A consistent approach to cost efficiency measurement

By

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Abstract

Consistent specifications of the allocative inefficiency function in "cost plus input share equations" systems may be difficult, if not impossible, to find because most plausible ones violate certain reasonable *a priori* conditions. Moreover, the models to which they lead give rise to highly non-linear likelihood functions that are very hard to estimate. In an effort to confront these difficulties, this paper adapts an idea first suggested by Greene (1993) that allocative inefficiency ought to be related to input prices and allocative distortions in the input share equations. The system of "cost plus input demand equations" that emerges is estimated by standard SUR techniques using data from private and state firms that operated in Greek manufacturing during the 1979-1988 period. Among other findings, the estimates show that overall inefficiency for private and state firms was 63.5% and 102.2%. In relative terms these figures imply that state firms were almost 61% less efficient than private firms were. Moreover, the evidence shows that responsible for this excess inefficiency of state firms were technical and allocative reasons by contributing 64% and 36%, respectively, as well as differences in the utilization of labor, capital and debt. Lastly, it is found that the magnitudes of technical and allocative inefficiencies depend critically upon a self-consistent specification of the allocative inefficiency function.

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I. Introduction

In the specification and estimation of cost efficiency following the fixed-effects approach in panel-data settings, researchers have been content either to ignore the relationship between the allocative inefficiency terms in the cost function and the share equations or to impose it in an ad hoc manner. For example, Atkinson and Halvorsen (1986), Kalirajan (1990), and Atkinson and Cornwell (1994) ignore it, whereas Ferrier and Lovell (1990) postulate that the inefficiency term in the cost function is a weighted average of the squared inefficiency terms in the share equations. Yet in both cases it has been known in the relevant literature that the resulting specifications lead to methodological inconsistencies that bias the estimates in unknown magnitudes and directions.

Our objective in this paper is twofold. The first is to suggest a possible remedy. In doing so, we modify the specification adopted by Ferrier and Lovell (1990) in the light of an insight presented by Greene (1993). More specifically, assuming that the allocative inefficiency term in the cost function is related to input prices in a way that satisfies certain conditions deriving from economic theory, we obtain a consistent set of input demand equations by applying Shephard's lemma. In turn the cost function and the input demand equations are estimated by means of the Seemingly Unrelated Regressions (SUR) estimator using representative firm data from nine two-digit industries of Greek manufacturing over the 1979-1988 period. Finally, in order to shed light on the biases that may result when the relationship in question is ignored or misspecified, we re-estimate the cost inefficiency components using several competing models from the aforementioned studies.

The second objective is to allow for the effects of ownership. In this regard Bitros (2000) finds that state firms operating in competitive industries under-perform their private counterparts both on technical and allocative grounds. But this is not generally the case, because certain other studies show for example that the type of ownership does not matter.[1] Hence, given that the data employed here are the same as the ones used in the above study by the first author, we consider it an excellent opportunity to check the robustness of his findings with respect to changes in the specification and the estimation of the model.

As to the results, these are quite illuminating. At the theoretical plane it is shown that consistent specifications of the allocative inefficiency function may be difficult, if not impossible, to find in "cost plus input share equations" systems, because most plausible specifications of this function violate certain reasonable *a priori* conditions. Then, at the empirical plane, from the es-

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[1] See, for example, Caves and Christensen (1980), Di Lorenzo and Robinson (1982), and Fare, Grosskopf and Logan (1985).

timated “cost plus input demand equations” system emerges that overall inefficiency for private and state firms was 63.5% and 102.2%. In relative terms these figures imply that state firms were almost 61% less efficient than private firms were. Moreover, the evidence shows that responsible for this excess inefficiency of state firms were technical and allocative reasons, by contributing 64% and 36%, respectively, as well as differences in the utilization of labor, capital and debt. Last, but not least, it is found that the magnitudes of technical and allocative inefficiencies depend critically upon a self-consistent specification of the allocative inefficiency function.

The paper is organized as follows. The econometric model adopted for the measurement of cost efficiency is presented in Section II. The data and the variables used in the estimations are discussed in Section III. The results and their interpretation are highlighted in Section IV. And, lastly, in Section V we summarize our conclusions.

II. Econometric models for cost efficiency measurement

The measurement of cost efficiency has a long-standing tradition in applied econometrics. Christensen and Greene (1976) applied a translog “cost plus input share equations” system with market-input prices to investigate the scale economies in U.S. power generation. Atkinson and Halvorsen (1984, 1986) adopted the same system, but with shadow-input prices, to evaluate over-capitalization and the relative efficiency in private and regulated U.S. electric utilities. Eakin and Kniesner (1988) employed a similar approach to investigate the cost efficiency in hospitals, and last but not least Ferrier and Lovell (1990) and Atkinson and Cornwell (1994a, 1994b) refined further this methodology by extending its application to panels of data from the banking and air-line industries, respectively.

