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ABSTRACT

Estimates of the Returns to Scale for US Manufacturing*

This paper estimates the degree of the returns to scale for 2-digit US manufacturing industries from the output-based primal and price-based dual equations implied by firms' cost-minimization problems. It seeks to reconcile the cyclical behaviour of the primal and dual productivity residuals by allowing for non-constant returns to scale and imperfect competition. We find significant differences between the estimates of the returns to scale parameter derived from the primal versus the dual equations. The existence of time-varying mark-ups reduces the incidence of significant differences in the primal versus dual returns to scale estimates for the durable goods industries but not for the non-durable goods industries. Likewise, the presence of the quasi-fixity of capital helps to reconcile the behaviour of the primal and dual productivity residuals for the durable but not for the non-durable goods industries.

JEL Classification: D24, E32
Keywords: returns to scale, mark-ups, quasi-fixity of capital, procyclical productivity

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NON-TECHNICAL SUMMARY

Determining the degree of returns to scale in an economy has important implications for many issues that are of interest to economists and policy-makers. It has been noted that the degree of returns to scale can affect the nature of measured productivity growth in the economy. With increasing returns to scale, an increase in output is accompanied by a decline in the marginal cost of producing goods. Thus, increases in efficiency that occur when the economy is operating at a higher scale can appear as increases in measured productivity. Likewise, the presence of increasing returns to scale requires an assumption about the extent of competition among firms. The observed magnitude of average profit rates for developed economies such as the United States are typically inconsistent with the presence of increasing returns to scale and perfect competition.

In this paper, we estimate the degree of returns to scale using data on both prices and quantities. The implications of the degree of returns to scale for the joint behaviour of output and inputs is clear: the percentage change in output is greater, equal to, or smaller than the weighted percentage change in inputs depending on whether there are increasing, constant, or decreasing returns to scale. The degree of returns to scale also has implications for the behaviour of costs. Under constant returns to scale, the percentage increase in the marginal cost of producing an additional unit of output is equal to the share-weighted percentage increase in factor prices. If there are increasing returns to scale, the increase in the marginal cost of producing goods is less than the percentage increase in the share-weighted factor prices, and greater otherwise.

In the literature on productivity, it has been noted that there are two equivalent measures of productivity. The primal productivity residual or the Solow residual shows the increase in output for a given level of the inputs. The dual productivity residual measures the decline in costs for a given level of the input prices. It has been shown that under constant returns to scale, perfect competition and variable utilization of inputs, the difference between the primal and dual productivity residuals is identically equal to zero. With non-constant returns to scale and imperfect competition in the product market, the difference between the cost-based primal and dual productivity residuals (calculated using the cost shares on the inputs) is equal to the endogenous changes in efficiency due to the presence of increasing (or decreasing) returns to scale. This fact allows us to estimate the degree of returns to scale in the economy from the so-called primal relationship linking the growth rates of output to the share-weighted growth rates of the inputs and the dual

relationship linking the growth rate of the product price to the share-weighted growth rates of the input prices.

We use annual data on industry-level gross output, labour input, the stock of capital, energy use and materials inputs together with their corresponding prices for 21 manufacturing industries for 1959–89. The data are described in detail in Jorgenson, Gollop and Fraumeni (1987) and Jorgenson (1990). An advantage of using these data is that they deal explicitly with the problem of measurement error in the hours worked series by constructing a labour input series that uses information from both the household and establishment surveys. Another feature of these data are that they are constructed by weighing the hours worked by different types of workers (distinguished by various demographic and occupational characteristics) by their relative wage rates. Thus, the labour input rises either because the number of hours worked rises, or because the ‘quality’ of this work increases. Similar adjustments are made to the capital and materials inputs. Consequently, the use of these data implies that the measurement error in the various inputs due to compositional effects across the business cycle is likely to be small.

We derive estimates of the returns to scale from the cost-based primal and dual equations by initially assuming that the mark-up price over marginal cost is a constant. We estimate the primal and dual equations for each of the 21 manufacturing industries separately. We also derive estimates that constrain the returns to scale parameter to be equal across industries for each equation and joint estimates that constrain the returns to scale parameter to be equal across the primal and dual equations for each industry. The method of estimation is instrumental variables estimation.

The single-equation estimates of the primal and dual equations implies that the incidence of decreasing returns to scale is greater based on the estimates of the primal equation compared to the estimates of the dual equation. By contrast, the dual equation estimates imply constant or increasing returns to scale. When we constrain the returns to scale parameter to be equal across industries, the restricted estimates from the primal and dual equations are both consistent with constant returns to scale. The cross-equation restrictions derived from the primal equation are rejected, however, while those from the dual equation are not. We also find that the over-identifying restrictions derived by constraining the returns to scale parameter to be equal across the primal and dual equations for 17 out of the 21 industries in our sample. Thus, the finding of differences in the value of the returns to scale from the output-based primal versus the price-based dual equation turns out to be statistically significant for the majority of the industries in our sample.

These results suggest that there are differences in the nature of the error terms in the primal versus dual equations. By contrast, under the assumption that the mark-up of price over marginal cost is a constant, the error terms in the primal and dual equations should be identical. To determine whether this relation holds in the data, we consider the regression of the primal productivity residual against a constant and the dual productivity residual and the corresponding reverse regressions. We find evidence against the null hypothesis in that the slope coefficient in either the direct regression or the reverse regression is significantly different from one for the majority of the industries in our sample. We also regress the difference between the primal and dual residuals against aggregate real value-added growth. We find that the difference between the primal and dual residuals is significantly related to real value-added growth.

Next, we introduce time-varying mark-ups and the quasi-fixity of capital as factors that might be useful for reconciling the primal and dual equation estimates of the returns to scale parameter. Allowing for a time-varying mark-up reduces the number of rejections of the over-identifying restrictions across the primal and dual equations for the durable goods industries by about half. By contrast, there is little or no change in the number of rejections for the non-durable goods industries. Likewise, the presence of the quasi-fixity of capital helps to reconcile the behaviour of the primal and dual productivity residuals for the durable but not for the non-durable goods industries.

1 Introduction

The procyclical behavior of measured productivity is one of the key issues in the recent macroeconomics literature. Among the various explanations that have been offered, the hypothesis that procyclical movements in productivity reflect endogenous changes in efficiency because the economy operates with increasing returns to scale has far-reaching implications.[1] Since increasing returns in the absence of imperfect competition is inconsistent with the small average profit rates in U.S. industries, a finding of increasing returns implies that alternatives must be developed to standard real business cycle models that typically assume perfect competition. The issue of the indeterminacy of equilibrium which arises in models of multiple equilibria also depends critically on the degree of returns to scale in the aggregate economy and the magnitude of the markup parameter.[2]

In earlier work, Hall (1988, 1990) finds large and significant markups and significant deviations from constant returns to scale using instrumental variables estimation with value-added data. Likewise, Caballero and Lyons (1992) provide evidence for the existence of external effects in industry-wide production functions. However, Basu and Fernald (1995a, 1997) argue that these effects are due to specification error arising from the use of value-added data under nonconstant returns to scale and imperfect competition. In recent work, Basu and Fernald (1995a,b,1997) and

[1]Other well-known explanations for procyclical productivity include exogenous changes in efficiency as stressed by Prescott (1986), unmeasured changes in factor utilization across the business cycle due to labor hoarding or variable input utilization rates as stressed by Abbot, Griliches, and Hausman (1988), Burnside, Eichenbaum, and Rebelo (1993), and Basu (1996), and external effects as in Caballero and Lyons (1992).

