent variable.

		1960-2005			
		Δf_{Kt}	Δf_{Lt}	Δf_{Et}	Δf_{Mt}
1	Agriculture	0.0436	-0.0109	0.0619	-0.0946
2	Metal Mining	0.0250	0.0679	-0.0004	-0.0925
3	Coal Mining	0.2147	-0.0500	-0.1019	-0.0627
4	Petroleum and Gas	0.1390	0.0167	-0.2380	0.0823
5	Nonmetallic Mining	0.0046	0.0279	0.0588	-0.0913
6	Construction	0.0309	0.0151	0.0155	-0.0614
7	Food Products	0.0655	0.0524	-0.0012	-0.1166
8	Tobacco Products	0.0434	0.0304	-0.0003	-0.0735
9	Textile Mill Products	0.0007	0.0041	0.0175	-0.0223
10	Apparel and Textiles	0.0545	-0.0493	-0.0009	-0.0043
11	Lumber and Wood	0.0444	-0.0509	0.0145	-0.0081
12	Furniture and Fixtures	0.0252	-0.0384	0.0044	0.0089
13	Paper Products	0.0176	0.0125	-0.0054	-0.0247
14	Printing and Publishing	0.0370	-0.0119	0.0020	-0.0271
15	Chemical Products	0.1094	0.1155	-0.0232	-0.2018
16	Petroleum Refining	0.1058	-0.0453	0.0695	-0.1300
17	Rubber and Plastic	0.0365	0.0181	0.0012	-0.0557
18	Leather Products	0.0790	-0.0291	0.0132	-0.0631
19	Stone, Clay, and Glass	0.0580	-0.0731	0.0097	0.0054
20	Primary Metals	0.0325	-0.0369	0.0262	-0.0217
21	Fabricated Metals	0.0874	-0.1150	0.0054	0.0223
22	Industrial Machinery	-0.0038	-0.0034	0.0031	0.0041
23	Electronic & Electric Equip	0.0849	-0.0897	0.0023	0.0025
24	Motor Vehicles	-0.0317	0.0151	0.0022	0.0145
25	Other Transportation Equip	0.0008	-0.0001	0.0008	-0.0015
26	Instruments	0.0426	-0.1127	0.0033	0.0667
27	Miscellaneous Mfg	0.0635	-0.1275	0.0021	0.0619
28	Transport and Warehouse	0.0458	-0.0903	0.0372	0.0073
29	Communications	-0.0436	0.0005	0.0018	0.0413
30	Electric Utilities	0.0567	-0.0096	-0.0716	0.0245
31	Gas Utilities	0.0161	0.0180	-0.0467	0.0125
32	Trade	-0.0057	-0.0471	-0.0096	0.0625
33	FIRE	-0.0272	-0.0006	0.0041	0.0237
34	Services	-0.0063	0.0040	0.0034	-0.0011
35	Goverment Enterprises	0.1797	-0.0316	0.0376	-0.1857

Table 3.6 Changes in the level of technology, sample period and projections
(negative of change in *f(t)*)

		-Δft per year		
		1960-2005	1995-2005	2005-2025
1	Agriculture	0.0129	0.0155	0.0316
2	Metal Mining	-0.0059	-0.0264	-0.0055
3	Coal Mining	0.0115	0.0280	-0.0192
4	Petroleum and Gas	-0.0079	-0.0049	-0.1203
5	Nonmetallic Mining	-0.0026	-0.0065	-0.0027
6	Construction	-0.0066	-0.0108	-0.0048
7	Food Products	0.0051	0.0054	0.0035
8	Tobacco Products	-0.0163	-0.0336	-0.0167
9	Textile Mill Products	0.0149	0.0187	0.0154
10	Apparel and Textiles	0.0102	0.0167	0.0095
11	Lumber and Wood	0.0013	0.0057	0.0010
12	Furniture and Fixtures	0.0059	0.0101	0.0063
13	Paper Products	0.0043	0.0125	0.0038
14	Printing and Publishing	-0.0025	0.0033	-0.0046
15	Chemical Products	0.0043	0.0047	-0.0147
16	Petroleum Refining	-0.0024	-0.0341	-0.0053
17	Rubber and Plastic	0.0082	0.0089	0.0074
18	Leather Products	0.0034	0.0035	0.0015
19	Stone, Clay, and Glass	0.0045	0.0055	0.0118
20	Primary Metals	0.0024	0.0103	0.0078
21	Fabricated Metals	0.0048	0.0040	0.0052
22	Industrial Machinery	0.0261	0.0500	0.0338
23	Electronic & Electric Equip	0.0375	0.0591	0.0522
24	Motor Vehicles	0.0019	0.0092	0.0045
25	Other Transportation Equip	0.0022	0.0042	-0.0021
26	Instruments	0.0101	0.0132	0.0172
27	Miscellaneous Mfg	0.0088	0.0115	0.0151
28	Transport and Warehouse	0.0088	0.0087	0.0123
29	Communications	0.0099	0.0083	0.0121
30	Electric Utilities	0.0024	0.0055	0.0128
31	Gas Utilities	-0.0078	-0.0119	-0.0046
32	Trade	0.0072	0.0063	0.0066
33	FIRE	0.0076	0.0082	0.0066
34	Services	-0.0035	-0.0011	-0.0041
35	Goverment Enterprises	0.0007	0.0042	-0.0114