In this paper, we draw on the Ferrier and Lovell (1990)[2] approach. More specifically, we start from their specification,

$$log\, C_{ft} = H(\mathbf{p}_{ft}, \mathbf{y}_{ft}; \boldsymbol{\theta}) + v_{0ft} + T_{ft} + A_{ft} \tag{1a}$$

$$A_{ft} = \sum_{i=1}^{k} F_i w_{ift}^2 \tag{1b}$$

$$S_{ift} = h_i(\mathbf{p}_{ft}, y_{ft}; \boldsymbol{\theta}) + v_{ift} + w_{ift} \tag{1c}$$

$$T_{ft} \geq 0\,,\; A_{ft} \geq 0\,,\; w_{ift} \gtrless 0 \quad F_i \geq 0 \tag{1d}$$

$$i = 1,\ldots,k;\; f = 1,\ldots,N;\; t = 1,\ldots,M$$

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[2] See also Kumbakhar (1991).

where C_{ft} stands for the cost of firm f at period t, S_{ift} represents the cost share of the i*th* input, $\mathbf{p}_{ft} \in \mathbf{R}^k$ is a $k \times 1$ vector of input prices, y_{ft} denotes output level, $\boldsymbol{\theta} \in \mathbf{R}^m$ is an $m \times 1$ vector of parameters, v_{ift} indicates an error term, T_{ft} and A_{ft} measure technical and allocative inefficiency, respectively, w_{ift} is the allocative distortion in the i*th* input, the F_i's denote the cost of input-specific allocative inefficiency, $H(\mathbf{p}_{ft}, \mathbf{y}_{ft}; \boldsymbol{\theta})$ signifies the functional form of the cost function, and the share equations have been derived by applying Shephard's lemma, namely $S_{ift} = \dfrac{\partial \log C_{ft}}{\partial \log p_{ift}}$, for all i, f, t. In this specification, F_i, T_{ft}, and w_{ift} are parameters and while w_{ift} may be positive, negative or zero, the F_i's are constrained to be nonnegative to reflect the implication that, choosing inputs in the wrong proportions, must increase costs.

The major drawback of this model is that input-specific allocative distortions, namely the w_{ift}'s, appear quadratically in the cost function but linearly in the share equations. The reason is that, using Shephard's lemma to obtain the share equations involves taking derivatives with respect to input prices, *not* the distortion parameters. As a result, in the estimation of technical and allocative inefficiency there arises an inconsistency, which has long been recognized in the relevant literature.

Here, in order to arrive at a consistent model, we adapt an insight presented by Greene (1993) but not exploited so far in similar analyses. Greene's suggestion is to set

$$log\, C_{ft} = H(\mathbf{p}_{ft}, \mathbf{y}_{ft}; \boldsymbol{\theta}) + v_{0ft} + T_{ft} + A_{ft} \tag{2a}$$

$$A_{ft} = exp(\sum_{i=1}^{k} u_{ift} p_{ift}) \tag{2b}$$

$$S_{ift} = h_i(\mathbf{p}_{ft}, y_{ft}; \boldsymbol{\theta}) + v_{ift} + u_{if} A_{ft} \tag{2c}$$

$$T_{ft} \geq 0,\ A_{ft} \geq 0,\ u_{ift} \gtrless 0 \tag{2d}$$

$$i = 1,\ldots,k;\ f = 1,\ldots,N;\ t = 1,\ldots,M\ ,$$

where u_{ift} is an allocative distortion parameter. However, this formulation suffers from two fundamental shortcomings. The first of them is that, even when the firm makes no allocative mistakes (i.e. $u_{ift} = 0$, for all i, t, given f), allocative inefficiency is *not* zero. To see this, observe from (2b) that, when all allocative distortions are zero, $A_{ft} = 1$. This implies that any firm will be 100% allocatively inefficient when in fact the firm makes no allocative errors! Moreover, subtracting unity from A_{ft} does not solve the problem, because the allocative term in (2a) is not guaranteed to be nonnegative.

The second shortcoming emanates from the realization that it may be extremely difficult, if not impossible, to find a consistent specification for (2b) in the confines of a "cost plus input share equations" system. Why is this so and why switching to a "cost plus input demand equations" system may provide a satisfactory remedy is the subject of the analysis that follows.

Let any mapping from prices and allocative distortions to allocative inefficiency be denoted by $A(\mathbf{p},\mathbf{u})$ and $A:\mathbf{R}_+^k \times \mathbf{R}^k \to \mathbf{R}$. Then,

Definition: A mapping is a proper allocative inefficiency function, if the following conditions hold.

(i) $A(\mathbf{p},\mathbf{u})$ is differentiable with respect to $\mathbf{p}$.

(ii) $A(\mathbf{p},\mathbf{u}) \geq 0$, for all $(\mathbf{p},\mathbf{u}) \in \mathbf{R}_+^k \times \mathbf{R}^k$.