[2]For example, Farmer and Guo (1994) require a value of the markup equal to 1.75 for the presence of multiple equilibria. Schmitt-Grohe (1995) shows minimum requirements on underlying parameters for various models to generate multiple equilibria. By contrast, multi-sector models such as those studied by Benhabib and Farmer (1994) and Perli (1995) require only a small degree of increasing returns to scale to display multiple equilibria. As another example, Rotemberg and Woodford (1992) argue that a markup parameter of 1.2 suffices to induce real wage increases in response to increases in government demand.

Burnside (1996) find that returns to scale are approximately constant at the 2-digit industry level. However, there is considerable dispersion in their estimates. For example, Burnside (1995) overwhelmingly rejects the cross-equation restrictions that are obtained by constraining the returns to scale parameter to be equal across industries.

In this paper, we use the implications of primal and dual versions of firms' optimization problem to estimate the degree of returns to scale. The estimates of the returns to scale parameter reported in the literature are production function estimates that incorporate the implications of firms' primal cost minimization problem. Using a generalized Leontief cost function approach, Morrison (1986, 1992) has derived estimates of the returns to scale and time-varying markups based on the dual cost minimization problem. In contrast to this work, we use restrictions from both the output-based primal equation and the price-based dual equation to estimate the degree of returns to scale. Our approach allows a unified treatment of the implications of firms' primal and dual optimization problems using simple nonparametric measures of productivity.

We derive separate estimates of the returns to scale from the primal equation relating output growth to share-weighted input growth and from the dual equation relating the change in the product price to the share-weighted change in factor prices and output growth. We show that allowing for a time-varying markup leads to a simple modification of the dual equation in that the percentage increase in the product price equals the percentage increase in marginal costs plus a term reflecting the cyclical variation in markups. Under the assumption that there is an independent source of variation in the primal versus dual equations, we also derive joint estimates of the returns to scale parameter obtained by imposing cross-equation restrictions across the primal and dual equations. Such estimates allow a test of the hypothesis that the primal versus dual equation-based returns to scale estimates are equal to each other.

An equivalent way to study the implications of firms' cost minimization problems is in terms of the cyclical behavior of the production-side primal productivity residual and the cost-side dual productivity residual. Ohta (1975), Morrison (1986, 1992) and others have shown that under constant returns to scale and perfect competition, the primal and dual productivity residuals are identically equal to each other. Ohta (1975) shows how to adjust the cost-side productivity measure for scale effects. Morrison (1986, 1992), Hall (1988) and others have shown the adjustment to the production-side and cost-side productivity measures under the assumption that price contains a markup of price over marginal cost. We extend this analysis to show that in presence of imperfect competition and nonconstant returns to scale, the difference between the primal and dual productivity residuals calculated using the cost shares of the inputs is equal to the percentage change in industry-specific markups.

In the macroeconomics literature, Shapiro (1987) and Roeger (1987) have used nonparametric measures of primal and dual productivity to test for the source of procyclical productivity movements. Shapiro ests for the equality of the primal and dual productivity residuals by assuming that returns to scale are constant and that product markets are perfectly competitive. He finds significant differences between the two residuals, which he attributes to the fixity of capital. Roeger (1995) argues that procyclical productivity movements may be due to imperfect competition in the product market. He seeks to reconcile the cyclical behavior of primal and dual productivity through the existence of a markup of price over marginal cost. However, his analysis is also based on the assumption of constant returns to scale. Furthermore, both Shapiro and Roeger base their findings on value-added data. In this paper, we show that Roeger's approach allows him to identify and estimate the markup parameter only under the assumption of constant returns to scale. Next, we show that there is specification error in the dual productivity measure that arises from the use of value-added data under imperfect competition and nonconstant returns to scale. This is similar to the analysis of the primal equation (see Basu and Fernald (1995a,b, 1996)) and it arises from the fact that under nonconstant returns to scale, the dual equation includes a term that accounts for scale effects on the percentage change in marginal cost. Finally, we derive the implications of the quasi-fixity of capital under nonconstant returns to scale and imperfect competiton for the cyclical behavior of the primal and dual productivity residuals.

As in Basu and Fernald (1995a,b, 1997) and Burnside (1996), we find evidence of constant or decreasing returns to scale based on production function estimates. However, there is considerable heterogeneity across firms. By contrast, the estimates derived from the dual equation imply that returns to scale are roughly constant or increasing. The restricted estimates of the degree of the returns to scale derived from both the primal and dual equation imply constant returns to scale. However, the cross-equation restrictions that are obtained by constraining the returns to scale parameter to be equal across industries are overwhelmingly rejected for the primal equation. Next, we derive estimates of the degree of the returns to scale by estimating the primal and dual equations jointly for each industry. We find that the overidentifying restrictions obtained by constraining the returns to scale parameter to be equal in the primal and dual equations are also rejected.

To determine the reasons for these differences, we examine the cyclical behavior of the primal versus the dual Solow residuals. In the absence of time-varying markups or other unobserved variables, the primal and dual (cost-based) Solow residuals should be identically equal to each other, irrespective of the degree of returns to scale. By constrast, we find the dual residual is not successful for explaining the variation in the primal residual for many of the industries considered in our study. Furthermore, contrary to the assumptions of the model, the difference between the primal and dual residuals displays marked procyclical behavior. Allowing for time-varying markups in the product price reduces the number of rejections of the overidentifying restrictions with respect to the returns to scale parameter across the primal and dual equations for the durable goods industries but not for the non-durable goods industries. Likewise, allowing for the quasi-fixity of capital helps to reconcile the cycical behavior of the primal and dual productivity residuals for the durable but not for the non-durable goods industries.

The remainder of this paper is organized as follows. Section 2 derives expressions for the output-based primal equation and price-based dual equation that are used in estimation. Section 3 describes the data and presents the estimates of the degree of the returns to scale based on the primal and dual equations under the assumptions that the markup of price over marginal cost is constant and that all factors are variable. Section 4 extends this analysis to allow for time-varying markups and the quasi-fixity of capital. Some concluding remarks are in Section 5.

2 A Framework

Productivity growth refers to the increase in efficiency of production over time. Solow (1958) introduced the concept of the primal productivity residual as a measure of exogenous technical change under constant returns to scale and perfect competition. Ohta (1975), Hulten (1986) and others have shown that the change in total factor productivity can also be calculated as a cost-side measure using data on factor and output prices under the same assumptions that Solow made.

When returns to scale are not constant, increases in output for a given level of inputs can occur due to endogenous increases in efficiency. Such endogenous increases in efficiency can also lead to a reduction in costs for a given level of factor prices. These facts show that it is possible to infer the magnitude of the returns to scale from output-based primal and price-based dual equations, respectively. To derive these equations, we make use of the implications of primal and dual versions of firms' cost minimization problems.