Table 3.7 Projected changes in the bias of technical change.

		2005-2025			
		Δf_{Kt}	Δf_{Lt}	Δf_{Et}	Δf_{Mt}
1	Agriculture	0.0097	0.0400	0.0096	-0.0593
2	Metal Mining	0.0096	0.0113	-0.0028	-0.0181
3	Coal Mining	-0.0243	0.0155	0.0307	-0.0220
4	Petroleum and Gas	-0.1198	-0.0213	0.1796	-0.0386
5	Nonmetallic Mining	-0.0071	0.0235	-0.0034	-0.0130
6	Construction	-0.0244	0.0221	-0.0084	0.0107
7	Food Products	-0.0016	0.0025	0.0005	-0.0014
8	Tobacco Products	0.0609	0.0435	0.0002	-0.1046
9	Textile Mill Products	-0.0229	0.0159	-0.0003	0.0073
10	Apparel and Textiles	-0.0048	-0.0064	0.0018	0.0094
11	Lumber and Wood	-0.0015	-0.0028	0.0017	0.0026
12	Furniture and Fixtures	-0.0052	0.0142	-0.0010	-0.0080
13	Paper Products	-0.0151	-0.0160	0.0089	0.0221
14	Printing and Publishing	-0.0550	0.0210	0.0004	0.0335
15	Chemical Products	0.0028	0.0072	-0.0031	-0.0069
16	Petroleum Refining	-0.0656	0.0258	-0.0027	0.0426
17	Rubber and Plastic	-0.0209	-0.0021	0.0015	0.0214
18	Leather Products	0.0183	-0.0346	-0.0002	0.0166
19	Stone, Clay, and Glass	-0.0260	0.0290	-0.0054	0.0025
20	Primary Metals	-0.0031	0.0107	0.0056	-0.0132
21	Fabricated Metals	-0.0070	0.0016	0.0027	0.0027
22	Industrial Machinery	0.0012	-0.0045	0.0006	0.0028
23	Electronic & Electric Equip	0.0017	-0.0019	0.0000	0.0001
24	Motor Vehicles	-0.0033	0.0031	0.0001	0.0002
25	Other Transportation Equip	0.0098	0.0141	0.0020	-0.0259
26	Instruments	-0.0275	0.0722	0.0035	-0.0482
27	Miscellaneous Mfg	0.0112	-0.0140	-0.0022	0.0050
28	Transport and Warehouse	-0.0231	0.0526	-0.0126	-0.0170
29	Communications	-0.0137	0.0049	-0.0004	0.0093
30	Electric Utilities	-0.0258	-0.0141	0.0295	0.0104
31	Gas Utilities	-0.0698	-0.0225	0.1388	-0.0465
32	Trade	-0.0042	0.0016	0.0013	0.0013
33	FIRE	-0.0022	-0.0052	-0.0001	0.0076
34	Services	-0.0175	0.0006	0.0021	0.0148
35	Goverment Enterprises	-0.0785	0.0441	-0.0152	0.0495

Table 3.8 Estimates of production functions in sub-tier structure of Electric Utilities

