The Impact of Environmental Regulations on Cost Structure, Productivity, and Social Welfare in Taiwan: An Example of Petrochemical Industry

(unfinished rough draft)

Chi-Hung Liao
Department of Economics
University of North Carolina, Chapel Hill

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Abstract

In this paper, a CES-translog production model with time variable and pollution abatement capital cost as one of the factor inputs is used to capture the production technology of naphtha cracking industry in Taiwan. There is no *a priori* restriction on the possibility of substitution between factor inputs and returns to scale. The total factor productivity (TFP), composed with technology progress and technology efficiency, is then used to estimate the performance of the petrochemical industry at the presence of environmental regulations. At the end of this paper, computable general equilibrium (CGE) model is used to evaluate the impact of environmental regulations on social welfare.

I. Introduction

The dilemma between environment and economic growth is an issue that many developing and newly industrialized countries are facing. With the rapid growth in economy, the opportunity cost, such as public health, of running dirty industries such as petrochemical industry is become more costly than ever. As a result, the government is implementing new and more stringent regulations to these industries. The impact of such environmental regulations on cost structure and productivity is the main topic of this study.

The immense integrating pollution by petrochemical industry is considered one major source of air and water pollution in Taiwan. In the past decade, Taiwan EPA has enforced much more stringent environmental regulations including Air Pollution Tax, Tradable Permits, Emission Regulation, and Promised Plan on petrochemical industries. Firms must pass Environmental Impact Evaluation before proceeding on the new project. Moreover, the objection from residents of the project site is a major obstacle that is yet to be solved.

This paper builds the production and cost function for naphtha cracking plants in Taiwan. With no *a priori* assumption on the production technology, the CES-translog production function is assumed and tested. Leontief production function, the appropriate production model for petrochemical industry suggested by Lau and Tamura (1972), is also tested. The pollution abatement costs is treated as a factor input because the pollution abatement cost is also a part of plant's expenditure accompanied with the production. Moreover, the presence of environmental abatement capital cost might force the plant to use other inputs such as material, labor, capital, or energy more efficiently than they used to, which will in turn increase the total productivity. We might get a biased result if we exclude the possibility that pollution abatement cost might affect the total productivity (Conrad and Wastl, 1995) or treat pollution abatement simply as a loss in total profits.

The total factor productivity (TFP) is used to measure the effect on the productivity over time after stringent environmental policy is imposed. TFP is decomposed into technology progress and technology efficiency in this study. Conventional TFP measurement approach cannot distinguish between technology progress and changes in technical efficiency, yet the two are analytically distinct and may have quite different policy implication. (Nishimizu and Page, 1982) Treating the technology progress and technology efficiency separately would help us to understand the source of productivity growth (decline) at the presence of stringent environmental regulations.

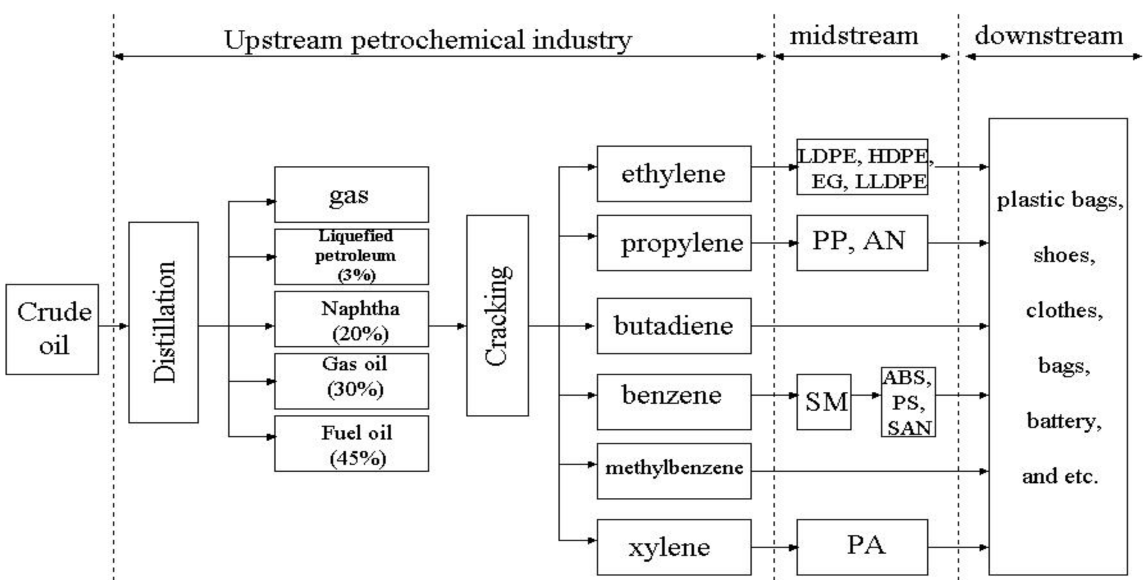
The petrochemical industry has traditionally been regarded as the "leading industry" in both developing and developed countries. The derivative outputs of petrochemical industry provide the materials that mid and downstream industries require. As the last part of this study, the computable general equilibrium (CGE) model will be used to simulate the impact of the environmental regulations on social welfare. The social accounting matrix (SAM), a comprehensive, economywide data framework, will be used to estimate the impact of environmental regulations on the petrochemical industry sector of the economy.