2.1 Implications of Firms' Cost Minimization Problem

We begin by considering the primal cost minimization problem. To describe this problem, consider a production function for gross output in the i'th sector Y_{it} as a function of labor, capital, materials, and a random technology shock as:

$$Y_{it} = F^i(L_{it}, K_{it}, M_{it}, Z_{it}), \tag{2.1}$$

where L_{it} denotes man-hours, K_{it} denotes services from capital, M_{it} denotes materials, and Z_{it} is a technology shock. The function F^i is assumed to be homogeneous of degree γ_i in L, K, and M, and homogeneous of degree one in Z. Let P_{it} denote the price of output in the i'th sector, P_{it}^L the wage rate, P_{it}^K the rental price of capital, and P_{it}^M the price of materials. To allow for imperfect competition in the product market, the output price is assumed to include a (possibly) time-varying markup over marginal cost as

$$\frac{P_{it}}{\mathrm{MC}_{it}} = \mu_{it},$$

where $\mu_{it} \geq 1$. Also define the revenue and cost shares of the inputs by

$$c_{it}^J = \frac{P_{it}^J J_{it}}{P_{it}^L L_{it} + P_{it}^K K_{it} + P_{it}^M M_{it}}, \quad J = L, K, M,$$

and

$$s_{it}^J = \frac{P_{it}^J J_{it}}{P_{it} Y_{it}}, \quad J = L, K, M.$$

We derive the primal equation by totally differentiating the production function and making use of the first-order conditions for cost minimization given by $P_{Jt} = \lambda_{it} F_J(L_{it}, K_{it}, M_{it}, Z_{it}), J = K, L, M$, where λ_{it} is a Lagrange multiplier that has the interpretation of marginal cost and F_J is the derivative of the production function with respect to the J'th input. Using the expression for the markup, it follows that

$$\frac{F_J J_{it}}{Y_{it}} = \mu_{it} \left(\frac{P_{Jt} J_{it}}{P_{it} Y_{it}} \right) = \mu_{it} s_{it}^J, \quad J = K, L, M.$$

Using the fact that $\gamma_i = \mu_{it} \sum_J s_{it}^J$ together with the definition of the cost shares c_{it}^J yields an expression for the primal equation as

$$\Delta y_{it} = \gamma_i \left[c_{it}^L \Delta l_{it} + c_{it}^K \Delta k_{it} + c_{it}^M \Delta m_{it} \right] + \Delta z_{it}, \tag{2.2}$$

where Δx denotes log-differences of X.

The estimates of the returns to scale parameter reported in the literature have been derived from the output-based primal equation in (2.2). Using instrumental variables estimation with value-added data, Hall (1988, 1990) reports evidence for the existence of significant increasing returns while Caballero and Lyons (1992) find evidence for strong external effects. Basu and Fernald (1995a,b, 1996) have argued that their respective findings of significant increasing returns and strong external effects are due to specification error arising from the use of value-added data under nonconstant returns and imperfect competition. Burnside (1996) and Burnside, Eichenbaum, and Rebelo (1995a,b) find that allowing for variable capacity utilization is important, and leads to a finding of constant returns to scale at the industry and aggregate level. Basu and Fernald (1995b) and Burnside (1996) also argue that heterogeneity across firms and aggregation effects tend to bias estimates of the returns to scale. For example, Burnside finds that constraining the returns to scale parameter to be equal across industries leads to spurious findings of increasing returns to scale at the aggregate level.

The restrictions of firms' dual cost minimization problem are obtained by considering a general cost function that depends on the input prices, the level of output, and the technology shock as

$$C_{it} = C(P_{it}^L, P_{it}^K, P_{it}^M, Y_{it}, Z_{it}). \tag{2.3}$$

From the firm's cost minimization problem, the degree of returns to scale is equal to the ratio of average cost (AC_{it}) and marginal cost (MC_{it}). Consistent with our approach in the primal problem, we assume that the degree of returns to scale is a time-invariant parameter.[3] Thus, we can write

$$\mathrm{MC}_{it} = \frac{\mathrm{AC}_{it}}{\gamma_i}.$$

Totally differentiatiing this expression, substituting for $\mathrm{MC}_{it} = \mathrm{AC}_{it}/\gamma_i$, $\mathrm{AC}_{it}Y_{it} = C_{it}$ and making use of Shepard's Lemma yields[4]

$$\begin{aligned}\Delta mc_{it} &= \frac{P^L_{it}L_{it}}{C_{it}}\Delta p^L_{it} + \frac{P^K_{it}K_{it}}{C_{it}}\Delta p^K_{it} + \frac{P^M_{it}M_{it}}{C_{it}}\Delta p^M_{it} + \frac{\mathrm{MC}_{it}}{\mathrm{AC}_{it}}\Delta y_{it} + \left(\frac{C_Z Z_{it}}{C_{it}}\right)\Delta z_{it} - \Delta y_{it} \\ &= c^L_{it}\Delta p^L_{it} + c^K_{it}\Delta p^K_{it} + c^M_{it}\Delta p^M_{it} + \left(\frac{1}{\gamma_i} - 1\right)\Delta y_{it} - \frac{1}{\gamma_i}\Delta z_{it}.\end{aligned}$$

The second line follows from the definitions of the cost shares.[5] This expression shows that exogenous technological improvement under increasing returns has a direct cost-reducing effect (captured by the term $-(1/\gamma_i)\Delta z_{it}$) and an indirect contribution due to scale effects (captured by the term $(1/\gamma_i - 1)\Delta y_{it}$).

The definition of the markup implies that the percentage change in the product price is equal to the percentage change in marginal costs plus the percentage change in the time-varying makup, or $\Delta mc_{it} = \Delta p_{it} - \Delta\mu_{it}$. Combining these results yields the expression for the dual equation as

$$\Delta p_{it} = c^L_{it}\Delta p^L_{it} + c^K_{it}\Delta p^K_{it} + c^M_{it}\Delta p^M_{it} + \left(\frac{1-\gamma_i}{\gamma_i}\right)\Delta y_{it} - \frac{1}{\gamma_i}\Delta z_{it} + \Delta\mu_{it}. \tag{2.4}$$

This expression shows that with increasing returns to scale and imperfect competition in the product market, the product price increases with increases in the share-weighted input prices and time-

[3]Notice that this differs from the approach in Morrison (1986, 1992) and others who make use of flexible functional forms such as the generalized Leontief or translog cost functions. In this latter approach, the returns to scale is a function of time-varying variables such as input prices and the levels of the quasi-fixed inputs.

[4]Recall that by Shepard's Lemma, the conditional factor demand function for the J'th input is equal to the derivative of the cost function with respect to the J'th input price as $J(P^L_{it}, P^K_{it}, P^M_{it}, Y_{it}, Z_{it}) = \partial C(P^L_{it}, P^K_{it}, P^M_{it}, Y_{it}, Z_{it})/\partial P^J_{it}$ for $J = L, K, M$.

[5]To derive this expression, we have also used the fact that $C_Z Z_{it}/C_{it} = -1/\gamma_i$. This is obtained by noting that $C_Z \frac{Z_{it}}{C_{it}} = -\lambda_{it}F_Z(Z_{it}/Y_{it})(Y_{it}/C_{it}) = -(\mathrm{MC}_{it}/\mathrm{AC}_{it}) = -1/\gamma_i$, where $C_Z = -\lambda_{it}F_Z$ by the envelope theorem and $F_Z Z_{it}/Y_{it} = 1$ by assumption.

varying markups and declines due to the direct and indirect effects of exogenous technological improvement. Provided valid instruments can be found that are uncorrelated with the growth rate of technology shocks, it also shows that an estimate of the returns to scale parameter can be obtained using data on prices and output.

In what follows, we make use of the information contained in both the primal and dual equation to estimate the degree of returns to scale. In Section 3, we present estimates of the primal and dual equations under the assumptions that the markup of price over marginal cost is constant and all factors are fully variable. We initially estimate the primal and dual equations separately. As in Basu and Fernald (1995a,1997) and Burnside (1996), we report estimates that leave the returns to scale parameter unrestricted across industries during the estimation of each equation as well as estimates that constrain the returns to scale parameter to be equal across industries. We also derive joint estimates of the returns to scale by imposing the cross-equation restrictions across the primal and dual equations.