Node	Name	α_i	β_{ik}					Δf_{it} 1960-05
1 Q	Gross output							
2 E	Energy							
	coal	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	oil mining	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	refining	0.465	0.000	0.000	0.076	-0.076	0.000	-0.265
	electric utilities	0.535	0.000	0.000	-0.076	0.076	0.000	0.265
	gas utilities	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3 M	Materials							
	construction	-0.035	-0.041	0.000	0.065	0.000	-0.024	-0.095
	Agriculture Mat.	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Metallic Mat.	0.014	0.065	0.000	-0.017	0.000	-0.048	0.015
	Nonmetallic Mat.	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Services Mat.	1.021	-0.024	0.000	-0.048	0.000	0.072	0.079
4 MA	Agriculture Materials							
	agriculture	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	food	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	tobacco	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Textile-Apparel	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Wood-Paper	1.000	0.000	0.000	0.000	0.000	0.000	0.000
5 MM	Metallic Materials							
	FM	0.005	-0.043	0.015	0.028			-0.032
	MC	-0.289	0.015	0.082	-0.097			-0.003
	EQ	1.285	0.028	-0.097	0.069			0.035
6 MN	NonMetallic Materials							
	nonmetal mining	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	chemicals	-0.148	0.000	0.069	-0.011	-0.058	0.000	-0.029
	rubber-plastics	0.252	0.000	-0.011	-0.116	0.127	0.000	0.045
	stone-clay-glass	0.896	0.000	-0.058	0.127	-0.069	0.000	-0.016
	misc mfg	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7 MS	Services Materials							
	transportation	0.044	0.106	-0.047	-0.022	-0.028	-0.010	-0.274
	trade	0.017	-0.047	0.077	-0.024	0.003	-0.009	-0.009
	FIRE	0.137	-0.022	-0.024	0.008	0.090	-0.052	0.052
	services	0.866	-0.028	0.003	0.090	-0.111	0.046	0.244
	OS	-0.064	-0.010	-0.009	-0.052	0.046	0.024	-0.013

Table 3.8 (cont) Estimates of production functions in sub-tier structure of Electric Utilities

Node	Name	α_i	β_{ik}				Δf_{it} 1960-05
8 TA	Textile-Apparel						
	textiles	1.081	-0.397	0.397	0.000		0.137
	apparel	-0.081	0.397	-0.397	0.000		-0.137
	leather	0.000	0.000	0.000	0.000		0.000
9 WP	Wood-Paper						
	lumber wood	0.160	0.099	0.000	-0.055	-0.043	0.240
	furniture	0.000	0.000	0.000	0.000	0.000	0.000
	paper	-0.120	-0.055	0.000	0.061	-0.005	-0.065
	printing	0.961	-0.043	0.000	-0.005	0.049	-0.175
10 OS	Other Services						
	communications	0.851	-0.239	0.239	0.000		-0.074
	govt. enterp	0.149	0.239	-0.239	0.000		0.074
	non-comp. imports	0.000	0.000	0.000	0.000		0.000
11 FM	Fab-other Metals						
	metal mining	0.000	0.000	0.000	0.000		0.000
	primary metals	-0.068	0.000	0.183	-0.183		-0.048
	fabricated metals	1.068	0.000	-0.183	0.183		0.048
12 MC	Machinery Materials						
	industrial machinery	0.770	0.225	-0.225			-0.004
	electrical mach.	0.230	-0.225	0.225			0.004
13 EQ	Equipment						
	motor vehicles	-0.082	0.102	0.000	-0.102		0.194
	other transp equip	0.000	0.000	0.000	0.000		0.000
	instruments	1.082	-0.102	0.000	0.102		-0.194

