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SECTORAL PRODUCTIVITY GROWTH AND PRICE-MARGINAL COST MARGINS IN THE INTERMEDIATE GOODS MARKET

BY ALISON KELLY-HAWKE

Suffolk University

Models of aggregate productivity growth linked to sectoral models of production typically assume that all intermediate goods markets are perfectly competitive. An econometric analysis reveals that many intermediate goods markets exhibit transactions at prices quite different than marginal cost. Measures of productivity growth that ignore these market imperfections are biased. A measure of the actual magnitude of the bias that emerges under the assumption of equating price to marginal cost is constructed.

I. INTRODUCTION

In all studies measuring productivity growth, the perfect markets assumption allows intermediate goods to be viewed as internal, offsetting transfers. Sectoral deliveries to intermediate demand, such as steel produced for the automobile industry, and intermediate purchases, such as steel consumed by the automobile industry, are self-canceling transactions within the economy. It is true that the steel transactions are offsetting in terms of quantities. However, the values, in terms of producers' and consumers' prices, are offsetting if and only if price is equal to marginal cost. This "crucial" assumption of perfect markets is not realistic and is one on which measurements of productivity growth depend sensitively.

In previous empirical work, Hall (1988) tests for the equality of price and marginal cost, where he theoretically examines the importance of intermediate inputs, but ignores the contribution of intermediate inputs in his estimates. Domowitz, Hubbard, and Petersen (1988) and Norbbin (1993) modify Hall's work; however, they focus solely on the manufacturing sector. Finally, all of these papers rely heavily on choosing instruments that are uncorrelated with sectoral productivity shocks.

Given the difficulties of finding instruments that are exogenous, Roeger (1995) provides an alternative method for estimating mark-up ratios that does not require the strong identifying assumptions found in the previous analyses. Roeger uses the hypothesis of imperfect competition to explain the apparent lack of correlation between price- and quantity-based productivity measures in U.S. manufacturing. In order to identify likely causes for measurement error in total factor productivity, he uses information from both residuals and demonstrates that these measures are highly correlated for U.S. manufacturing when he controls for the presence of a mark-up component.

This paper shows that a simple variant of imperfect competition cannot reconcile price- and quantity-based productivity measures. This occurs because

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once the assumption of perfect competition is relaxed, the aggregate rate of productivity growth is expressed as a cost-weighted sum of the sectoral rates of productivity growth *plus* a term that reflects an inequality between price and marginal cost in intermediate goods markets (Kelly, 1993). This additional term, a dead-weight loss term, is quite independent of the sectoral productivity growth rates and, moreover, this term is ignored by the quantity-based model. The direction and magnitude of the dead-weight loss term cannot be known *a priori*; this is significant because it implies that it is not possible to adjust the quantity-based model of aggregate productivity growth by some factor that would account for sectoral mark-ups in intermediate goods markets.

Due to the failure of the quantity-based model to recognize the contributions of intermediate input to productivity growth, this paper focuses solely on the price-based model and employs this model to document the disparity between price and marginal cost in intermediate goods markets. A new method for testing the equality of price and marginal cost is introduced. In addition, this paper examines data on output and inputs for 35 two-digit industries and these data reveal that many U.S. industries have marginal cost very different from price. Finally, it is found that the assumption of marginal cost pricing is found to bias measures of aggregate productivity growth by as much as one-half percentage point per year.

This paper is organized as follows. Section II describes the productivity model and outlines the theoretical foundation for estimating industry price-marginal cost markups. Section III describes the econometric method used and section IV presents the results. Section V compares the value of aggregate productivity growth when the equality of price and marginal cost is a maintained assumption to the value obtained when price differs from marginal cost.

II. Modeling Strategy

This section explicitly derives the estimating equation which is ultimately used to measure the disparity between price and marginal cost for producers in an individual intermediate goods market. The appropriate specification of an industry's technology is based on a gross output production function for each producing sector rather than a value-added production function:

$$X_j = f^j(K_j, L_j, M_{1j}, \ldots, M_{nj}, t), \tag{1}$$

where X_j, K_j, L_j, and M_{ij} are the quantities of gross output, capital, labor, and the i-th intermediate input, respectively, in the j-th industry.