2.2 Primal and Dual Measures of Productivity

An equivalent way of examining the implications of firms' primal and dual cost minimization problems is in terms of primal and dual measures of productivity. The primal productivity residual is defined as the difference between the rate of change of real output and the share-weighted rate of change in inputs. The dual productivity residual is defined as the difference between the share-weighted rate of change in input prices and the rate of change of the product price. The primal productivity residual SC_{it}, expressed in terms of cost shares, is

$$\mathrm{SC}_{it} = \Delta y_{it} - c_{it}^{L}\Delta l_{it} - c_{it}^{K}\Delta k_{it} - c_{it}^{M}\Delta m_{it}, \tag{2.5}$$

while the dual cost-based productivity residual SPC_{it} is

$$\mathrm{SPC}_{it} = c_{it}^{L}\Delta p_{it}^{L} + c_{it}^{K}\Delta p_{it}^{K} + c_{it}^{M}\Delta p_{it}^{M} - \Delta p_{it}. \tag{2.6}$$

In the macroeconomics literature, the properties of the primal and dual productivity residuals have been used to construct tests for the sources of cyclical fluctuations. Hall (1990) argues that under constant returns to scale and perfect competition, the primal productivity residual should be uncorrelated with "all variables known to be neither causes of productivity shifts nor to be caused by productivity shifts." He interprets the predictability of the Solow residual by such variables as military spending as evidence against the null hypothesis of constant returns or perfect competition. In related work, Shapiro (1987) and Roeger (1995) use the relation between the primal and dual productivity residuals to test for the source of cyclical fluctuations. Shapiro (1987) tests for deviations from constant returns to scale and perfect competition by regressing the primal productivity residual against the dual productivity residual. Roeger's (1995) approach is to estimate industry markups by making use of the difference between the primal and dual productivity residual under constant returns to scale but imperfect competition. Morrison (1992) uses the implications of a generalized Leontief cost function approach to account for scale effects, imperfect competition, and the quasi-fixity of inputs on the cyclical behavior of primal and dual productivity measures.

A similar analysis can be performed in our setup. To illustrate this, we derive alternative representations for the primal and dual productivity residuals as[6]

$$\mathrm{SC}_{it} = \left(1 - \frac{1}{\gamma_i}\right) \Delta y_{it} + \frac{1}{\gamma_i} \Delta z_{it} \tag{2.7}$$

and

$$\mathrm{SPC}_{it} = \left(1 - \frac{1}{\gamma_i}\right) \Delta y_{it} + \frac{1}{\gamma_i} \Delta z_{it} - \Delta \mu_{it}. \tag{2.8}$$

These expressions show that both the primal and dual productivity residuals differ from the growth rate of exogenous technology shocks provided returns to scale are not constant ($\gamma_i \neq 1$). With

[6] These expressions are obtained by substituting for the share-weighted growth rates of the inputs and their prices in (2.5) and (2.6), respectively.

time-varying markups ($\mu_{it} \neq \mu_i$), a second factor that separates the dual productivity residual from exogenous technology shocks is the cyclical variation in markups. Furthermore, as Hall (1988, 1990) and others have noted, if there are increasing returns to scale, then the primal residual is procyclical due to endogenous changes in efficiency even in the absence of procyclical technology shocks. The expression in (2.8) also shows that the dual residual will be procyclical provided the effect of endogenous changes in efficiency is not offset by procyclical movements in markups.

In the above discussion, the primal and dual productivity residuals are defined in terms of the cost shares of the inputs. Following Hall (1988, 1990), it is possible to define primal and dual productivity residuals in terms of the revenue shares of the inputs. The primal revenue-based productivity residual SR_{it} is

$$\mathrm{SR}_{it} = \Delta y_{it} - s_{it}^{L}\Delta l_{it} - s_{it}^{K}\Delta k_{it} - s_{it}^{M}\Delta m_{it}, \tag{2.9}$$

while the dual revenue-based productivity residual SP_{it} is

$$\mathrm{SP}_{it} = s_{it}^{L}\Delta p_{it}^{L} + s_{it}^{K}\Delta p_{it}^{K} + s_{it}^{M}\Delta p_{it}^{M} - \Delta p_{it}. \tag{2.10}$$

Roeger (1995) has argued that the difference between the primal and dual revenue-based productivity residuals can be used to determine the importance of imperfect competition for explaining procyclical productivity movements. Since his analysis is based on the assumption of constant markups, we assume that $\mu_{it} = \mu_i$. Substituting for Δy_{it} in the expression for SR_{it} and using the fact that with increasing returns and non-zero constant markups, $\mu_i\left(s_{it}^{L} + s_{it}^{K} + s_{it}^{M}\right) = \gamma_i$ while under constant returns and no markups, $s_{it}^{L} + s_{it}^{K} + s_{it}^{M} = 1$, yields

$$\begin{aligned}\mathrm{SR}_{it} &= \Delta y_{it} - s_{it}^{L}\Delta l_{it} - s_{it}^{K}\Delta k_{it} - s_{it}^{M}\Delta m_{it} \\ &= (\mu_i - 1)\left[s_{it}^{L}(\Delta l_{it} - \Delta k_{it}) + s_{it}^{M}(\Delta m_{it} - \Delta k_{it})\right] + (\gamma_i - 1)\Delta k_{it} + \Delta z_{it}. \end{aligned}\tag{2.11}$$

Proceeding in the same way and using the fact that $\gamma_i c_{it}^J = \mu_i s_{it}^J$, the dual revenue-based productivity residual can be expressed as

$$\begin{aligned}\mathrm{SP}_{it} &= s_{it}^L \Delta p_{it}^L + s_{it}^K \Delta p_{it}^K + s_{it}^M \Delta p_{it}^M - \Delta p_{it} \\ &= \left(1 - \frac{\mu_i}{\gamma_i}\right)\left[s_{it}^L(\Delta p_{it}^L - \Delta p_{it}^K) + s_{it}^M(\Delta p_{it}^M - \Delta p_{it}^K)\right] - \left(\frac{1-\gamma_i}{\gamma_i}\right)\Delta y_{it} + \frac{1}{\gamma_i}\Delta z_{it}. \qquad (2.12)\end{aligned}$$

We can simplify these expressions further as follows.

$$\mathrm{SR}_{it} = \frac{\mu_i - 1}{\mu_i}\Delta y_{it} - \frac{\mu_i - \gamma_i}{\mu_i}\Delta k_{it} + \frac{1}{\mu_i}\Delta z_{it}, \qquad (2.13)$$

$$\mathrm{SP}_{it} = \left(\frac{\gamma_i - \mu_i}{\mu_i}\right)(\Delta p_{it} - \Delta p_{it}^K) - \left(\frac{1-\gamma_i}{\mu_i}\right)\Delta y_{it} + \frac{1}{\mu_i}\Delta z_{it}. \qquad (2.14)$$

Taking the difference between SR_{it} and SP_{it} yields an expression that is independent of the growth rate of the technology shock as

$$\mathrm{SR}_{it} - \mathrm{SP}_{it} = \left(\frac{\mu_i - \gamma_i}{\mu_i}\right)\left[\Delta y_{it} - \Delta k_{it} + \Delta p_{it} - \Delta p_{it}^K\right]. \qquad (2.15)$$