(iii) (Sign condition). For a fixed $\mathbf{p} \in \mathbf{R}_+^k$, $A(\mathbf{p},\mathbf{u}) = 0$, if and only if $\mathbf{e}(\mathbf{p},\mathbf{u}) \equiv \dfrac{\partial A(\mathbf{p},\mathbf{u})}{\partial \mathbf{p}} = 0$, all i, and $\mathbf{e}(\mathbf{p},\mathbf{u})$ is positive, negative or zero.

(iv) (Monotonicity condition). $A(\mathbf{p},\mathbf{u})$ is strictly increasing in $|e_i(\mathbf{p},\mathbf{u})|$, all $\mathbf{p} \in \mathbf{R}_+^k$, all i.

(v) (Implementability condition). The equation $\sum_{i=1}^{k} e_i(\mathbf{p},\mathbf{u}) = 0$ is amenable to an analytic solution with respect to u_i, for some i.

Conditions (i) and (ii) are obvious. Condition (iii) requires that no allocative inefficiency be present when all allocative distortions are zero. Notice that allocative distortions are not the u_{if}'s, but rather the extra terms that appear in the share equations due to the presence of allocative inefficiency, namely the e_i's. These terms are obtained by Shephard's lemma, they are given by $\mathbf{e}(\mathbf{p},\mathbf{u}) \equiv \dfrac{\partial A(\mathbf{p},\mathbf{u})}{\partial \mathbf{p}}$, and their signs are unrestricted *a priori*. Condition (iv) guarantees that allocative inefficiency is strictly increasing in absolute allocative distortions. Condition (v) requires that the input shares sum to unity.[3] And, finally, conditions (iii) and (iv) taken together imply that $A(\mathbf{p},\mathbf{u})$ has a global minimum at $\mathbf{e}(\mathbf{p},\mathbf{u}) = 0$.

Now, in principle, there may exist numerous functional forms for $A(\mathbf{p},\mathbf{u})$ that meet all *a priori* conditions. However, we found it impossible to discover a reasonably simple one. To highlight the sources of the difficulty, consider the following modification of Greene's func-

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[3] The implications of this condition are discussed later on.

tion: $A(log\,\mathbf{p},\mathbf{u}) = exp(\sum_{i=1}^{k}|u_i|\,log\,p_i)$. This violates conditions (*iii*) and (*iv*) because, if $u = 0$, $A = 1$, and the specification is generally non-monotonic with respect to $|u_i|$'s. Or, as an alternative, consider the functional form $A(\log\mathbf{p},\mathbf{u}) = \exp(\sum_{i=1}^{k}|u_i|\log p_i)\cdot(\mathbf{u}'\mathbf{u})^{1/2}$, where the last term is included to ensure that $A = 0$, if $u = 0$. Then the distortion terms in the share equations would be $e_i(\mathbf{p},\mathbf{u}) = \dfrac{\partial A(\log\mathbf{p},\mathbf{u})}{\partial\,log\,p_i} = |u_i|\,A$. But this is an unreasonable specification because all distortion terms are nonnegative, thus violating condition (*iii*). Another example is the functional form $A(\mathbf{p},\mathbf{u}) = \sum_{i=1}^{k}|u_i|^{p_i}$. In this case the allocative distortion terms are given by $e_i(\mathrm{p},\mathrm{u}) = \dfrac{\partial A(\mathrm{p},\mathrm{u})}{\partial\,log\,p_i} = p_i\,log\,|u_i|\cdot|u_i|^{p_i}$. When $u_i = \pm 1$, for all i, $e_i(\mathbf{p},\mathbf{u}) = 0$, for all i. But then $A(\mathbf{p},\mathbf{u})$ is not zero and condition (iii) is again violated. Still another example is the simple functional form $A(\mathbf{p},\mathbf{u}) = \sum_{i=1}^{k}p_i|u_i|$. Then $e_i(\mathbf{p},\mathbf{u}) = |u_i|$ and condition (iii) is violated because each allocative distortion term is constrained to be nonnegative, thus implying that the firm is prohibited from underestimating its optimal share equation for input *i*.

Moreover, in "cost plus input share equations" systems, there arises the following generic problem. Since input shares must sum to unity, we must have $\sum_{i=1}^{k}e_i(\mathbf{p},\mathbf{u}) = 0$. But this condition is extremely difficult to satisfy for values other than $u_i = 0$, for all i.[4] To appreciate the problem, consider $A(\log\mathbf{p},\mathbf{u}) = \sum_{i=1}^{k}|u_i|^{\log p_i}$ with the normalization $\mathbf{p} > 1$. Since we must respect the constraint that input shares sum to unity, it must hold that $\sum_{i=1}^{k}e_i(\mathbf{p},\mathbf{u}) = \sum_{i=1}^{k}log\,|u_i|\cdot|u_i|^{log p_i} = 0$. So, if we wanted to solve with respect to, say, u_k, we would have to face a nonlinear function that can be solved only by numerical methods. Therefore, the second fundamental shortcoming is that:

> **Conclusion**: Reasonable allocative inefficiency functions in "cost plus input share equations" systems violate one or more of the *a priori* conditions.