Hall (1988) shows that using value-added (net output) instead of true production data (gross output) leads to an overestimate of the true Solow residual. In order to illustrate this result, it is helpful to review the relationship between production output and value-added output:

$$X_{VA,t} = \frac{X_t - \gamma_t m_t}{1 - \gamma_t}, \tag{2}$$

where $X_{VA,t}$ is the value-added output, X_t is the production output, γ_t is the intermediate input share, and m_t is the change in intermediate input less the change in capital.

Hall then uses this relationship to show that the true Solow residual will be overestimated by

$$e_t = e_{VA,t}(1-\gamma_t), \tag{3}$$

where e_t is an estimate of the rate of change in gross output and $e_{VA,t}$ is an estimate of the rate of change in value-added that is not caused by changes in input.

Totally logarithmically differentiating equation (1) with respect to time yields the equation for the rate of sectoral productivity growth, e_j,

$$e_j = \frac{\dot{X}_j}{X_j} - \frac{\partial \ln X_j}{\partial \ln K_j}\frac{\dot{K}_j}{K_j} - \frac{\partial \ln X_j}{\partial \ln L_j}\frac{\dot{L}_j}{L_j} - \sum_i \frac{\partial \ln X_j}{\partial \ln M_{ij}}\frac{\dot{M}_{ij}}{M_{ij}}, \tag{4}$$

where the dot over a variable indicates the conventional time derivative.

Maintaining constant returns to scale but not requiring that price equal marginal cost, the values for the elasticities in equation (4) may be re-expressed in the following form:

$$e_j = \frac{\dot{X}_j}{X_j} - \frac{p_{kj}K_j}{MC_jX_j}\frac{\dot{K}_j}{K_j} - \frac{p_{lj}L_j}{MC_jX_j}\frac{\dot{L}_j}{L_j} - \sum_i \frac{p_{ij}M_{ij}}{MC_jX_j}\frac{\dot{M}_{ij}}{M_{ij}}, \tag{5}$$

where p_{kj}, p_{lj}, and p_{ij} are the prices paid by producers for capital, labor, and intermediate inputs, respectively; MC_j is the marginal cost in the j-th sector. Thus, the sectoral rate of productivity growth is expressed as the rate of growth of the corresponding sector's output less a weighted average of the rates of growth of capital, labor, and intermediate inputs in the sector. Under the assumption of constant returns to scale, $MC_j = AC_j$ (where AC_j is the average cost in the j-th sector), the weights in equation (5) are equivalent to input shares in total cost.

Under constant returns to scale it is possible to make a substitution for the price of capital in the j-th sector, p_{kj}. The shares,

$$\frac{p_{kj}K_j}{MC_jX_j}, \quad \frac{p_{lj}L_j}{MC_jX_j} \quad \text{and} \quad \sum_i \frac{p_{ij}M_{ij}}{MC_jX_j},$$

are competitive factor shares and thus sum to one. The denominator for each of the shares represents total cost which is a variable whose value is known. The prices and quantities of labor and intermediate input are also known. Thus, the following constraint holds:

$$\frac{p_{kj}K_j}{MC_jX_j} = 1 - \frac{p_{lj}L_j}{MC_jX_j} - \sum_i \frac{p_{ij}M_{ij}}{MC_jX_j}. \tag{6}$$

Inserting this constraint into equation (5) and rearranging terms yields:

$$e_j = \frac{\dot{x}_j}{x_j} - \frac{p_{lj}L_j}{MC_jX_j}\frac{\dot{l}_j}{l_j} - \sum_i \frac{p_{ij}M_{ij}}{MC_jX_j}\frac{\dot{m}_{ij}}{m_{ij}}, \tag{7}$$

where x_j, l_j, and m_{ij} are the ratios of gross output, labor, and the i-th intermediate input, respectively, to capital.

Due to the apparent random element underlying productivity growth, one can view the rate of sectoral productivity growth, e_j, as the sum of a constant underlying growth rate, θ_j, and a random element, μ_j. The sectoral rate of productivity growth can thus be written as follows:

$$e_j = \theta_j + \mu_j. \tag{8}$$

[For ease of exposition the time subscript has been omitted from e_j and μ_j in equation (8).] Inserting equation (8) into (7) and rearranging yields:

$$\frac{\dot{x}_j}{x_j} = \theta_j + \frac{p_{lj} L_j}{MC_j X_j} \frac{\dot{l}_j}{l_j} + \sum_i \frac{p_{ij} M_{ij}}{MC_j X_j} \frac{\dot{m}_{ij}}{m_{ij}} + \mu_j. \tag{9}$$

Multiplying the input growth rates in equation (9) by a "well-chosen 1," (p_j/p_j) leads to the following equation:

$$\frac{\dot{x}_j}{x_j} = \theta_j + \frac{p_j}{MC_j} \frac{p_{lj} L_j}{p_j X_j} \frac{\dot{l}_j}{l_j} + \sum_i \frac{p_j}{MC_j} \frac{p_{ij} m_{ij}}{p_j X_j} \frac{\dot{m}_{ij}}{m_{ij}} + \mu_j, \tag{10}$$

where p_j is the price received by producers in the j-th industry.