Roeger uses a version of (2.15) to estimate the markup parameter μ_i. He assumes that returns to scale are constant and that the difference between the primal and dual residuals consists solely of measurement error that is uncorrelated with the right-side variables. It is easy to see that under these assumptions the markup parameter can be estimated by OLS. However, if returns to scale are not constant, the expression in (2.15) shows that the markup parameter and the returns to scale parameter cannot be identified separately from regressions of $\mathrm{SR}_{it} - \mathrm{SP}_{it}$ on $\Delta y_{it} - \Delta k_{it} + \Delta p_{it} - \Delta p_{it}^K$. Letting $B_i = (\mu_i - \gamma_i)/\mu_i$, the OLS estimate of the markup parameter is obtained implicitly from the relation $\mu_i = \gamma_i/(1 - B_i)$. If $\gamma_i \neq 1$, then for any given estimate of B_i, the estimate of the markup parameter μ_i is overstated relative to its true value depending on whether there are decreasing returns to scale, and understated otherwise. By contrast, the approach that we described in Section 2 allows us to use the information contained in the dual residual to estimate the degree of returns to scale without specifying the nature of markups if markups are constant, and to estimate the magnitude of time-varying markups under arbitrary assumptions about the degree of returns to scale.

2.3 The Use of Real Value-Added Data

In this study, we use gross output as our measure of production. Basu and Fernald (1995a,b,1996) have argued convincingly on a number of occasions that the natural measure of production at a disaggregated level is gross output, not real value-added. However, if our interest is to ultimately understand the behavior of aggregate output, then focusing on the behavior of industry-level real value-added has merit because aggregate real output is just the sum of industry-level real value-added, with the value of real intermediate inputs cancelled out. For this reason, much of the recent macroeconomics literature has focused on the magnitude of the returns to scale in aggregate real value-added. Following Basu and Fernald (1995a,b,1996), we briefly describe the specification error that arises in the output-based primal equation from the use of value-added data. We then show the effects of using value-added data in the estimation of the price-based dual equation.

Nominal value-added is nominal output minus the value of intermediate inputs as

$$P_{it}^{V} V_{it} = P_{it} Y_{it} - P_{it}^{M} M_{it}. \tag{2.16}$$

There are several alternative indices for constructing a measure of real value-added. One convenient approach is to define real value-added growth using a Divisia index of real output and materials growth as

$$\Delta v_{it} = \frac{\Delta y_{it} - s_{it}^{M}\left(\Delta m_{it} - \Delta y_{it}\right)}{1 - s_{it}^{M}} = \Delta y_{it} - \left(\frac{s_{it}^{M}}{1 - sit^{M}}\right)\Delta m_{it}. \tag{2.17}$$

This measure seeks to define real value-added growth as the growth rate of output minus the productive contribution of intermediate inputs, normalized by the share of nominal value-added in the value of gross output. Thus, real value-added is like a partial Solow residual, which subtracts off intermediate input growth from output growth. However, as Basu and Fernald (1995a,b,1996) note, such a definition of real value-added growth is valid only under perfect competition and constant returns to scale.

To derive the appropriate representation for real value-added growth under more general assumptions, we substitute for Δy_{it} in equation (2.4) using the definition in (2.17) and make use of the fact that $\gamma_i c_{it}^J = \mu_i s_{it}^J$ to obtain

$$\Delta v_{it} = \left[\frac{(1-c_{it}^M)\gamma_i}{1-\gamma_i c_{it}^M}\right]\Delta x_{it}^V + \left[\frac{(\mu_i - 1)s_{it}^M}{(1-\mu_i s_{it}^M)(1-s_{it}^M)}\right](\Delta m_{it} - \Delta y_{it}) + \frac{\Delta z_{it}}{1-\gamma_i c_{it}^M}. \tag{2.18}$$

There are several differences between the representations in equations (2.17) and (2.18), respectively. First, with imperfect competition, real value-added data subtracts off intermediate input growth using revenue shares whereas with imperfect competition the productive contribution of the inputs exceeds their revenue share. Hall (1990) and others have used regressions of real value-added growth on the share-weighted growth rates of the primary inputs as

$$\Delta v_{it} = \gamma_i^V x_{it}^V + \Delta z_{it}^V, \tag{2.19}$$

where $\Delta x_{it}^V = (c_{it}^L \Delta l_{it} + c_{it}^K \Delta k_{it})/(c_{it}^L + c_{it}^K)$. Thus, estimating (2.19) when (2.18) is the correct specification also leads to omitted variables bias. Since the coefficient on $\Delta m_{it} - \Delta y_{it}$ is positive, the effect of this omitted variables bias depends on the covariance between the growth of materials intensity with the instruments. Even if the bias is zero, however, regressions of real value-added growth on share-weighted primary input growth estimate the term

$$\gamma_i^V = \frac{(1-c_{it}^M)\gamma_i}{1-\gamma_i c_{it}^M}, \tag{2.20}$$

which differs from the returns to scale in gross output if γ_i is not equal to one.[7]

[7] Basu and Fernald (1995b,1996) have shown that the parameter γ_i^V has an economic interpretation if F is assumed to have the separable form $Y_{it} = G(V^P(L_{it}, K_{it}, Z_{it}), H(M_{it})$, with all returns to scale arising from V^P, G being homogeneous of degree of one in V^P and H, and H being homogeneous in M. In this case, the sum of the elasticities of V^P with respect to labor and capital has the form described by equation (2.20).

To determine the nature of the specification error that arises from the use of real value-added data in the dual equation, we substitute for the growth rate of the price of real value-added implied by taking the total differential of (2.16), and use the expression for real value-added growth in equation (2.17) in equation (2.4) to obtain

$$\Delta p_{it}^V = \frac{(1-c_{it}^M)}{(1-s_{it}^M)}\left[c_{L,it}^V \Delta p_{it}^L + c_{K,it}^V \Delta p_{it}^K\right] + \frac{(1-\gamma_i)}{\gamma_i}\Delta v_{it}$$
$$+\frac{(c_{it}^M - s_{it}^M)}{(1-s_{it}^M)}\Delta p_{it}^M + \frac{(1-\gamma_i)}{\gamma_i(1-s_{it}^M)s_{it}^M}\Delta m_{it} - \frac{1}{\gamma_i(1-s_{it}^M)}\Delta z_{it}, \tag{2.21}$$

where $c_{J,it}^V$ denote the cost shares in value-added as $c_{J,it}^V = P_{it}^J J_{it}/(P_{it}^L L_{it} + P_{it}^K K_{it})$ for $J = L, K$. Using the fact that

$$\frac{1-c_{it}^M}{1-s_{it}^M} = \frac{\gamma_i - \mu_i s_{it}^M}{\gamma_i(1-s_{it}^M)} = \frac{c_{it}^M - s_{it}^M}{(1-s_{it}^M)},$$

we can re-write this equation as

$$\Delta p_{it}^V = \frac{(c_{it}^M - s_{it}^M)}{(1-s_{it}^M)}\left[c_{L,it}^V \Delta p_{it}^L + c_{K,it}^V \Delta p_{it}^K + \Delta p_{it}^M\right]$$
$$+\frac{(1-\gamma_i)}{\gamma_i}\Delta v_{it} + \frac{(1-\gamma_i)}{\gamma_i(1-s_{it}^M)s_{it}^M}\Delta m_{it} - \frac{1}{\gamma_i(1-s_{it}^M)}\Delta z_{it}, \tag{2.22}$$