[4] The main problem being that generally it cannot be solved analytically with respect to any u_i in terms of $\mathbf{p}$ and u_j, $(j \neq i)$.

In light then of this conclusion, we switched our search for an easily operationalizable functional form of $A(\mathbf{p},\mathbf{u})$ to “cost plus input demand equations” systems.

Working in this direction, we managed to obtain the functional form that is shown in (3b) below:

$$C_{ft} = H(\mathbf{p}_{ft}, \mathbf{y}_{ft}; \boldsymbol{\theta}) + v_{0ft} + T_{ft} + A_{ft} \tag{3a}$$

$$A_{ft} = \sum_{i=1}^{k} | u_{ift} | \, p_{ift}^{\phi_{if}} \tag{3b}$$

$$X_{ift} = h_i(\mathbf{p}_{ft}, y_{ft}; \boldsymbol{\theta}) + v_{ift} + \phi_{if} p_{ift}^{\phi_{if}-1} | u_{ift} | \tag{3c}$$

$$T_{ft} \geq 0, \; A_{ft} \geq 0, \; \phi_{if} \gtrless 0 \tag{3d}$$

$$i = 1,...,k; \; f = 1,...,N; \; t = 1,...,M,$$

where X_{ift} is the demand of the ith input, $h_i(\mathbf{p}_{ft}, y_{ft}; \boldsymbol{\theta})$ represents the functional form of the demand for the ith input, and the input demand equations $X_{ift} = \dfrac{\partial C_{ft}}{\partial p_{ift}}$, for all i, f, t, have been derived by Shephard’s lemma. Aside of its simplicity, (3b) has three merits. First, the ϕ_{if} ’s are parameters that take negative or positive values, thus implying that the allocative distortions in the input demand equations may vary in either direction. Second, since $e_i(\mathbf{p},\mathbf{u}) = | u_{ift} | \phi_i p_{ift}^{\phi_i - 1}$, for all i, we can write $A(\mathbf{p},\mathbf{u}) = \sum_{i=1}^{k} | e_i(\mathbf{p},\mathbf{u}) | \cdot | \phi_i |^{-1}$. From this it is clear that $A(\mathbf{p},\mathbf{u})$ is strictly increasing in allocative distortions $(\phi_i \neq 0)$. Finally, observe that the input demand equations incorporate allocative distortions in a consistent way.

Next, for reasons that will become evident shortly, suppose the set of firms $\{1,...,N\}$ is decomposed into subsets P and S of private and state firms respectively. To calculate technical inefficiency, we take deviations from ownership-specific frontiers. In particular, if N_P and N_S denote the number of firms in each subset, $T_P^* = \min_{f \in P} T_f$ and $T_S^* = \min_{f \in S} T_f$ are the estimated parameters of the least technically inefficient firm in each group, and C_P^* and C_S^* stand for the average sample-period costs of the corresponding firms, we compute the following measures:

Technical inefficiency for private firms $\longrightarrow$ $T_p = M_P^{-1} \sum_{f \in P} (T_f - T_P^*) / C_P^*$ (4.a)

Technical inefficiency for state firms ⟶ $T_S = M_S^{-1} \sum_{f \in S} (T_f - T_S^*) / C_S^*$ (4.b)

Technical inefficiency due to ownership ⟶ $T_O = T_P - T_S$. (4c)

To justify these measures consider the subset of private firms. Since technical inefficiency must be nonnegative, we follow standard practice and define $T_f - T_P^*$ to be the deviation of technical inefficiency of private firm *f* from the least technically inefficiency firm in the same subset. In turn, these deviations are expressed as a percentage of the average sample-period costs incurred by the least technically inefficient private firm, i.e. $(T_f - T_P^*) / C_p^*$. Finally, by summing these normalized deviations for all private firms and dividing by their number, we obtain the index of average technical inefficiency for private firms. The analysis is similar for state firms.

Next, with the help of the estimated parameters φ_{if} and u_{if} we compute the following allocative inefficiency measures:

Allocative inefficiency for private firms ⟶ $A_P = (\sum_{i=1}^{k} M^{-1} \sum_{f \in P} | u_{ift} | \overline{p}_{if}^{\phi_{if}}) / \overline{C}_P$ (5.a)

Allocative inefficiency for state firms ⟶ $A_S = (\sum_{i=1}^{k} M^{-1} \sum_{f \in S} | u_{ift} | \overline{p}_{if}^{\phi_{if}}) / \overline{C}_S$ (5.b)

Allocative inefficiency due to ownership ⟶ $A_O = A_P - A_S$ (5.c)

Input-specific allocative inefficiency (private firms) ⟶ $A_{Pi} = M_P^{-1} \sum_{f \in P} | u_{ift} | \overline{p}_{it}^{\phi_{if}-1} / \overline{C}_P$ (5.d)

Input-specific allocative inefficiency (state firms) ⟶ $A_{Si} = M_S^{-1} \sum_{f \in S} | u_{ift} | \overline{p}_{if}^{\phi_{if}-1} / \overline{C}_S$ (5.e)

In these expressions $\overline{p}_{if} = M^{-1} \sum_{t=1}^{M} p_{ift}$, and $\overline{C}_P$ and $\overline{C}_S$ denote the average sample-period costs of private and state firms, respectively.