Table 3.9 Estimates of import demand functions

		import share 2000 (%)	Estimated coefficients α	β	Estimated ft(2005)-ft(1960)
1	Agriculture	7.5	0.0040	0.0059	0.0761
2	Metal Mining	0.0	0.0993	0.0195	0.1264
3	Coal Mining	4.8	0.0115	0.0012	0.0379
4	Petroleum and Gas	75.3	0.0066	0.0150	0.4294
5	Nonmetallic Mining	14.4	0.0000		0.0000
6	Construction	0.0	0.0000		0.0000
7	Food Products	7.2	0.0000	-0.0208	0.0560
8	Tobacco Products	3.9	0.0292	0.0047	0.0610
9	Textile Mill Products	16.3	0.0314	-0.0983	0.1562
10	Apparel and Textiles	115.7	0.0005	0.0206	0.4567
11	Lumber and Wood	16.1	0.1313	0.0196	0.0700
12	Furniture and Fixtures	0.0	0.0547	0.0150	0.1914
13	Paper Products	12.3	0.0170	-0.0056	0.1299
14	Printing and Publishing	3.0	0.0020	-0.0068	0.0267
15	Chemical Products	19.3	0.0000	0.0169	0.1339
16	Petroleum Refining	31.9	0.0000	0.0185	0.1327
17	Rubber and Plastic	16.6	0.0234	-0.0305	0.1325
18	Leather Products	252.4	0.2999	0.0546	0.6280
19	Stone, Clay, and Glass	15.4	0.1440	0.0131	0.1498
20	Primary Metals	25.9	0.0068	-0.2053	0.2814
21	Fabricated Metals	10.3	0.1219	-0.1240	0.1094
22	Industrial Machinery	36.6	0.0180	-0.1226	0.1356
23	Electronic & Electric Equip	43.3	0.0000	0.0949	0.0627
24	Motor Vehicles	44.6	0.0000	0.0518	0.2367
25	Other Transportation Equip	19.3	0.1099	0.0091	0.1263
26	Instruments	27.3	0.1667	0.0070	0.1809
27	Miscellaneous Mfg	103.5	0.0000	0.0506	0.4401
28	Transport and Warehouse	-0.9	0.0018	-0.0009	0.0217
29	Communications	0.0	0.0000		0.0000
30	Electric Utilities	1.2	0.0020	-0.0244	0.0104
31	Gas Utilities	0.0	0.0000		0.0000
32	Trade	-1.8	0.0000		0.0000
33	FIRE	0.2	0.0000	0.0003	0.0014
34	Services	0.3	0.0000	-0.0074	0.0030
35	Goverment Enterprises	0.0	0.0000	0.0000	0.0000