By contrast, the dual equation expressed in terms of real value-added data directly is

$$\Delta p_{it}^V = c_{L,it}^V \Delta p_{it}^L + c_{K,it}^V \Delta p_{it}^K + \frac{1-\gamma_i^V}{\gamma_i^V}\Delta v_{it} - \frac{1}{\gamma_i^V}\Delta z_{it}^V, \tag{2.23}$$

where the cost shares in value-added are given by $c_{J,it}^V = P_{it}^J J_{it}/(P_{it}^L L_{it} + P_{it}^K K_{it})$ for $J = L, K$. Comparing equations (2.23) and (2.21) shows that as long as the share of materials in total costs c_{it}^M is not equal to its share in total revenue s_{it}^M, the relationship between the growth rate of the price of real value-added and the share-weighted growth rates of the primary input prices is misspecified. Furthermore, there is an omitted variables problem in (2.22) due to the exclusion of the rate of change of the materials price under nonconstant returns to scale and imperfect competition. Finally, the representation in (2.23) erroneously excludes the growth rate of materials input when $\gamma_i \neq 1$.

We can use the above results to determine the bias that arises from the use of real value-added data in the difference between the primal and dual productivity residuals. Let SR_{it}^V and SP_{it}^V denote the revenue-based primal and dual residuals defined in terms of real value-added growth. Substituting for Δv_{it} and Δp_{it}^V using (2.17) and the total derivative of (2.16), respectively, in the defining expression for $\mathrm{SR}_{it} - \mathrm{SP}_{it}$ yields

$$\begin{aligned}
\mathrm{SR}_{it} - \mathrm{SP}_{it} &= \Delta y_{it} - s_{it}^L \Delta l_{it} - s_{it}^K \Delta k_{it} - s_{it}^M \Delta m_{it} + \Delta p_{it} - s_{it}^L \Delta p_{it}^L - s_{it}^K \Delta p_{it}^K - s_{it}^M \Delta p_{it}^M \\
&= (1 - s_{it}^M) \left[\Delta v_{it} - s_{L,it}^V \Delta l_{it} - s_{K,it}^V \Delta k_{it} + \Delta p_{it}^V - s_{L,it}^V \Delta p_{it}^L - s_{K,it}^V \Delta p_{it}^k \right] \\
&= (1 - s_{it}^M) \left[\mathrm{SR}_{it}^V - \mathrm{SP}_{it}^V \right], \qquad (2.24)
\end{aligned}$$

where $s_{J,it}^V = P_{it}^J J_{it} / P_{it}^V V_{it}$ denotes the share of input J in real value-added and $s_{it}^J = (1 - s_{it}^M) s_{J,it}^V$. Thus, the difference between the primal and dual Solow residuals based on gross output data is just one minus the revenue share of materials times the relevant quantity based on real value-added data.[8] Making similar substitutions on the right-side of equation (2.15) and using the result in (2.24) yields

$$\begin{aligned}
\mathrm{SR}_{it}^V - \mathrm{SP}_{it}^V &= \frac{1}{1 - s_{it}^M} \left[\mathrm{SR}_{it} - \mathrm{SP}_{it} \right] \\
&= \left(\frac{\mu_i - \gamma_i}{\mu_i} \right) \left[\Delta v_{it} - \Delta k_{it} + \Delta p_{it}^V - \Delta p_{it}^K + \frac{s_{it}^M}{1 - s_{it}^M} (\Delta m_{it} + \Delta p_{it}^M) \right]. \qquad (2.25)
\end{aligned}$$

Thus, the true difference between the value-added primal and dual residuals depends on two additional terms. The first is the weighted growth rates of materials inputs and the second is the change in materials' prices. If these omitted variables are correlated with the remaining terms on the right-side of equation (2.25), then markup estimates based on the dual productivity residual with value-added data will be inconsistent.

[8] A similar result is obtained by Domowitz, Hubbard, and Petersen (1988).

3 Estimation Results

In this section, we present estimates of the returns to scale using the simple framework that we described in Section 2. In this section, we assume that sectoral markups are constant and that all factors are variable. In the next section, we allow for time-varying markups and the quasi-fixity of capital. We begin by describing the data.

3.1 Data

The data consist of annual observations on industry-level gross output, labor input, the stock of capital, energy use, and materials inputs together with their corresponding prices for 21 manufacturing industries for 1959-1989. The data are described in detail in Jorgenson, Gollop, and Fraumeni (1987) and Jorgenson (1990). These data have been used by Basu and Fernald (1995a,b, 1997) and Burnside (1996) to estimate returns to scale at the industry level and for the aggregate private economy.

The Jorgenson data deal explicitly with the problem of measurement error in the hours worked series by constructing a labor input series that uses information from both the household and establishment surveys. (See Jorgenson, Gollop, and Fraumeni 1987, Ch. 3.) Thus, they account for the criticism raised by Prescott (1986) and Evans (1992) that the hours data obtained from household surveys typically differ from hours data based on establishment surveys.[9] The Jorgenson data set are also constructed by weighing the hours worked by different types of workers (distinguished by various demographic and occupational characteristics) by their relative wage rates.[10] Thus, the

[9] The measure of labor input that in the Jorgensom data set is consistent with the U.S. national income and product accounts, which are based on establishment surveys. The information in household surveys is used to distribute industry totals derived from establishment surveys according to various demographic and occupational characteristics.

[10] The rationale behind this procedure is that differences in observed wages reflect relative marginal products.

labor input rises either because the number of hours worked rises, or because the "quality" of this work increases.[11] Consequently, the use of the Jorgenson data implies that the measurement error in the various inputs due to compositional effects across the business cycle is likely to be small.

The quantities and prices in the Jorgenson data set are constructed such the payments to all the inputs exhaust the value of output. More precisely, the quantity of output in sector i denoted q_i is defined as $q_i = (vk_i + vl_i + ve_i + vm_i)/po_i = (vk_i + vl_i + ve_i + vt_i)/pi_i$, where vk_i, vl_i, ve_i, vm_i denote the value of capital services, labor inputs, energy inputs, and material inputs, respectively, po_i denote the price of output that producers receive, pi_i denotes the price of output that consumers pay, and vt_i is the value of taxes paid by each sector. The real values of all the inputs are obtained by dividing nominal values by the relevant prices as $vk_i/pk_i, vl_i/pl_i, ve_i/pe_i$, and vm_i/pm_i.

To define the required payments to capital series that is valid under arbitrary assumptions about the returns to scale, we use unpublished data from Dale Jorgenson.[12] For this purpose, a series on the user cost of capital r is constructed following Hall and Jorgenson (1967), Hall (1990), and Caballero and Lyons (1992), $r = (\rho + \delta)(1 - c - \tau d)/(1 - \tau)$ and ρ is the required rate of return on capital, δ is the depreciation rate, c is the asset specific investment tax credit, τ is the corporate tax rate, and d is asset specific present value of depreciation allowances. The required payment for any type of capital, $P_t^K K_t$, is then $r\pi_t^K K_t$, where $\pi_t^K K_t$ is the current-dollar value of the stock of this type of capital. In each sector, data on the current value of 52 types of capital plus land and inventories are used.

[11] Similar adjustments are made to the capital and materials inputs.

[12] These data were kindly provided to us by Susanto Basu.