For estimation purposes, we assume that the error terms in (3) have a $k-$variate normal distribution, namely that $\mathbf{v}_{ft} = [v_{0ft}, v_{1ft}, \ldots, v_{k,ft}]' \sim N(0, \mathbf{\Sigma})$. This enables us to use standard Seemingly Unrelated Regressions (SUR) estimating techniques, instead of the more complicated approaches employed in the literature.[5] Moreover, in order to exploit the panel structure of our

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[5] These approaches give rise to highly non-linear likelihood functions that are very hard to estimate. For an example see the shadow price formulation of Eakin and Kniesner (1988)

data, we assume that

$$T_{ft} = T_f \, , \; u_{ift} = u_{if} \, , \text{for all } f, t \tag{6}$$

This implies that technical and allocative distortions are invariant with respect to time and makes it unnecessary to assume that they are independent of input prices and/or output level.[6] Finally, it is noted that estimation of the model requires the introduction of firm-specific dummy variables.

III. Data, definitions and measurement of variables

The crucial part of the data used in the estimations comes from balance sheets, income statements, and other sources of 19 manufacturing firms that operated continuously in Greece from 1979 to 1988 under the control of state-owned banks. Initially the number of companies at our disposal was much larger, but due to various data limitations, many of them had to be excluded. For example, by defining ownership on the basis of who owned at least 50% of the share capital, a large number of firms had to be dropped because the state controlled smaller percentages in their share capital. Also, several firms were left out because they did not have continuous records of operations over the sample period. Still other firms were left out because of data inconsistencies that could not be satisfactorily resolved, or because they did not belong to the manufacturing sector.

In principle the efficiency of these state firms ought to be compared to a set of similar manufacturing enterprises whose only difference lied in their ownership structure. But any attempt to select such a control sample would be open to the likelihood of selection bias. For this reason we adopted the following strategy. We grouped the 19 firms into the 9 two-digit Standard Industrial Classification (SIC) industries to which they belonged and in each of them we divided the aggregated variables by the number of firms. Hence, in the industries having more than one firm, what is observed is the performance of an "average" or "representative" state firm.[7] Since their efficiency would have to be contrasted to similar "average" or "repre-

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[6] It would have been possible to assume that T_{ft} follows a half-normal or exponential distribution. In that case, a two-step estimator proposed by Jondrow *et al*. (1982) could have been used to measure technical efficiency. The statistical properties of this two-step estimator are, for the most part, unknown. Moreover, in that case one would have to assume that technical inefficiency is independent of input prices.

[7] The distribution of state firms in the sample by industry was the following: 3, Food (20), 2, Beverages (21), 3, Textiles (23), 1, Wood and cork (25), 1, Paper and paper products (27), 1, Printing and publishing (28), 3, Chemicals (31), 1, Non-metallic minerals (33), 4, Metal products (35).

sentative" private firms, we then did the same with the corresponding 9 two-digit industries using data from the *Annual Survey of Industry*, of the National Statistical Service of Greece, and the *Annual Report*, of the Confederation of Greek Industries.

Turning now to the variables, the following list explains how they were defined and measured. The subscripts t and I index respectively the two-digit industry and the year of the observation in the sample.

y_{it} = real output, defined as: $(s_{it}/p^y_{it}) + [(in_{it}/p^y_{it}) - (in_{it-1}/p^y_{it-1})]$, where s_{it} is net sales, p^y_{it} is the Wholesale Price Index for manufacturing output and in_{it} refers to inventories of goods and raw materials.

L_{it} = number of employees.

K_{it} = real stock of net capital generated through the perpetual inventory method. More specifically, the formula $K_{it} = i_{it} + (1 - \delta_{0t})K_{it-1}$ was used. In this, I_{it} denotes gross investment, deflated by the implicit price deflator for fixed investment in manufacturing p^i_{it}, δ_{0t} is the depreciation rate, calculated as the ratio of depreciation charges over the value of net capital in the benchmark year, and k_{it-1} is the real stock of net capital in the previous period. As K_{i0}, the real value of net capital in 1979 was used.