II. Nature and Characteristics of Petrochemical Industry

There are currently six upstream naphtha cracking petrochemical factories in Taiwan. Five of them (Naphtha Cracking Plant Number 1 to 5) are owned by China Petroleum Corp. (CPC), the monopoly petroleum company before 1986, and Naphtha Cracking Plant Number 6 is owned by Formosa Plastic Corp. (FPC), the largest private-owned upstream petrochemical company currently in Taiwan. All of these six naphtha cracking plants are located at or near the harbor to save the transportation cost of shipping the crude oil. The naphtha cracking plants use the naphtha distilled from the crude oil and produce six intermediate chemical compounds, ethylene, propylene, butadiene, benzene, methylbenzene, and xylene. These chemical compounds then become the input for midstream petrochemical factories and will be synthesized or transformed into polymers such as ABS and PP (two of the most popular chemical intermediate products). Finally factories will use these polymers and turn them into final goods such as plastic, rubber, batteries, etc.

Figure 1 shows a simplified petrochemical industry flow chart. The upstream petrochemical industry refers to the refinery and cracking process from crude oil to ethylene, propylene, benzene, butadiene, methylbenzene, and xylene. The midstream factories turn these six chemical compounds into polymers. Downstream factories obtain these chemical polymers from midstream factories and use them as material input. Most manufacturing factories are categorized as downstream group. They use these polymers to produce final goods such as shoes, plastic bags, etc. We can see the reason why the petrochemical industry is often regarded as the "leading industry" in both developing and developed countries due to its important role in the economy.

Figure 1: Simplified Petrochemical Industry Flow Chart



source: China Petroleum Corp.

Petrochemical industry has the following characteristics:

1) Joint products and joint inputs are typical in every stage of production. There are more or less fixed proportions among inputs and outputs, given the nature of chemical reactions (Lau & Tamura, 1972)
2) Production techniques among different producers are similar: rigid specification on the physical conditions of production have to be met (Lau & Tamura, 1972)
3) The operation of a plant is continuous with the exception of maintenance and minor repair work because of the high cost and the difficulties of starting up (Lau & Tamura, 1972)
4) Petrochemical plants are "output-takers". The size and production capacity of a plant is determined when the plant is first built. Petrochemical plants are seeking the cost-minimizing combination inputs given the same amount of output.

Based on the nature of petrochemical industry, upstream and midstream petrochemical industries always cluster together because the intermediate products between upstream and midstream plants are usually in the form of unstable and inflammable liquid or gas. Thus the chemical compounds are transported by pipelines within short distance. The downstream factories are more footloose because the input they require is in stable liquid or solid forms. This explains why downstream factories can freely move to other places that have comparative advantage in labor. In the past two decades, Taiwanese downstream industries have moved to China to seek for competitive labor and larger market. The upstream and midstream petrochemical industries have been proposing to set up their branches in China but are rejected by current policy.

The study subject of this paper is the upstream naphtha cracking petrochemical plants. The reason to choose the upstream but not midstream plants is because the midstream factories are often diverse in equipments and outputs, which makes the analysis complicated and might lead to tenuous results. Moreover, naphtha cracking outputs are the most value-adding products compared with other petrochemical products. In short, the homogeneity of production procedure and the value-adding characteristic for the upstream naphtha cracking petrochemical plant make it a good subject to study.