3.2 Returns to Scale Estimates

In what follows, we derive estimates of the returns to scale from the cost-based primal equation in (2.2) and the cost-based dual equation in (2.4). Initially we assume that markups are constant, which implies that the term $\Delta\mu_{it} = 0$ in equation (2.4). The single-equation primal and dual estimates in Table 1 are obtained from the instrumental variables estimation of the primal and dual equations separately for each of the 21 manufacturing industries. The system estimates in Table 1 are derived by using three-stage least squares (3SLS) estimation for all 21 manufacturing industries. The restricted estimate reported in this table is obtained by constraining the returns to scale parameter to be equal across industries for each equation. Finally, the restricted estimates in Tables 2 and 5 are obtained by constraining the returns to scale parameter to be equal across the primal and dual equations for each industry.

An industry-specific constant and a dummy variable that allows a trend break after 1973 are included in each equation, and a constant and trend are included in the instrument set. The instrument set that is used includes the growth rate of real military purchases, the growth rate of the world price of oil, and a dummy variable representing the political party of the president data plus one lagged value of each of these variables. The mean and weighted mean of the unrestricted estimates reported in Tables 1 and 2 are defined as

$$\bar{\gamma} = \frac{1}{N}\sum_{i=1}^{N}\gamma_i, \qquad \bar{\gamma}^w = \frac{1}{N}\sum_{i=1}^{N}s_i\gamma_i,$$

where s_i is the average share of industry i in total manufacturing value-added over the sample period. The dispersion measures for the unrestricted estimates are defined as

$$\sigma_\gamma^2 = \frac{1}{N}\sum_{i=1}^{N}(\gamma_i - \bar{\gamma})^2, \qquad (\sigma_\gamma^w)^2 = \frac{1}{N}\sum_{i=1}^{N}s_i(\gamma_i - \bar{\gamma}^w)^2.$$

The single-equation estimates reported in Table 1 shows that the average industry appears to display constant or slightly decreasing returns to scale: for 15 out of the 21 manufacturing industries, the null hypothesis of constant returns to scale cannot be rejected at conventional significance levels. However, there is considerable dispersion in the estimates across industries. Although the mean and weighted mean of the primal equation estimates in Table 1 imply slightly decreasing returns to scale, the values of σ_γ^2 and $(\sigma_\gamma^w)^2$ imply that constant or increasing returns to scale are also consistent with the data. A different picture emerges when the estimates derived from the dual equation are considered. Here the single-equation estimates are, in general, larger than the primal equation estimates. For this equation, the null hypothesis of constant returns to scale cannot be rejected for the majority of the industries in the sample and the mean and weighted mean of the estimates are larger than those for the estimates derived from the primal equation.

The system estimates in Table 1 that use information on all 21 industries merely sharpen the results obtained for each industry separately. For example, based on the primal equation estimates, there are 6 non-durable goods industries and 3 durable goods industries for which the hypothesis of constant returns can be rejected in favor of decreasing returns, and 1 non-durable goods and 2 durable goods industries for which constant returns can be rejected in favor of increasing returns. When the returns to scale parameter is constrained to be equal across industries, the hypothesis of constant returns to scale cannot be rejected at the 5% level. However, the median, mean, and weighted mean of the unrestricted estimates are all smaller than the restricted estimate.[13] Consistent with this finding, the overindentifying restrictions that are obtained by constraining the returns to scale parameter to be equal across industries are rejected. The value of the relevant test statistic, which is distributed as $\chi^2(20)$, is equal to 76.98, which implies a marginal significance level close to zero. These results are similar to the findings reported by Basu and Fernald (1995a,b,1997) and Burnside (1996).

[13]The restricted estimate of γ_i reported in this table refer to the estimate that is obtained by constraining the returns to scale to be equal across all 21 manufacturing industries for the primal and dual equations separately.

For the dual equation system estimates, the evidence against constant returns to scale is less pronounced compared to the primal equation estimates for non-durable goods industries while the hypothesis of constant returns can be rejected against the alternative of increasing returns for 5 out of the 11 durable goods industries. By contrast, there are only 2 non-durable goods industry and 1 durable goods industries for which constant returns can be rejected in favor of decreasing returns to scale. In this case, the mean, median, and weighted mean of the unrestricted estimates are all greater than one while the restricted estimate is almost identically equal to one. Moreover, the overidentifying restrictions associated with setting the returns to scale parameter to be equal across industries cannot be rejected at conventional significance levels.

These results suggest that the inference that can be drawn about the magnitude of the returns to scale parameter differs when one considers the primal versus dual equation. First, the incidence of decreasing returns to scale is greater based on the estimates of the primal equation than the estimates of the dual equation. By contrast, the dual equation estimates imply constant or increasing returns to scale. While the restricted estimates from the primal and dual equations are both consistent with constant returns to scale, the cross-equation equations derived from the primal equation are rejected while those from the dual equation are not. If the findings based on the primal equation are accepted as the basis for the estimates of returns to scale in manufacturing, then there is the problem of decreasing returns to scale for a number of non-durable goods industries, which, if taken literally, would imply that firms are operating, on average, above efficient scale. Basu and Fernald (1995b) have argued that aggregation or re-allocation effects at the firm level may be used to justify such findings at the industry level. However, their analysis does not address the issue of differences in inference about the returns to scale parameter from the primal versus the dual equation.[14]

[14] One possible reason that instrumental variables estimation of the dual equation may yield different estimates of

To determine whether these differences are significant, we present estimates of γ_i that impose the overidentifying restrictions across the primal and dual equations in (2.2) and (2.4) for each industry. Notice that implementing this approach requires that the error term in at least one of these equations contains an independent source of error that is uncorrelated with the instruments. Otherwise, there will an exist an exact dependency between the primal and dual equations describing output growth and the growth rate of the product price, respectively. Under the null hypothesis that the framework that we have presented in Section 2 is correct and that the markup of price over marginal cost is a constant, one candidate for such an independent source of error in the dual equation is measurement error in the product price. As Baily and Gordon (1988), prices indices are typically prone to measurement error because they fail to account adequately for quality improvements. Provided the instruments are uncorrelated with such errors, it is possible to obtain consistent estimates of γ_i from joint estimation of equations (2.2) and (2.4).

The estimation of the primal and dual equations with cross-equation restrictions is achieved by defining the disturbance terms h_{it}^1 and h_{it}^2 as

$$h_{it}^1 \equiv \Delta z_{it} + \epsilon_{it}^1 = \Delta y_{it} - \gamma_i \left[c_{it}^L \Delta l_{it} + c_{it}^K \Delta k_{it} + c_{it}^M \Delta m_{it} \right] \tag{3.1}$$

$$h_{it}^2 \equiv \frac{1}{\gamma_i} \Delta z_{it} + \epsilon_{it}^2 = \left[c_{it}^L \Delta p_{it}^L + c_{it}^K \Delta p_{it}^K + c_{it}^M \Delta p_{it}^M - \Delta p_{it} \right] + \frac{1-\gamma_i}{\gamma_i} \Delta y_{it}, \tag{3.2}$$

where ϵ_{it}^1 and ϵ_{it}^2 are idiosyncratic errors in the primal and dual equations. Define the vector $h_{it} = (h_{it}^1, h_{it}^2)'$. Let Z_t denote a $q \times 1$ vector of instruments that are assumed to be uncorrelated with the