Fig. 3.1. Biases of technical change, fitted and projected; Petroleum Refining

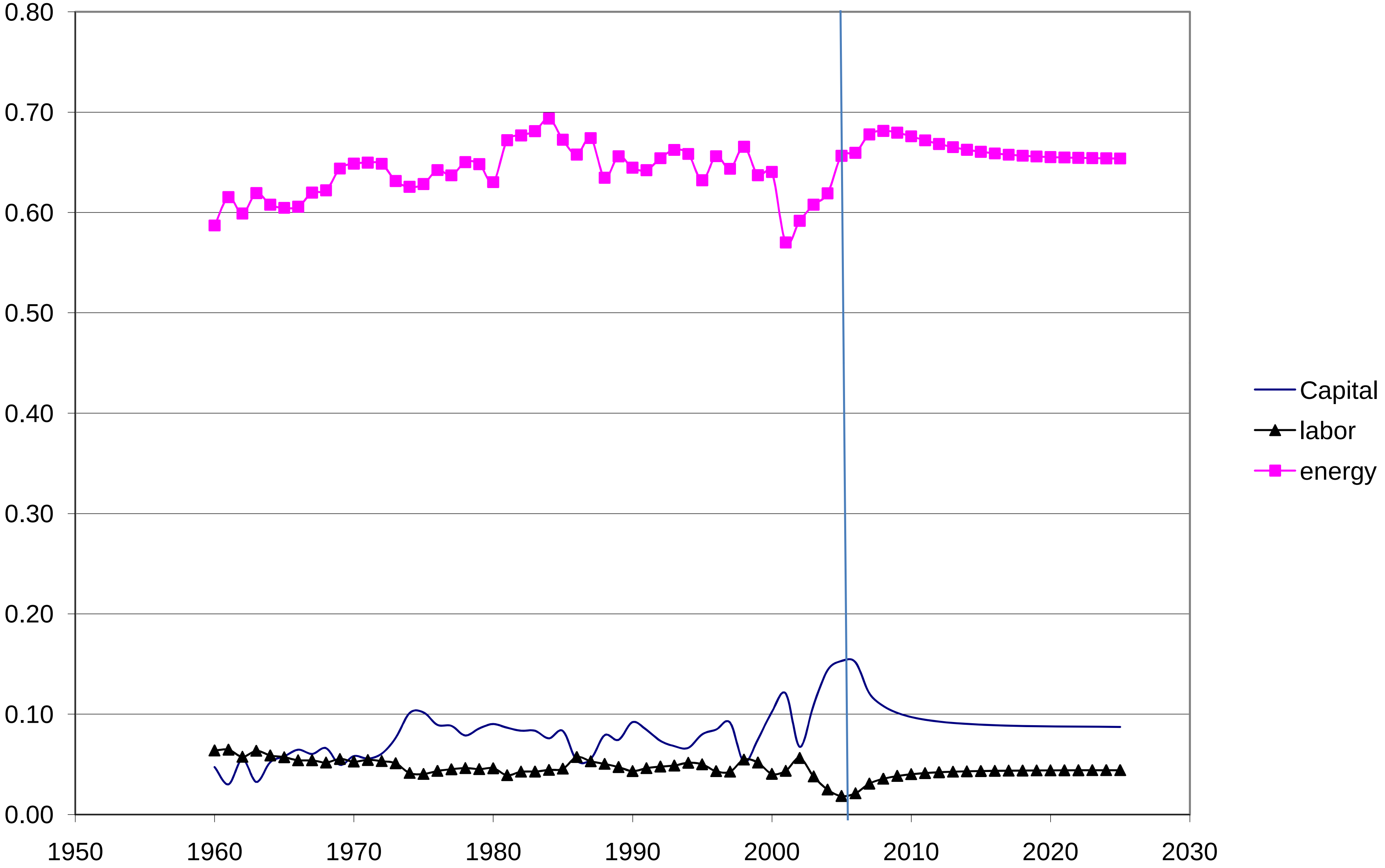

Fig. 3.2 Biases of technical change for energy input,fitted and projected; Energy Industries