Subtracting the following term,

$$\frac{p_{lj} L_j}{p_j X_j} \frac{\dot{l}_j}{l_j} + \sum_i \frac{p_{ij} M_{ij}}{p_j X_j} \frac{\dot{m}_{ij}}{m_{ij}},$$

from both sides of equation (10) yields:

$$\frac{\dot{x}_j}{x_j} - \frac{p_{lj} L_j}{p_j X_j} \frac{\dot{l}_j}{l_j} - \sum_i \frac{p_{ij} M_{ij}}{p_j X_j} \frac{\dot{m}_{ij}}{m_{ij}} = \theta_j + \left(\frac{p_j}{MC_j} - 1 \right) \left(\frac{p_{lj} L_j}{p_j X_j} \frac{\dot{l}_j}{l_j} + \sum_i \frac{p_{ij} M_{ij}}{p_j X_j} \frac{\dot{m}_{ij}}{m_{ij}} \right) + \mu_j. \tag{11}$$

It is important to note that the left-hand side of equation (11) is not equivalent to the sectoral rate of productivity growth because the weights premultiplying the input growth rates are not the cost shares required by the definition of productivity growth. With perfect markets, however, $p_j = MC_j$, and thus the term $((p_j/MC_j) - 1)$ on the right-hand side of equation (11) reduces to zero. In this instance, sectoral productivity growth is measured as the residual of

$$\frac{\dot{x}_j}{x_j} - \frac{p_{lj} L_j}{p_j X_j} \frac{\dot{l}_j}{l_j} - \sum_i \frac{p_{ij} M_{ij}}{p_j X_j} \frac{\dot{m}_{ij}}{m_{ij}}$$

or simply $\theta_j + \mu_j$. Once the assumption of perfect markets is relaxed, one must also account for the degree of disparity between price and marginal cost in the output market. Allowing $\alpha = (p_j/MC_j) - 1$, yields:

$$Y_j = \theta_j + \alpha Z_j + \mu_j, \tag{12}$$

where Y_j is the left-hand side of equation (11), θ_j is the constant underlying growth rate of sectoral productivity growth, μ_j is the random component of the rate of sectoral productivity growth, and Z_j is

$$\frac{p_{lj}L_j}{p_jX_j}\frac{\dot{l}_j}{l_j}+\sum_i \frac{p_{ij}M_{ij}}{p_jX_j}\frac{\dot{m}_{ij}}{m_{ij}}.$$

Equation (12) will be the estimating equation used to test for the equality of price and marginal cost.

III. Econometric Method

Under the conventional assumption of perfect markets ($p_j = MC_j$), α in equation (12) should equal zero. If α is found to be different from zero, then one can conclude that price differs from marginal cost in the specified industry. Following the lead of Hall (1988) and Roeger (1995), this analysis also assumes that α is constant for the whole period 1947–89. Much recent work has concentrated on cyclical movements of markups. However, as Chatterjee and Cooper (1993) note, the evidence advanced so far does not convincingly refute the assumption of acyclical markups.[1]

There are some limitations of such an empirical model that attributes all evidence of $\alpha \neq 0$ to the model of price different from marginal cost. For example, finding $\alpha > 0$ could occur when there are hiring costs and capital adjustment costs. Similarly, $\alpha < 0$ could infer a situation other than long-run equilibrium. Thus, it should be noted that $\alpha \neq 0$ does not necessarily infer the presence of imperfect markets. However, the present model is sufficient for the investigation of the extent of bias in the model of productivity growth that assumes price equals marginal cost. The model in equation (12) is adopted noting that the assumption of a long-run equilibrium establishes the presumption that $\alpha \geq 0$.