III. Literature Review

1) Production function of Petrochemical industry

Transcendental logarithmic (Translog) production function was developed by Christensen and *et al* (1973). The function is the flexible functional form, assuming flexible elasticity of substitution between inputs and also no restriction on return to scale. In addition, translog production function is a general form of the Cobb-Douglas production function. Kymn and Hisnanick (2001) explores the CES-translog production function, which relaxes the assumption of strong separability in CES and Cobb-Douglas production function (Berndt and Christensed, 1973). The CES-translog cost function specification allows for testing homotheic technology with Hicks-neutral technical change. By applyng Shephard's lemma, it is possible to derive the input demand functions, as well as the partial elasticities of substitution and the cross-partial price elasticities if demand for a generalized CES-translog production structure. Pollak, Sickles, and Wales (1984) also did some estimation using the CES-translog. Their result showed that the CES-translog is superior to translog cost function in most cases.

Lau and Tamura (1972) studied the Japanese petrochemical processing industry and offered several important statistical results. They concluded that upstream petrochemical plants have nonhomothetic Leontief isoquants. They are nonhomothetic because the expansion path is not necessarily a ray through the origin. They are called Leontief because of the zero elasticities of substitution between all pairs of inputs. This paper hence used four inputs: capital, labor, energy, and resources to analyze the cost structure. The following are their findings:

- They found very substantial economies of scale with respect to labor.
- It appears that in the petrochemical processing industry, the labor required is a constant independent of the level of output.
- We cannot reject the hypothesis that the coefficient of energy and resources are the same.
- It is consistent with the customary assumption of the constancy of the technical coefficients of the intermediate inputs both across output levels and over time.

Finally, they reaffirmed that the nonhomothetic Leontief production function provides an adequate description of the petrochemical processing industry and may also be applicable to other processing industries which operate under similarly rigid technological conditions.

The paper by Griffin (1972) demonstrates the analysis approach for deriving the petroleum refinery industry’s short-run properties of cost curves. It was useful for both the single and joint product cases. In both cases the results here substantiated the classical assumption about short-run cost functions, i.e., that marginal cost slope upward and average costs were U-shaped. The rising marginal costs phenomenon could be linked directly to the ability of process analysis to capture the switching between and within process equipment as output expanded and impinged on the capacities of the carious process units.

2) Total Factor Productivity

Generally, productivity denotes the effectiveness of production technology, which may be measured by cost of production or input requirement for the particular product. We can have higher productivity by lowering the cost of production or lowering input requirement. Thus, in the case of one output and many inputs, the ratio of output to weighted average input requirement shows the production productivity or the total factor productivity (TFP).

A conventional expression for TFP growth is:

$$T\hat{F}P = \sum_j w_j \, \hat{y}_j - \sum_i v_i \, \hat{x}_i \qquad (1)$$

where w_j is the weight share of total revenue contributed by the jth output, v_i is the weight share of total cost contributed by ith input. Hats represent the growth rates and y_j and x_i represent jth output and ith input, respectively. Owyong (n.d.) did a general overview of productivity growth. Other than definition and some extension of total factor productivity, he made several comments on the measurement of capital and other inputs.

Literatures about the total factor productivity and other productivity growth measurement are mainly centered around the conventional approach. However, Nishimizu and Page (1982) decompose total factor productivity into two sources: technical progress and technical efficiency. They argued that conventional measures of total factor productivity change cannot distinguish between technology progress and changes in technical efficiency, yet the two are analytically distinct and may have quite different policy implication. The theoretical framework that Nishiminu and Page used was a translog production function with quadratic time variable included. This decomposition is especially important for the study of environmental regulation impact on petrochemical industry research. Using the decomposition will allow us to look at which factor, technical progress or technical efficiency, contributes the growth of TFP after imposing stringent environmental regulations.

The paper by Berman and Bui (2001) studies oil refineries using TFP approach. They found that South Coast petroleum refineries in California increased productivity. The abatement costs may severely overstate the true cost of environmental regulation. This study chose similar plant in Louisiana and Texas as a comparison group. Conrad and Wastl (1995) also suggest using the TFP approach to estimate the industries in German. They proposed to treat compliance with environmental regulation as an unproductive input linked to the use of productive material inputs. Their result showed that pollution abatement costs reduced the level of total factor productivity in Germen industries.