D_{it} = short-term and long-term obligations deflated by the Wholesale Price Index for manufacturing output.

w_{it} = annual employee remuneration in current prices, including bonuses, social security contributions and other fringe benefits.

r_{it} = nominal rate of interest. It was calculated as a weighted average of short- and long-term interest rates using as weights the short-term and long-term loans from banks at the two-digit industry level.

c_{it} = nominal user cost of capital. This was generated with the help of the formula:

$$c_{it} = p^i_{it}(r_{it} + \delta_{it}),$$

where p^i_{it} is the implicit price deflator for fixed investment in manufacturing, and δ_{it} is the ratio of annual depreciation charges over the value of net capital stock at the end of the previous year.

The data to construct the private firm variables $y_{it}, L_{it}, K_{i0}, I_{it}$ *and* w_{it} were extracted from the *Annual Survey of Industry* of the National Statistical Service of Greece. The data to compute the variables D_{it} and δ_{it} were obtained from the *Annual Report* of The federation of Greek Industries, and, finally, data for all other variables were obtained from the 1989 issue of *Macroeconomic Times Series of the Greek Economy*, which is published intermittently by the Bank of Greece.

With regard to the data from the *Annual Survey of Industry* it should be noted that they refer to establishments, not firms. To any researcher not familiar with this source of information it would be natural to suspect that mixing its data with those from the *Annual Report* would introduce inconsistencies. Such a suspicion would be unfounded in the present case because during the period of the sample only a few large manufacturing companies operated more than one establishment. However, in addition, it is worth pointing the following. The only possibility for data inconsistency arises with respect to D_{it} because they are measured on a firm basis. In these two cases the observations were adjusted to allow for the number of establishments that the average firm in the annual survey of large-scale manufacturing operated during the sample years.

IV. Empirical results and interpretations

Our specification of system (3) is based on a transcendental cost function with three variable inputs (labor, capital, and debt).[8] All standard economic theory restrictions are incorporated in the estimation stage.[9] Regarding the parameters ϕ_{if} and u_{if}, what we would have liked to do would have been to allow them to vary freely for each firm and each input. However, with 18 firms and three inputs, this would require estimation of 108 parameters, something that we considered excessive in the present application. For this reason, subject to statistical testing, we carried out the estimations assuming that both parameters vary freely across inputs but remain constant within the sub-samples of private and state firms.

The results are shown in Table 1 below. Looking at the t-ratios of the parameter estimates we see that they are all statistically significant at the 5% confidence level. On the reassurance of this finding, observe that overall inefficiency for private firms amounted to 63.5%, whereas for state

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[8] If a firm operates in a financially suppressed environment, as the firms in our sample did at the investigated period, one can show that from the first-order conditions to profit maximization there emerges a system of interrelated factor demands including debt. For a detailed justification of the adopted specification, see Bitros (2000).

[9] In the cost function and input demand functions we included the trend, the trend squared and interactions of trend with output and prices.

Insert Table 1 here

firms it was 102.2%. From these figures it turns out that in absolute terms both private and state firms were very inefficient during the period of the sample. But in relative terms state firms were almost 61% (102.2/63.5) less efficient than private firms. Moreover, from the figures in the bottom row of the table emerges that responsible for this excess inefficiency were technical and allocative reasons by contributing 64% and 36%, respectively.

Next, in order to shed some light on the implications of the specification of equation (3b), we estimated three competing models and compared the results with those from Table 1. The first model is that which Ferrier and Lovell (FL) have proposed. The second model, referred to as (MG), is the modified Greene model. Its modification is obtained by setting $A(\mathbf{p},\mathbf{u}) = exp(\sum_{i=1}^{k} u_{if} \, log \, p_{ift}) \cdot (\sum_{i=1}^{k} u_{if}^2)^{1/2}$, where $u_{if} = u_{iP}$ if $f \in P$, $u_{if} = u_{iS}$ if $f \in S$, and the distortion function is given by $e_i(\mathbf{p},\mathbf{u}) = u_{if} A / p_{ift}$. The incorporation of the term $(\sum_{i=1}^{k} u_{if}^2)^{1/2}$ ensures that allocative inefficiency is zero when $u_{if} = 0$, for all i, f.

Table 2 gives the estimates from the aforementioned models. From these we observe that, the parameters corresponding to the technical inefficiency of private firms are not statistically differ-

Insert Table 2 here

ent from zero, whereas the parameters corresponding to the technical inefficiency of state firms are generally statistically significant and roughly of the same order with those of the consistent model. Hence, the competing models underestimate seriously the technical inefficiency of private firms. Turning next to the allocative inefficiency, from the results in the extreme right column of Table 2 we see that the competing models underestimate it for both private and state firms, but more so for private firms. By implication, we may conclude that the specification of the allocative inefficiency function is very critical because inconsistent models, among other biases, overestimate the overall inefficiency of state firms relative to that of private firms.