In the estimating equation θ_j represents the average annual rate of productivity growth in the j-th sector if and only if a profit-maximizing, long-run equilibrium exists. This term measures sectoral productivity growth regardless of whether price equals marginal cost, but does require that the industry equate marginal revenue with long-run marginal cost. Thus, a value of $\alpha \geq 0$ is not inconsistent with a profit-maximizing long-run equilibrium. However, if marginal revenue is less than long-run marginal cost, perhaps because of non-profit-maximizing behavior or subsidies, then θ_j is still an intercept—it is still an average growth rate of the dependent variable—it is just not equal to sectoral productivity growth.

IV. Results

The results of applying equation (12) to individual data are reported in Table 1. The data set is discussed in the Data Appendix. The inferences regarding sectoral productivity growth are consistent with conventional beliefs and, more specifically, the conclusions drawn from a related study of productivity growth

[1]In addition, in order to show that price mark-ups remain constant over time, two tests of model stability (the CUSUM and the CUSUMSQ tests) were performed. In short, the null hypothesis that the coefficient attached to price mark-ups is the same in every period could not be rejected. In other words, for each industry, both tests suggest that the model is stable over time.

TABLE 1

REGRESSION RESULTS FROM EQUATION (12), 1947–89

Industry	$\hat{\theta}$		$\hat{\alpha}$	
Agriculture	0.014	(1.897)	−0.093	(−0.589)
Metal mining	−0.002	(−0.154)	−0.155	(−1.254)
Coal mining	0.008	(0.747)	0.021	(0.179)
Crude petroleum and natural gas	−0.013	(−1.220)	−0.748	(−4.063)
Nonmetallic mineral mining	0.012	(1.594)	0.554	(3.192)
Construction	0.002	(0.847)	0.040	(0.865)
Food and kindred products	0.005	(1.859)	0.041	(0.377)
Tobacco manufacturers	−0.002	(−0.348)	−0.335	(−2.814)
Textile mill products	0.012	(3.244)	−0.076	(−1.631)
Apparel and other textile products	0.013	(6.831)	0.007	(0.233)
Lumber and wood products	0.003	(0.697)	−0.097	(−2.136)
Furniture and fixtures	0.008	(2.812)	0.129	(3.145)
Paper and allied products	0.004	(1.255)	0.189	(3.737)
Printing and publishing	−0.000	(−0.072)	0.152	(2.886)
Chemicals and allied products	0.014	(2.082)	0.201	(1.616)
Petroleum refining	0.006	(0.818)	−0.364	(−6.078)
Rubber and plastic products	0.006	(1.415)	−0.009	(−0.227)
Leather and leather products	−0.000	(−0.002)	−0.184	(−1.895)
Stone, clay, and glass products	0.005	(2.184)	0.225	(7.107)
Primary metals	−0.003	(−0.792)	0.127	(4.214)
Fabricated metal products	0.006	(2.768)	0.127	(4.788)
Machinery, except electrical	0.013	(3.771)	0.173	(4.852)
Electrical machinery	0.018	(6.923)	0.082	(3.076)
Motor vehicles	0.008	(2.671)	0.241	(13.837)
Other transportation equipment	0.006	(1.474)	−0.052	(−1.617)
Instruments	0.013	(3.628)	0.094	(1.984)
Miscellaneous manufacturing	0.015	(2.864)	0.150	(2.140)
Transportation warehousing	0.009	(2.449)	0.291	(3.217)
Communication	0.021	(4.937)	0.031	(0.258)
Electric utilities	0.014	(4.174)	−0.059	(−0.443)
Gas utilities	0.001	(0.183)	−0.066	(−0.556)
Trade	0.012	(3.953)	0.316	(3.309)
Finance, insurance and real estate	0.002	(0.837)	0.030	(0.286)
Other services	0.000	(0.029)	0.207	(1.953)
Government enterprises	−0.005	(−0.863)	−0.021	(−0.119)

Note: $\hat{\theta}$ is the estimated average annual rate of productivity growth; $\hat{\alpha}$ is the estimated price–cost mark-up; t statistics are in parentheses.

by Fraumeni and Jorgenson (1986). In particular, 28 industries show a small positive value for the rate of sectoral productivity growth. Of these 28 industries, 14 have values of $\hat{\theta}$ significant at the 1 percent level and one has a value of $\hat{\theta}$ significant at the 5 percent level. Seven industries show a small negative value for the rate of sectoral productivity growth; however, these values are not significant.