3) Approaches to Evaluate The Impact of Environmental Regulation

There have been some debates over how environmental regulations affect the economic performance or industry's competitiveness. The topic has been studied using partial or general equilibrium approaches, yet a general consensus has not been reached.

In the past decade, the validities of some environment-related hypotheses have been tested, such as Pollution Haven Hypothesis and the Porter Hypothesis. The Pollution Haven Hypothesis states that unilateral increases in environmental control have frequently been objected to on the grounds that domestic firms may lose their competitiveness edge to foreign competitors who are not subject to the same restrictions. According to this line of reasoning, domestic firms shift their production, and hence employment, to countries with less restrictive environmental standards (Bommer, 1999). The Porter Hypothesis, on the contrary, suggests that more severe environmental regulation may have a positive effect on firms' performance by simulating innovations (Porter and van der Linde, 1995). Empirically, we find weak support for the Pollution Haven Hypothesis (e.g. Smarzynska and Wei, 2001). Bommer (1999) showed that an entrepreneur may relocate production for strategic reasons if he expects a tightening of environmental regulation. As for the Porter Hypothesis, there are both agreeing and disagreeing papers, e.g. Lanoie, Patry, and Lajeunesse (2001) provided an empirical analysis of the relationship between the stringency of environmental regulation and total factor productivity growth in the Quebec manufacturing sector. Their result showed that the contemporaneous result is negative; however, the opposite result is observed with lagged regulation variables. The paper by Palmer, Oates, and Portney (1995) argued that the environmental protection cost was more expensive than Porter and van der Linde (1995) predicted. So one should be aware of the substantial cost coupled with the implementation of environmental regulations.

Copeland and Taylor (1994) discussed the correlation between pollution and international trade. They built a North-South model and examined how trade between two countries differentiated solely by income can affect environmental quality. The results showed that income gains arising from an opportunity to trade could affect pollution in a different way than income gains obtained through economic growth. Also, economic growth has different effects on pollution in a free trade regime than in autarky. Although, by optimally setting the environmental policy, potential increases in pollution generated by economic growth in autarky can be prevented by a policy-induced switch to cleaner methods of production. International trade opens up a different channel that may nevertheless lead to an increase in world pollution.

4) Computable general equilibrium model

Computable general equilibrium (CGE) models are used widely in policy analysis. The base of the CGE models is the Social Accounting Matrix (SAM), which is a comprehensive, economywide data framework, typically representing the economy of a nation. A succinct explanation by Löfgren, Hanes, Harris, Rebecca L., and Robinson, Sherman (2001) is: …technically, a SAM is a square matrix in which each account is represented by a row and a column. Each cell shows the payment from the account of its column to the account of its row, its expenditures along its column. The underlying principle of double-entry accounting requires that, for each account in the SAM, total revenue (row total) equals total expenditure (column total).

The main reason to use a CGE model is to provide a quantitative evaluation of the effects of government policies. In most interesting policy settings economic theory provides guidelines for judging if a policy will be beneficial or not for some household, but often cannot give a quantitative answer. It is at this point that quantitative models enter the policy stage.

Just as the name suggests, the CGE model has the advantage in a comprehensive policy analysis throughout the whole economy. If something is changed in one part of the economy due to a government policy, then there will be effects on the other parts of the economy, and these are automatically taken into account when one computes effects using a general equilibrium model. CGE models are natural extensions of conventional Input-Output (IO) model. CGE models take into account substitution possibilities in terms of, for example, labor or capital intensive technology choices as well as the circular flow of income across consuming households and producing firms.

Despite some criticism of the assumptions in the CGE models, we could get certain policy implication from the result. We could simulate the effect of the additional environmental capital cost in petrochemical industry on the economy's different sectors and different income stratum. Given the important position that the petrochemical industry stands in the economy, it is sensible to trace through the effect that begins from this leading industry.

IV. Empirical Model

The following function is a general expression of the production model:

$$Q(X_1(t), X_2(t), \ldots, X_n(t), t) \tag{2}$$

where Q is the total output of petrochemical products, X_k is *kth* input out of total *nth* inputs, and *t* represents the time variable.