Using the same data Bitros (2000) estimated that, relative to private firms, state-owned enterprises incurred 46.2% higher costs per unit of output. Clearly, considering the differences in modeling and estimation techniques, this figure comes fairly close to the overall inefficiency that was reported in Table 1 for the self-consistent model (61%). So, when evaluated on this basis, his model may be considered to be quite robust. But when its evaluation is made by reference to the sources of inefficiency, the differences that emerge are quite significant. In particular, to the excess inefficiency of state firms Bitros (2000) finds that technical and allocative inefficiencies contributed 35.3% and 55.2%, respectively, whereas their contribution according to the self-consistent model was 64% and 36%. By implication then, *the model proposed by Bitros (2000) appears to: a) underestimate overall inefficiency of state firms, and b) reverse the order of inefficiencies in the sense that it attributes more of the overall inefficiency to allocative rather than technical reasons.*

Now let us look closer into the allocative mistakes that firms do. Relevant in this respect are the values of the fundamental parameters shown in Table 3. From these we observe that all estimates

Insert Table 3

are statistically significant at comfortable levels of confidence. Next, notice that $\phi_L, \phi_K, \phi_D > 0$. This implies that both private and public firms over-used all inputs. But given that $u_K = 0$, only private firms were efficient with respect to capital. Moreover, since the values of u_i's turned out to be higher for state than for private firms, the evidence is that public firms used all inputs less efficiently than private firms did.[10]

However, even though an examination of u_i's is necessary to understand the direction of factor misalignments, reaching more definite conclusions about the allocative mistakes of firms requires the decomposition of allocative inefficiency by factor of production. This is necessary because, how markets affect the efforts of firms to optimize the utilization of inputs, can only be answered by looking at measures that incorporate prices as well. Thus, according to the results shown in Table 4, 55.4% of allocative inefficiency by private firms is related to labor, whereas for public firms the same inefficiency is 54.3%. The corresponding figures for debt are 44.5% and

Insert Table 4

32.7%, and the balance is accounted for by capital. Actually the latter is about 13% for public firms, but practically zero for private firms.

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[10] For this model we performed also a Wald test that the ϕ_{if}'s are the same for private and public firms. The test was performed by estimating a model where both the ϕ_{if}'s and u_{if}'s were allowed to differ as between private and state firms and testing the ϕ_{if}'s by allowing for possibly different u_{if}'s. The p-value of the relevant chi-square statistic was 0.191.

Given that labor and financial markets during the period of the sample were highly distorted by all sorts of impediments imposed by the state, our expectations were that both types of firms would turn out to be highly inefficient from an allocative point of view. So we were not surprised by these results. Nor did the finding surprise us that overall allocative inefficiency in private firms turned out to be lower than that in state firms (see Table 1). After all, private firms are free from the extra controls to which state firms are subjected, and hence, they ought to adjust faster and more precisely to changing market conditions. Turning next to the debt-related allocative inefficiency, our expectation was that private firms would suffer more relative to state firms, because at the time credits to the former from the banking system were under a complex system of quotas and other credit-rationing devices. The results show that this is what happened, thus suggesting that financial markets operated in practice under an anti-business bias.

V. Conclusions

In this paper we pursued two objectives. The first was to discover a specification for the allocative inefficiency function such that the input share equations could be derived consistently through Shephard's lemma, whereas the second aimed at estimating the resulting system and comparing its results to competing models from the relevant literature. To accomplish the first objective we adapted the idea first suggested by Greene (1993) that allocative inefficiency ought to be related to input prices. The system of "cost plus input demand equations" that emerged was then estimated by Seemingly Unrelated Regression techniques using data from a sample of private and state firms operating in Greek manufacturing during the 1979-1988 period. This allowed us to achieve the second objective.

At the theoretical plane we showed that consistent specifications of the allocative inefficiency function may be difficult, if not impossible, to find in "cost plus input share equations" systems, because most reasonable specifications of this function violate either the monotonicity or the implementability condition. For this reason, we switched to a "cost plus input demand equations" framework and managed to obtain a specification that treats allocative misalignments in a self-consistent manner. Under this new approach it is no longer necessary to assume at the empirical plane that technical or allocative inefficiency is independent of relative prices, an hence, the improvement over past endeavors should be encouraging. Moreover, estimation is significantly simplified since standard SUR techniques may be used instead of the non-linear likelihood functions estimated in the relevant literature.

The empirical results point to the following conclusions. *First*, technical inefficiency was estimated to be 28.5% of costs for private firms and 53.2% for public firms. *Second*, the corresponding percentages for allocative inefficiency were 39% and 45% of costs. *Third*, these estimates showed that there was a significant ownership effect as public firms turned out to be 61% less efficient compared to private firms. *Fourth*, state firms use all inputs inefficiently. *Fifth*, private firms use physical capital efficiently. *Last*, but certainly not least, estimates of technical and allocative inefficiency depend critically upon a self-consistent specification of the allocative inefficiency function.