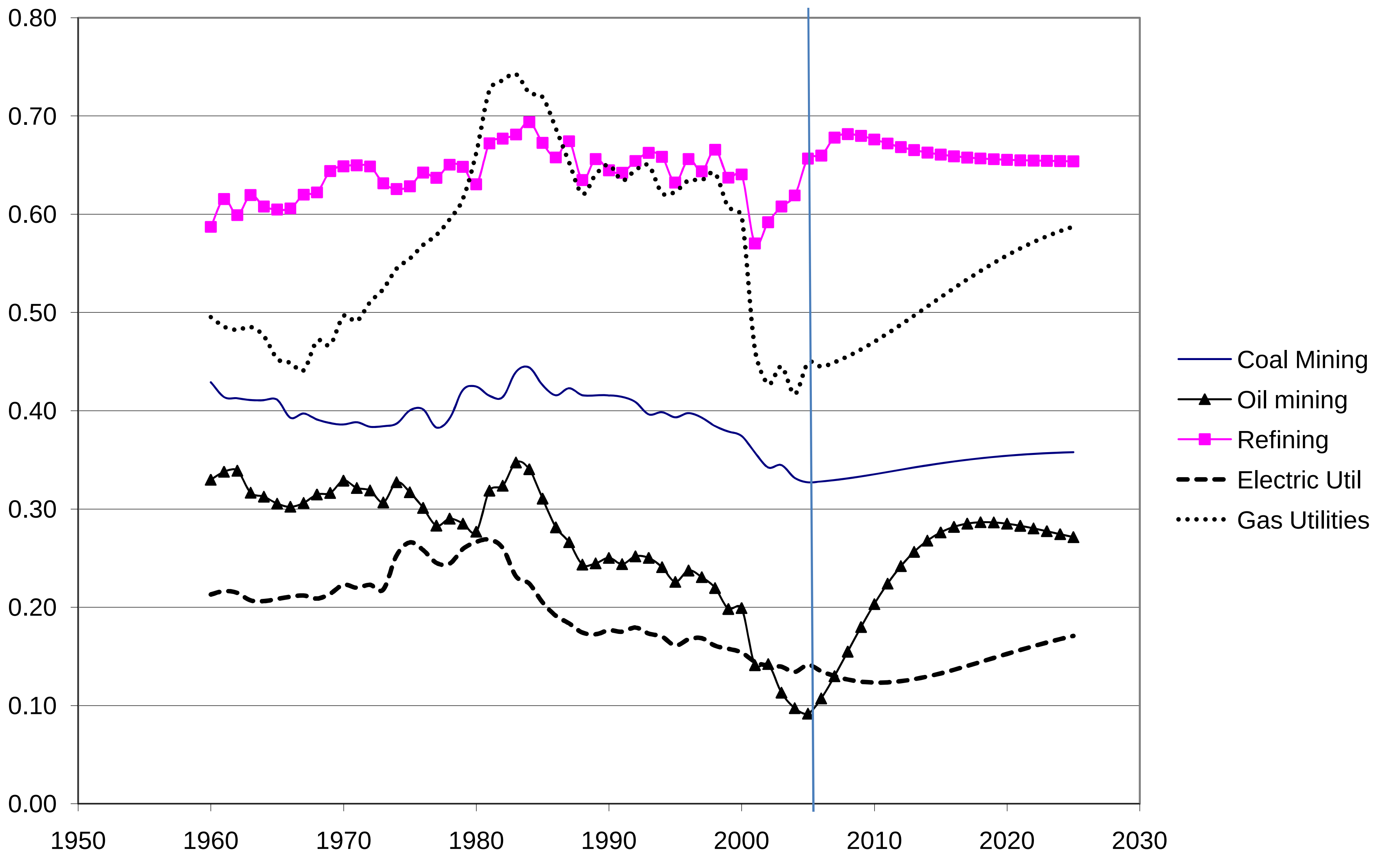

Fig. 3.3. Price technology term in selected industries

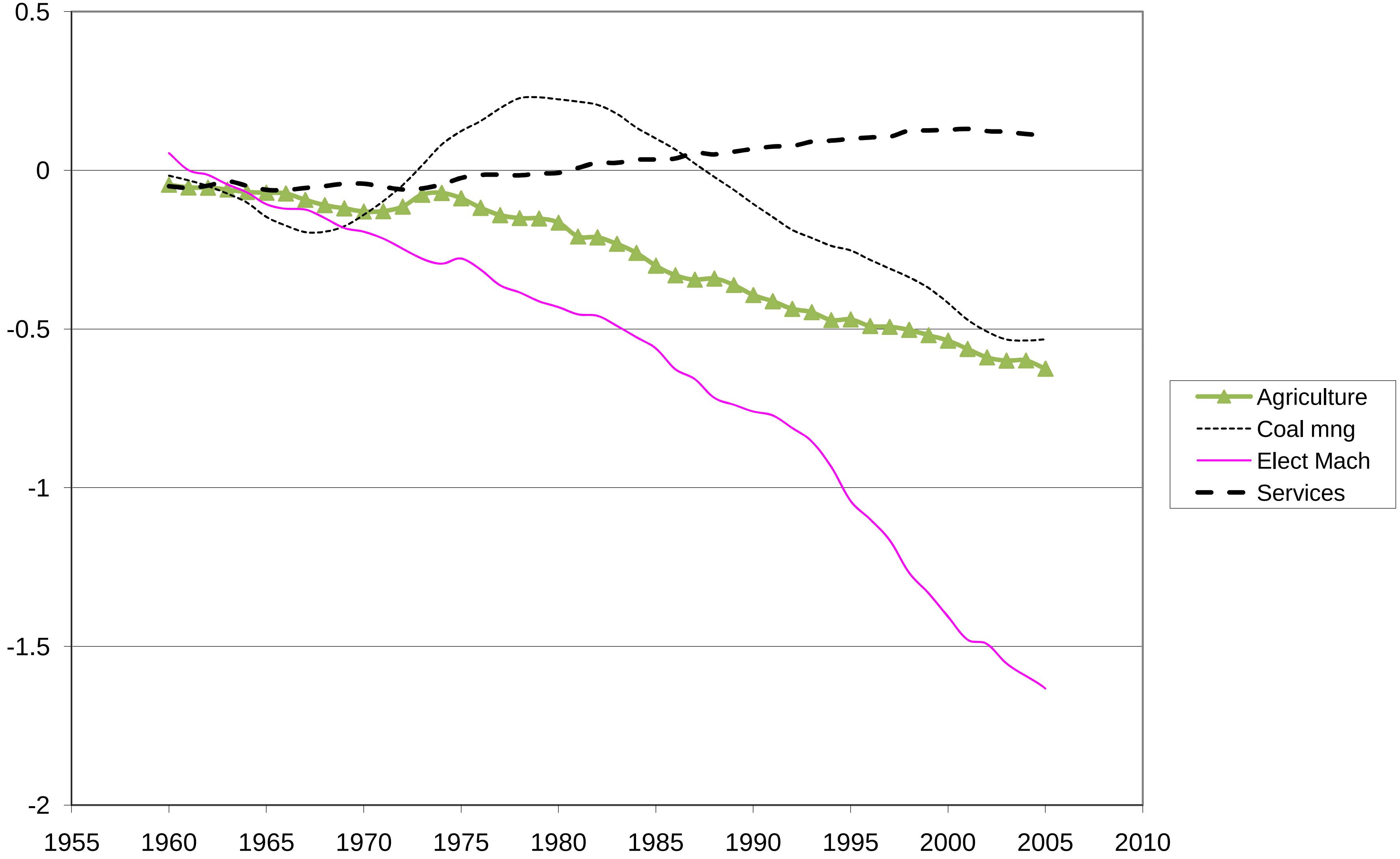

Fig. 3.4. Projections of price technology term in energy industries