Conventional approach of measuring the total factor productivity is described in equation (1). However, this approach can only estimate the total output progress net of the contribution from the input increase. Thus, the conventional TFP does not give us any information about the source of the output growth.

Derived from Nishimizu and Page (1982), consider the production equation (2) and for any observed combination of output and inputs at time *t*, the following inequality holds:

$$q(t) \le Q(X(t), t) \tag{3}$$

Here we use *X(t)* to represent the input vector, *q(t)* is the aggregate output at time *t*. This inequality happens when firms do not employ its inputs with the productivity level of "best practice" at the observed input mix. Denoting by $\hat{t}$ and $\hat{q}$ the best practice or potential productivity and output levels, we can rewrite (3) for an "interior firm" operating at less than the best practice:

$$\begin{aligned} q(t) &= Q(X(t), t) \\ &< Q(X(t), \hat{t}) = \hat{q}(t) \end{aligned} \tag{4}$$

Furthermore, we define the technology efficiency by the following:

$$e(t)\hat{q}(t) = Q(X(t), t), \; (0 \le e \le 1) \tag{5}$$

An alternative definition for *e(t)* is the maximum factor of increase in actual output that can be produced with the observed input employed at the potential productivity levels:

$$q(t) / e(t) = Q(X(t), \hat{t}) \tag{6}$$

These two definitions are equivalent in this framework. Efficiency *e* can be further reduced to an output level comparison between *q* and $\hat{q}$ at the observed input mix *X(t)*:

$$e(t) = \frac{q(t)}{\hat{q}(t)} \tag{7}$$

From the first inequality in (4), the rate of total factor productivity observed is:

$$\dot{Q}(X,t) = \dot{q}(t) - Q_X(t)\dot{X}(t) \tag{8}$$

where the dot over variables denotes logarithmic time derivatives. If we combine equation (6), we can rewrite equation (8) as:

$$\dot{Q}(X,t) = \dot{Q}(X,\hat{t}) + \dot{e}(t) + [Q_X(\hat{t}) - Q_X(t)]\dot{X}(t) \tag{9}$$

In equation (9), the rate of technological change of the "best practice" frontier, $\hat{Q}(X,\hat{t})$, represents the “true” rate of technological progress. The change in the relative efficiency is captured by the term $\dot{e}(t)$, which represents the rate at which any observed firm is moving toward or away from the best practice frontier. In the following text we will refer the $\dot{e}(t)$ as the technological efficiency change. The last component represents the effort of an interior firm to reach its potential output. So the TFP is now defined as three components: technological progress, technological efficiency change, and output elasticity differences between the frontier and the interior.

Let h represents a scalar, such that:

$$Q(hX_1(t),...,hX_n(t),t) = h^{\theta} Q(X_1(t),...X_n(t),t) \tag{10}$$

The scale effects will be constant when $\theta = 1$, increasing when $\theta > 1$, and decreasing when $\theta < 1$. We assume that technology is a scale invariant variable which can be captured by time variable in the following specification.

In the estimation of the production function, the conventional approach has been to impose strong restrictions on separability on factors and thus ignore some important features of production technology. The CES-translog production function, just like the name suggests, includes both the CES and the trasnlog as special cases and imposes limited *a priori* restriction on the relationship between factors. The CES-translog is essentially a second-order Taylor series approximation with the first order expansion substituted by the CES production function. The n-factor CES-translog production function with technology and scale effects is: (Nishimizu and Page, 1982 and Pollak, Sickles, and Wales, 1984)

$$\ln Q(t) = \alpha_0(t) + \ln[\sum_{k=1}^{n} \alpha_k X_k(t)^{1-S}]^{\theta/(1-S)}$$
$$+ 0.5[\sum_{k=1}^{n}\sum_{j=1}^{n} \alpha_{kj} \ln X_k(t) \ln X_j(t)] \tag{11}$$

where

$$\alpha_0(t) = \alpha_0 + \alpha_t t + \frac{1}{2}\beta_{tt} t^2 \tag{11'}$$

where S is the elasticity of substitution, t is the time variable which captures the technology progress over time. The specification of $\alpha_o(t)$ is the same with Nishimizu and Page's. The value of θ is defined as above, the production function exhibits constant return to scale when $\theta=1$, increasing returns to scale when $\theta>1$, decreasing returns to scale when $\theta<1$. The following restrictions apply to this CES-translog function:

$$\alpha_{kj} = \alpha_{jk}, \quad \sum_{k=1}^{n} \alpha_{kj} = \sum_{j=1}^{n} \alpha_{kj} = 0, and \sum_{k=1}^{n} \alpha_{k} = 1$$