Table 2 isolates the 19 industries that have a statistically significant point estimate of α. The hypothesis of the equality of price and marginal cost ($H_0 : \alpha = 0$) is strongly rejected for 15 of the 35 industries at the 1 percent significance level and is rejected at the 5 percent significance level for four others. Table 2 lists 15 industries as "Mark-up Industries." In these instances, there is sufficient statistical evidence to conclude that $\alpha > 0$, or equivalently, price is greater than marginal cost which infers that imperfect competition is present.

In four industries, categorized in Table 2 as "Mark-down Industries," the data suggest that marginal cost is greater than price. This type of outcome ($\alpha < 0$)

TABLE 2

INDUSTRIES EXHIBITING IMPERFECT MARKETS

	$\hat{a}$	% of Output Demanded as Intermediate Input	Sectoral Productivity Growth 1948–68	Sectoral Productivity Growth 1969–89
Markdown Industries				
Lumber and wood products	−0.097	1.000	0.0017	0.0017
Tobacco manufacturers	−0.335	0.171	0.0000	−0.0012
Petroleum refining	−0.364	0.599	0.0022	0.0058
Crude petroleum and natural gas	−0.748	1.000	0.0035	−0.0132
Markup Industries				
Electrical Machinery	0.082	0.499	0.0058	0.0081
Instruments	0.094	0.329	0.0048	0.0046
Primary metals	0.127	1.000	−0.0016	−0.0019
Fabricated metal products	0.127	0.890	0.0018	0.0020
Furniture and fixtures	0.129	0.078	0.0027	0.0037
Miscellaneous manufacturing	0.150	0.286	0.0055	0.0061
Printing and publishing	0.152	0.581	0.0019	−0.0027
Machinery, except electrical	0.173	0.419	0.0000	0.0087
Paper and allied products	0.189	0.870	0.0015	0.0015
Other services	0.207	0.385	0.0001	0.0010
Stone, clay, and glass products	0.225	0.946	0.0015	0.0021
Motor vehicles	0.241	0.341	0.0058	0.0000
Transportation and warehousing	0.291	0.592	0.0061	0.0027
Trade	0.316	0.295	0.0056	0.0016
Nonmetallic mineral mining	0.554	1.000	0.0064	0.0036

Note: $\hat{a}$ is the estimated price–cost mark-up.

implies that a long-run disequilibrium exists and thus $\hat{\theta}$ cannot be equated with sectoral productivity growth. It should be noted, however, that the estimating model is not constrained to have an outcome of price greater than marginal cost. A negative estimate of α is a perfectly legitimate result. It still infers that price is different from marginal cost and has an equally important influence in the following section when the aggregate rate of productivity growth is calculated.

V. CALCULATING AGGREGATE PRODUCTIVITY GROWTH

Data on output and inputs for 35 two-digit industries reveals that 19 of 35 U.S. industries have marginal cost very different from price. Present models of productivity growth, however, maintain that price is equal to marginal cost. Thus, the purpose of this section is to investigate the extent and direction of bias in the model of productivity growth that assumes price is equal to marginal cost.

If perfect markets is the underlying assumption, then the rate of aggregate productivity growth can be expressed as a weighted sum of the sectoral rates of productivity growth (Gollop, 1979):

$$E = \sum_j \frac{C_j}{C_G} e_j \tag{13}$$

where C_j is the total cost of gross output in the j-th industry and C_G is the total cost of producing gross output in all industries. The annual rate of aggregate productivity growth under the assumption that price equals marginal cost for all

TABLE 3

RESULTS FROM EQUATION (13) AND EQUATION (14), 1948–89

Year	Price = Marginal Cost[a]	Price ≠ Marginal Cost[b]	Bias[c]
1948	0.009	−0.024	0.033
1949	−0.001	−0.006	0.005
1950	0.029	0.043	−0.013
1951	−0.001	−0.002	0.001
1952	−0.003	−0.003	0.001
1953	0.011	0.021	−0.011
1954	−0.002	−0.011	0.008
1955	0.023	0.038	−0.016
1956	−0.006	−0.007	0.001
1957	0.002	0.014	−0.012
1958	0.002	−0.007	0.008
1959	0.020	0.029	−0.010
1960	0.004	0.001	0.004
1961	0.004	−0.000	0.004
1962	0.014	0.021	−0.007
1963	0.013	0.011	0.002
1964	0.017	0.018	−0.002
1965	0.014	0.019	−0.005
1966	0.008	0.010	−0.002
1967	−0.001	−0.016	0.015
1968	0.014	0.016	−0.001
1969	0.004	0.010	−0.006
1970	−0.000	0.007	0.007
1971	0.013	0.019	−0.005
1972	0.016	0.021	−0.005
1973	0.004	0.010	−0.006
1974	−0.019	−0.021	0.001
1975	−0.000	−0.004	0.004
1976	0.019	0.024	−0.005
1977	0.010	0.015	−0.005
1978	0.001	0.004	−0.003
1979	−0.008	−0.008	0.000
1980	−0.011	−0.014	0.003
1981	0.003	0.002	0.001
1982	−0.010	−0.010	−0.000
1983	0.009	0.015	−0.006
1984	0.015	0.017	−0.002
1985	0.002	0.002	0.001
1986	0.012	0.013	−0.001
1987	0.001	0.002	−0.001
1988	0.005	0.003	0.001
1989	−0.002	0.002	−0.000