Bibliography

1. Atkinson, S. E., and R. Halvorsen, (1984), "Parametric efficiency tests, economies of scale, and input demand in U.S. electric power generation", *International Economic Review*, 25, 647-662.
2. ---, (1986), "The relative efficiency of public and private firms in a regulated environment: The case of U.S. electric utilities", *Journal of Public Economics*, 29, 281-294.
3. --------------------- and Cornwell, C., (1994a), "Parametric estimation of technical and allocative inefficiency with panel data", *International Economic Review*, Vol. 35, pp. 231-243.
4. ---, (1994b), "Estimation of output and input technical efficiency using flexible functional form and panel data", *International Economic Review*, Vol. 35, pp. 245-255.
5. Bitros, G. C., (2000), "Firm ownership and economic efficiency", Mimeo, Department of Economics, Athens University of Economics and Business.
6. Caves, D. W. and Christensen, L. R., (1980), "The relative efficiency of public and private firms in a competitive environment: The case of Canadian railroads", *Journal of Political Economy*, Vol. 88, pp. 958-976.
7. Christensen, L. R. and Greene, W., (1976), "Economies of scale in U. S. electric power generation", *Journal of Political Economy*, Vol. 84, pp.655-676
8. Di Lorenzo, T. J. and Robinson, R., (1982), "Managerial objectives subject to political market constraints: electric utilities in the US", *Quarterly Review of Economic and Business*, Vol. 22, pp. 113-125.
9. Eakin, B. K. and T. J. Kniesner, (1988), "Estimating a non-minimum cost function for hospitals", *Southern Economic Journal*, 54, 583-597.
10. Fare, R., Grosskopf, S. and Logan, J., (1985), "The relative performance of publicly owned and privately owned electric utilities", *Journal of Public Economics*, Vol. 26, 89-106.
11. Ferrier, G., and K. Lovell, (1990), "Measuring cost efficiency in banking: Econometric and linear programming evidence", *Journal of Econometrics*, 46, 229-245.
12. Greene, W., (1993), "The econometric approach to efficiency analysis", in H. O. Fried, C. A. Knox Lovell, and S. S. Schmidt (eds.), *The measurement of productive efficiency: Techniques and Applications* (Oxford: Oxford University Press).

13.Jondrow, J., C. A. K. Lovell, I. S. Materov, and P. Schmidt, (1982), "On the estimation of technical inefficiency in the stochastic frontier production model", *Journal of Econometrics,* 19, 233-238.

14.Kalirajan, K., (1990), "On measuring economic efficiency", *Journal of Applied Econometrics*, Vol. 5, pp. 75-86.

15.Kumbakhar, S., (1991), "Estimation of technical inefficiency in panel data models with firm- and time-specific effects", *Economics Letters,* 36, 43-48.

Table 1 Estimates of inefficiency from model (3)[1]

Firms	Sources of inefficiency	
	Technical[2]	Allocative[3]
Private	.285(2.09)	.350 (2.16)
State	.532(5.72)	.490(3.34)
Ownership[4]	.247(2.17)	.140(2.85)

Notes: 1. The estimations were performed using SHAZAM.
2. Figures in the parentheses represent the values of t-statistic
3. It is worth pointing out that in our application average factor prices do not exhibit substantial variation within private and state firms, so allocative inefficiency measures are representative.
4. Reports the difference between state and private firms.

Table 2 Comparison of estimates from various models[1]

Models	Firms	Sources of inefficiency	
		Technical	Allocative
Consistent[2]	Private	.285(2.09)	.350 (2.16)
	State	.532(5.72)	.490(3.34)
	Ownership	.247(2.17)	.140(2.85)
FL	Private	.06(.21)	.016(3.82)
	State	.615(5.58)	.193(4.02)
	Ownership	.557(1.98)	.177(3.97)
MG	Private	.452(1.06)	$.28\ 10^{-3}$(.058)
	State	.458(6.01)	.038(5.97)
	Ownership	.0057(.01)	.038(4.85)
N[3]	Private	.227(1.19)	
	State	.501(4.84)	
	Ownership	.274(1.58)	

Notes: 1. See notes in Table 1.
2. This is the same model that was presented in Table 1.
3. N stands for naïve because it consists of a cost function without allocative inefficiency component.

Table 3 Parameter estimates from model (3)

	u_K	u_L	u_D	ϕ_K	ϕ_L	ϕ_D	p[1]
Private	0.00[2]	23.9 (2.81)	35.7 (3.69)	1.31 (15.64)	1.22 (16.53)	0.905 (1.45)	.0055
State	54.0 (13.7)	31.8 (5.08)	52.5 (5.13)				

Notes: 1. p is the p-value of the chi-square test that u_{if} 's are the same for private and public firms. From the value of the statistic we conclude that they are statistically different.
2. 0.00 means an entry that is less than 10^{-4}.

Table 4 Decomposition of allocative inefficiency by ownership and productive factor[1]

Ownership	Capital	Labor	Debt
Private[2]	0.00[3]	.554(1.92)	.445(2.37)
Public	.130(2.81)	.543(3.37)	.327(3.67)

Notes: 1. See notes in Table 1.
2. Row sums are unity (100%).
3. This figure was of the order of magnitude 10^{-4}.