A special case, generalized Leontief production function is a subset of the CES-translog production function. Simply impose the restriction that the substitution between factor inputs equal to zero (or $S \to \infty$) and we can get a generalized Leontief production function:

$$\ln Q(t) = \alpha_0(t) + 0.5[\sum_{k=1}^{n}\sum_{j=1}^{n} \alpha_{kj} \ln X_k(t) \ln X_j(t) \qquad (12)$$

Further, the first order condition associated with this production function that describe production, Q, at minimum cost are:

$$\frac{\partial Q(t)}{\partial X_k(t)} = \theta \, [\frac{\alpha_k X_k(t)^{1-S}}{\sum_{k=1}^{n} \alpha_k X_t(t)^{1-S}}] + \sum_{j=1}^{n} \alpha_{kj} \ln X_j(t) \qquad (13)$$

All differences in productivities across t are assumed to be captured in $\{\alpha_t\}$ and $\{\beta_{tt}\}$, thus the factor parameter $\{\alpha_k\}$ and the structure of factor substitution possibilities described by $\{\alpha_{kj}\}$ are invariant across time t. The total factor productivity change is the change of output with respect to time with all factors held constant:

$$\frac{\partial \ln Q(t)}{\partial t} = \alpha_t + \beta_{tt} t \qquad (14)$$

This specification is especially reasonable for the petrochemical industry. Even though the Naphtha cracking plant has rather inflexible production capacity and technology. We do not exclude the possibility of technology progress by introducing the time variant parameter.

The CES-translog function production frontier under the "best-practice" at different points in time is:

$$\ln \hat{Q}(t) = (\hat{\alpha}_0 + \hat{\alpha}_t\, t + \frac{1}{2}\hat{\beta}_{tt}\, t^2) + \ln[\sum_{k=1}^{n} \hat{\alpha}_k\, X_k(t)^{1-S}]^{\theta/(1-S)}$$
$$+ 0.5[\sum_{k=1}^{n}\sum_{j=1}^{n} \hat{\alpha}_{kj} \ln X_k(t) \ln X_j(t)] \qquad (15)$$

where $\hat{\alpha}_t$ captures the rate of technology progress at a frontier point around which the Taylor-series expansion approximates the frontier. $\hat{\beta}_{tt}$ is measuring the rate of change in technological progress, if the technology has a increasing, constant, or decreasing contribution to the marginal production, we should see a positive, zero, or negative sign for $\hat{\beta}_{tt}$.

Our objective function is to find the unknown parameters to minimize the following:

$$\min\ (\hat{\alpha}_0 + \hat{\alpha}_t\, t + \frac{1}{2}\hat{\beta}_{tt}\, t^2) + \ln[\sum_{k=1}^{n} \hat{\alpha}_k\, X_k(t)^{1-S}]^{\theta/(1-S)}$$
$$+ 0.5[\sum_{k=1}^{n}\sum_{j=1}^{n} \hat{\alpha}_{kj} \ln X_k(t) \ln X_j(t)] - \ln Q(t) \qquad t = 1,\ \ldots,\ T \qquad (16)$$

The constraints of the model are imposed by the restrictions on the observations securing the observed input-output combinations to lie on or below the frontier:

$$(\hat{\alpha}_0 + \hat{\alpha}_t\, t + \frac{1}{2}\hat{\beta}_{tt}\, t^2) + \ln[\sum_{k=1}^{n} \hat{\alpha}_k\, X_k(t)^{1-S}]^{\theta/(1-S)}$$
$$+ 0.5[\sum_{k=1}^{n}\sum_{j=1}^{n} \hat{\alpha}_{kj} \ln X_k(t) \ln X_j(t)] \geq \ln Q(t) \qquad (17)$$

The CES-translog production function is not assuming constant return to scale as the conventional translog production function. (Nishimizu and Page, 1982) Instead, it has the flexibility of testing whether the industry is increasing, constant, or decreasing returns to scale.