[a]Value for the Aggregate Rate of Productivity Growth when "Price equals Marginal Cost."

[b]Value for the Aggregate Rate of Productivity Growth when "Price differs from Marginal Cost."

[c]Bias is calculated by subtracting Price ≠ Marginal Cost from Price = Marginal Cost.

35 industries is calculated for the years 1948–89. The results are reported in the second column of Table 3.

If price differs from marginal cost, then the rate of aggregate productivity growth has the following form (Kelly, 1993):

$$E=\sum_j \frac{C_j}{C_G} e_j+\sum_j \sum_i \frac{(p_{ij}-MC_{ij})M_{ij}}{C_G} \frac{\dot{m}_{ij}}{m_{ij}}. \tag{14}$$

The influence of price different from marginal cost on the measure of productivity growth is reflected in the last term. This term explicitly identifies the contributions of intermediate goods markets on the measure for aggregate productivity growth. In this study, price is equal to marginal cost in 16 of the 35 industries, thus their contribution to the last term is zero.

However, with price equal to marginal cost as a maintained assumption, simply summing the weighted sectoral rates of productivity growth fails to account for any degree of imperfect competition that may be present in intermediate goods markets. In order to correct for any bias that this methodology could impose, one must first identify the industries that exhibit a significant disparity between price and marginal cost in the output market. Then, the growth rate of output in each sector that serves as an intermediate goods supplier is also incorporated into the last term in equation (14).

In addition to identifying the industries with a statistically significant point estimate of α, Table 2 also shows the percentage of an industry's output that is demanded as intermediate input.[2] For instance, 7.8 percent of the furniture and fixtures industry's output is used as input in another industry.

Once the percentage of output that serves as intermediate input and the price-marginal cost mark-up are specified for each industry, these values are then incorporated into the last term in equation (14):

$$\sum_j \sum_i \frac{(p_{ij} - MC_{ij})M_{ij}}{C_G} \frac{\dot{M}_{ij}}{M_{ij}}.$$

For example, the furniture and fixtures industry's contribution to the last term has the following form:

$$(0.078)(0.129) \frac{X_j}{C_G} \frac{\dot{X}_j}{X_j},$$

where 0.078 represents the percentage of output that serves as intermediate input and 0.129 represents the price-marginal cost mark-up.

The sum over each industry's contribution is then calculated and this sum is equal to the last term in equation (14). The third column in Table 3 ("Price$\neq$ Marginal Cost") shows the rate of aggregate productivity growth when price differs from marginal cost.[3] As noted, the Price$\neq$Marginal Cost measure accounts for the degree of disparity between price and marginal cost in intermediate goods markets. The column labeled "bias" equals the "Price = Marginal Cost" column

[2]The July 1991 issue of *The Survey of Current Business* presents the tables of the *Benchmark Input–Output Accounts of the United States 1982* in summary form. One of the tables (*The Use of Commodities by Industries*) calculates the value of an industry's output that is demanded as intermediate input.

[3]It should be noted that the value for the rate of aggregate productivity growth allowing for price different from marginal cost is an approximation for the "true" value for the rate of aggregate productivity growth. This occurs because the estimates for the sectoral rates of productivity growth for the four industries that exhibited price below marginal cost are not equal to the "true" measures of the sectoral rates of productivity growth due to their long-run disequilibrium. However, since the assumption of long-run equilibrium is only violated in 4 of the 35 industries, the estimates of θ for these four industries will be incorporated into the calculation for the rate of aggregate productivity growth.

less the "Price ≠ Marginal Cost" column or the bias that emerges if one calculates the rate of aggregate productivity growth by simply summing the sectoral rates of productivity growth.