In the hypothesis testing and empirical studies, the information we have is usually cost side. The n-factor CES-trasnlog cost function is given by:

$$\ln c(Q,w,t) = a_0(t) + a_q \ln Q + \ln[\sum_{k=1}^{n} a_k w_k{}^{1-S}]^{1/(1-S)}$$

$$+0.5[\sum_{k=1}^{n}\sum_{j=1}^{n} a_{kj} \ln w_k \ln w_j + a_{qq}(\ln Q)^2] \qquad (18)$$

$$+\sum_{k=1}^{n} a_{kq} \ln w_k \ln Q$$

Here, parallel restriction on the parameters apply to the specification:

$$\sum_{k=1}^{n} a_k = 1, a_{kj} = a_{jk}, \sum_{k=1}^{n} a_{kj} = \sum_{j=1}^{n} a_{kj} = 0, \sum_{k=1}^{n} a_{kq} = 0$$

Applying Shephard's Lemma to the cost function yields the respective cost share equations:

$$S_k = [\frac{a_k w_k{}^{1-S}}{\sum_{k=1}^{n} a_k w_k{}^{1-S}}] + \sum_{k=1}^{n} a_{kj} \ln w_k + a_{kq} \ln Q \quad \text{where k=1, …, n} \qquad (19)$$

A special case, the Leontief cost function, was proposed by Pollak, Sickles, and Wales (1984). They argued that the generalization from the translog to CES-translog can be applied to the n-factor CES-generalized Leontief cost funtion:

$$c(Q,w) = Q[\sum_{k=1}^{n} a_k w_k{}^{1-S}]^{1/(1-S)}$$

$$+Q\sum_{k=1}^{n} \sum_{j=1, j\neq k}^{n} a_{kj} w_k{}^{0.5} w_j{}^{0.5} \qquad (20)$$

where $a_{kj} = a_{jk}$ for all k, j.

Repeating the Shephard's Lemma, the cost minimizing factor demand functions in input-output form are given by:

$$H_k = \frac{a_k}{w_k{}^S}[\sum_{k=1}^{n} a_k w_k{}^{1-S}]^{S/(1-S)} + \sum_{j=1, j\neq k}^{n} a_{kj} (\frac{w_j}{w_k})^{1/2} \qquad (21)$$

where H_k is again the cost share of input k.

For all CES-translog models, we use the standard model scenario which assumes that the production technology is homothetic, technology is Hicks-neutral, the factor prices are exogenous and the factor shares adjust instantaneously to changes in factor prices.

V. Data and Hypothesis Testing

In this study of naphtha cracking industry, inputs are categorized into four factors. They are fuel (F), labor (L), public utility (U), and pollution abatement cost (Z). They are denoted as X_F, X_L, X_U, and X_Z, respectively. The outputs of the naphtha cracking plant are ethylene, propylene, and butadiene. Since these three outputs are derivatives in the same production process. We treat the simple additive of the physical weight as the total output.

$$Q = \sum_{j=1}^{3} Q_j \tag{22}$$

The price of the factor is derived from the value-weighted average of the itemized price data. We do not include the capital cost in the regression model for two reasons, one is that the capital cost is not presented in the annual report, another reason is that the capital is regarded as the fixed cost and does not change annually, the contribution from fixed capital input is categorized into the constant term.

The data that we obtained is from only one of the Naphtha Cracking Plants (NC) (due to the confidentiality, the number of the plant cannot be revealed). The time variable t is assumed to be 1 for February 1994, and increase with an increment 1 quarterly ever since, the reason being that the NC started its first production in February 1994. Among all the factors, the value of the fuel takes a major proportion which ranges from 60 to 80 percent every year. The cost data we currently have is monthly data from January 2000 to January 2002. The output data covers from 1996 to 2002 and thus quite sufficient. There are 18 parameters that we need to estimate, they are: $\alpha_{u,} \alpha_{l,} \alpha_{f,} \alpha_{z,}$ $S, \alpha_{ul,} \alpha_{uf,} \alpha_{uz,} \alpha_{lf,} \alpha_{lz,} \alpha_{fz,} \alpha_{ff,} \alpha_{zz,} \alpha_{uu,} \alpha_{ll,}$. Currently we only have complete data for 25 months (see appendix), which is not sufficient if we need to obtain an accurate story about the production technology. We expect to receive more data in the following two weeks.

We use the nonlinear regression to capture the CES-translog production function in equation (11). We can further test the hypothesis whether the elasticity between factors is not significantly different from zero as Lau and Tamura (1972) suggested. If we are not able to reject the null hypothesis that the production function is a Leontief type production function, we can substantially decrease the parameters that we need to estimate by using the Leontief production function in the estimation of TFP change.

The rate of technological progress for each region is computed by combining the frontier parameters with observed input levels as in equation (14) for each year. The level of technological efficiency as defined in (7) and can be obtained as the antilog of the slack variables in out linear programming constraints (17). The rate of change in technical efficiency is approximated by taking the log differences of successive time periods. Therefore, we can construct the total factor productivity by adding up the rate of technical progress change and the rate of change in technical efficiency. This measurement of TFP is different from conventional approach yet gives us more information about the source of productivity growth or decline through time.

VI. Appendix

The production and cost data of one of the Naphtha Cracking plant dating from January 2000 to January 2002.

Month	t	Q	U	P_U	L	P_L	F	P_F	Z	P_Z
Jan-00	25	62372.78	243034.15	243.05	317.00	115244.81	36651.55	4539.30	221957.75	1804.53
Feb-00	25	62579.47	240289.71	243.97	311.92	114315.09	35504.14	4571.12	223274.94	1802.21
Mar-00	25	62786.16	237545.27	244.88	306.83	113385.38	34356.74	4602.95	226785.73	1799.89
Apr-00	26	62992.85	234800.83	245.79	301.75	112455.66	33209.33	4634.77	257051.49	1797.56
May-00	26	63199.54	232056.39	246.70	296.67	111525.95	32061.92	4666.59	256719.18	1795.24
Jun-00	26	63406.23	229311.95	247.61	291.58	110596.23	30914.51	4698.42	295830.99	1792.92
Jul-00	27	63612.92	226567.51	248.53	286.50	109666.52	29767.11	4730.24	279332.23	1790.59
Aug-00	27	63819.61	223823.07	249.44	281.42	108736.80	28619.70	4762.07	243204.36	1788.27
Sep-00	27	64026.30	221078.63	250.35	276.33	107807.09	27472.29	4793.89	330399.54	1785.94
Oct-00	28	64232.99	218334.18	251.26	271.25	106877.37	26324.88	4825.72	258624.84	1783.62
Nov-00	28	64439.68	215589.74	252.17	266.17	105947.66	25177.47	4857.54	258287.88	1781.30
Dec-00	28	64646.37	212845.30	253.09	261.08	105017.94	24030.07	4889.37	295309.32	1778.97
Jan-01	29	64853.06	210100.86	254.00	256.00	104088.22	22882.66	4921.19	312690.03	1776.65
Feb-01	29	65059.75	207356.42	254.91	250.92	103158.51	31953.73	4953.02	331798.59	1774.32
Mar-01	29	65266.44	204611.98	255.82	245.83	102228.79	30921.06	4984.84	311872.03	1772.00
Apr-01	30	65473.13	201867.54	256.73	240.75	101299.08	29888.40	5016.67	253063.71	1769.68
May-01	30	65679.81	199123.10	257.65	235.67	100369.36	28855.73	5048.49	256266.09	1767.35
Jun-01	30	65886.50	196378.66	258.56	230.58	99439.65	27823.06	5080.32	291229.70	1765.03
Jul-01	31	66093.19	193634.22	259.47	225.50	98509.93	26790.39	5112.14	290846.26	1762.70

Aug-01	31	66299.88	190889.78	260.38	220.42	97580.22	25757.73	5143.97	309827.01	1760.38
Sep-01	31	66506.57	188145.34	261.29	215.33	96650.50	24725.06	5175.79	270740.75	1758.06
Oct-01	32	66713.26	185400.90	262.21	210.25	95720.78	23692.39	5207.62	254581.28	1755.73
Nov-01	32	66919.95	182656.46	263.12	205.17	94791.07	22659.73	5239.44	254244.31	1753.41
Dec-01	32	67126.64	179912.01	264.03	200.08	93861.35	21627.06	5271.27	253907.35	1751.09
Jan-02	33	67333.33	177167.57	264.94	195.00	92931.64	20594.39	5303.09	253570.39	1748.76

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