A positive (negative) bias indicates that by using the Price = Marginal Cost approach, one would overestimate (underestimate) the value for aggregate productivity growth. Of the 43 years covered in this study, the Price = Marginal Cost approach overestimates the value for aggregate productivity growth 19 times and this bias averages 0.5 percentage points. The Price = Marginal Cost approach underestimates the value for aggregate productivity growth 23 times and here the bias averages −0.5 percentage points. It should also be noted that the Price = Marginal Cost approach and the Price ≠ Marginal Cost approach do not produce equivalent values in any year. (In Table 3 a zero bias appears in only two time periods. This occurs because of rounding.) In fact, in any given year an average of 0.5 percent of the aggregate rate of productivity growth is biased if the measure is formulated using the Price = Marginal Cost approach. In order to illustrate this point further, suppose one calculated the average rate of productivity growth (assuming that price equals marginal cost) over all industries and all years and obtained the value 1.0 percent. By recognizing that this calculation contains, on average, a one-half percentage point bias, then one can conclude that this rate of productivity growth can be biased by as much as 50 percent.

With the exception of a few short time periods, there is really no systematic pattern of negative or positive biases. For example, from 1964–66, 1971–73, 1976–78, and 1982–84 the Price = Marginal Cost approach consistently underestimates aggregate productivity growth. The Price = Marginal Cost approach fails to account for the increasing efficiency which intermediate goods markets contribute to aggregate productivity growth.

An examination of Table 3 also reveals that the magnitude of the biases has lessened over time. This result can be explained by examining the sectoral productivity growth rates of the 19 industries that showed evidence of price significantly different from marginal cost. Columns 4 and 5 of Table 2 show average sectoral productivity growth rates from 1948–68 and 1969–89, respectively. A comparison of these two time periods indicates that the four industries with the largest mark-ups (motor vehicles, transportation and warehousing, trade, and nonmetallic mineral mining) and two industries with large mark-downs (tobacco and crude petroleum and natural gas) experienced significant decreases in average productivity growth. One possible implication of this decline in average productivity growth is that the magnitude of the positive and negative contributions to the last term in equation (14) has also declined; thus, the bias between the Price = Marginal Cost and the Price ≠ Marginal Cost measures has also become smaller.

Nonetheless, a bias still exists and its direction and magnitude cannot be known *a priori*. This is significant because it implies that it is not possible to adjust the Price = Marginal Cost approach by some factor that would account for sectoral mark-ups. Thus, in order to measure productivity growth correctly, one must explicitly account for the contributions of intermediate input to productivity growth—a simple variant of imperfect competition cannot reconcile the Price = Marginal Cost and the Price ≠ Marginal Cost productivity measures.

VI. Concluding Remarks

The conclusion from the model is that over one-half of the industries exhibit a significant disparity between price and marginal cost. The evidence suggests that the measure for aggregate productivity growth cannot be calculated as the simple weighted sum of the sectoral rates of productivity growth. This method ignores the 19 instances when price is different from marginal cost. In fact, the Price = Marginal Cost measure of productivity growth is only consistent with 16 of the 35 industries. Models of aggregate productivity growth that ignore market imperfections are biased.

Data Appendix

The data used in this study are annual time-series prices and quantities of output, intermediate input, labor, and capital for 35 U.S. industrial sectors between 1947 and 1989. A full description of the data and sources is found in *Productivity and U.S. Economic Growth*, authored by Jorgenson, Gollop, and Fraumeni (JGF). In short, JGF generate estimates of prices and quantities of output from the producers' point of view, excluding from the value of output excise and sales taxes and including subsidies paid to producers (pp. 487–507). They derive an estimate of intermediate input by subtracting estimates of value added from corresponding estimates of output. JGF then use their data on prices and quantities of intermediate input to construct price and quantity indices of intermediate input (pp. 487–507).

JGF employ a novel feature in the generation of labor input data in that they utilize data from both establishment and household surveys. They generate indices of labor input cross-classified by the two sexes, eight age groups, five educational groups, two employment classes, ten occupational groups, and fifty-one industries (pp. 387–407). In a manner analogous to their derivation of prices and quantities of labor input, JGF construct indices of capital input for each of the industrial sectors cross-classified by six types of assets and two legal forms of organization (pp. 439–59).

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