γ_i than the primal equation is due to small sample bias in the dual equation. This small sample bias may occur because the instruments do not correlate very well changes with changes in real output, Δy_{it}. To avoid this problem, we could consider re-writing the dual equation as

$$\Delta y_{it} = \left(\frac{\gamma_i}{1-\gamma_i} \right) \left[\Delta p_{it} - c_{it}^L \Delta p_{it}^L - c_{it}^K p_{it}^K - c_{it}^M p_{it}^M \right] + \frac{1}{1-\gamma_i} \Delta z_{it}.$$

Unfortunately, we cannot implement this approach because it implies that the coefficient $\gamma_i/(1-\gamma_i)$ is infinite under the null hypothesis of constant returns to scale.

growth rates of the exogenous technology shock and the idiosyncratic errors ϵ_{it}^1 and ϵ_{it}^2. Under these assumptions, $E\left[h_{it} \otimes Z_t\right] = 0$. This set of conditions forms the basis for the generalized method of moments estimator that can be used to estimate the unknown parameters of the model and to test its overidentifying restrictions. (See Hansen, 1982.) The procedure is to form sample counterparts of the population orthogonality conditions $E\left[h_{it} \otimes Z_t\right] = 0$, and to minimize a quadratic form that weights the set of sample orthogonality conditions with an optimal weighting matrix.

Table 2 reports the results of this estimation. In this table, γ_i^P and γ_i^D refer to the estimates of the returns to scale obtained from the primal and dual equations, respectively, when these equations are estimated jointly for each industry but the cross-equation restrictions with respect to γ_i are not imposed. By contrast, γ_i refers to the restricted estimate of the returns to scale parameter from the joint estimation for each industry. The results in this table show that the null hypothesis that the returns to scale parameter is the same in the primal and dual equations is rejected at conventional significance level for 17 of the 21 industries in our sample. There are only 4 non-durable goods industries for which constraining the returns to scale parameter to be equal across the primal and dual equations does not lead to a statistical rejection of the cross-equation restrictions. Thus, the finding of differences in the value of the returns to scale from the output-based primal versus the price-based dual equation turns out to be statistically significant for the majority of the industries in our sample.

These results suggest that there are differences in the behavior of the error terms in the primal versus dual equations which are leading to the strong rejections of the cross-equation restrictions with respect to the returns to scale parameter. By contrast, under the assumption that the markup of price over marginal cost is a constant, equations (2.7) and (2.8) in Section 2 imply that the error terms in the primal and dual equations should be identical. A simple way of determining whether this relation holds in the data is to consider the regression of the primal residual SC_{it} against a constant and the dual residual SPC_{it} as

$$\mathrm{SC}_{it} = \alpha_i + \beta_i \mathrm{SPC}_{it} + \epsilon_{it}^{P}, \tag{3.3}$$

and the reverse regression of the dual residual againt the primal as

$$\mathrm{SPC}_{it} = \eta_i + \theta_i \mathrm{SC}_{it} + \epsilon_{it}^{D}. \tag{3.4}$$

Under the null hypothesis that the primal and dual versions of firms' cost minimization problem is correctly specified, the coefficients α_i and η_i should equal zero and β_i and θ_i equal unity. Furthermore, β_i should equal $1/\theta_i$. We estimate these relations by OLS because under the null hypothesis, if there exist any error in these relations, it is comprised of classical measurement error.

Table 3 displays the results of these regressions. Part (a) of Table 3 reports the results of estimating the regressions in equation (3.3) while part (b) reports the results for estimating reverse regressions in equation (3.4). For 8 out of the 21 industries in our study, the null hypothesis that $\beta_i = 1$ in a regression of the primal productivity residual on the dual productivity residual can be rejected at conventional significance levels. Turning to the reverse regressions reported in part (b) of Table 3, we find that the null hypothesis of $\theta_i = 1$ is rejected for 16 out of the 21 industries in our sample, and that two-thirds of the rejections occur for the durable goods industries. Thus, neither the regression of the primal residual on the dual nor the regression of the dual on the primal residual supports the finding that these residuals are identically equal to each other. A third way of expressing this finding is presented in part (c) of Table 3, which shows the estimated value of $1/\beta_i$. Comparing the estimated values of $1/\beta_i$ with estimates of θ_i, we see that in none of the cases is $\theta_i = 1/\beta_i$. For 2 industries, we even have that a negative relationship between the primal and dual productivity residuals. Thus, the regression results in Table 3 show that accounting for scale effects is not sufficient to reconcile the time series behavior of the primal and dual productivity residuals.

To determine the nature of other factors that may affect SC_{it} and SPC_{it}, we regress the difference between the primal and dual residuals against aggregate real value-added growth as

$$\mathrm{SC}_{it} - \mathrm{SPC}_{it} = a_i + b_i \Delta v_t + \varepsilon_{it}{}^{15} \tag{3.5}$$

If the difference between the primal and dual residuals are solely due to classical measurement error-type shocks, then we should find that the coefficient on real value-added growth is not significantly different from zero.

Our results are reported in Table 4. For 13 out of the 21 industries in our study, the null hypothesis that the difference between the primal and dual productivity residual is uncorrelated with aggregate real value-added growth can be rejected at conventional significance levels. Furthermore, real value-added growth is positively correlated with the difference in the productivity residuals for the majority of the industries in our study. This is in contrast to Roeger (1995), who finds that after allowing for a constant markup, the difference between the revenue-based primal and dual residuals does not depend on aggregate real-added growth. As a way of gaining additional information about the cyclical properties of the primal versus dual productivity residuals, we also consider the correlations of SC_{it} and SPC_{it} with Δv_t. The main finding that emerges from the correlation reported in Table 4 is that the primal productivity residual SC_{it} is more positively related to real value-added growth than the dual productivity residual.

[15] We constructed a measure of aggregate real value-added as a Divisia index of sectoral real value-added, with the weights defined as the share of nominal value-added in each sector to total nominal value-added over the 34 private industries in the Jorgenson data set as

$$\Delta v_t = \sum_{i=1}^{n} w_{it} \Delta v_{it}.$$

Here Δv_t denotes the percentage change in aggregate real value-added, Δv_{it} is the percentage change in sectoral real value-added, and the weights w_{it} are defined as $w_{it} = P_{it}^V V_{it} / \sum_{i=1}^{n} P_{it}^V V_{it}$.

4 Alternative Explanations

In the literature on productivity growth, it has been suggested that such features as time-varying markups, quasi-fixities of inputs, and adjustment costs may be other important determinants of procyclical productivity. However, much of this literature has not focused on reconciling the cyclical behavior of the primal and dual residuals. In what follows, we first allow for time-varying markups in the product price as one potential source of misspecification that can be used account for the differences in the estimates of the returns to scale parameter from the primal versus dual equations. Second, we extend the analysis in Shapiro (1987) and examine the impact of the quasi-fixity of capital under non-constant returns to scale and imperfect competition.

4.1 Time-varying Markups

Following Hall (1988), a number of papers have stressed the importance of allowing for imperfect competition in explaining procyclical productivity movements. Domowitz, Hubbard, and Petersen (1988) use a disaggregated panel data set of four-digit SIC industries to estimate the impact of market structure on the markup over marginal cost. Unlike the analysis in Hall (1988) and other subsequent papers, they use data on gross output and allow for time-varying variables to influence industry markups. Morrison (1992), (1994) studies the cyclical behavior of markups using a Generalized Leontief (GL) cost function and a functional form for the output demand equation that resembles input demand functions generated from the GL framework. Galeotti and Schiantarelli (1994) estimate Euler equations for the capital stock by allowing for time-varying markups, adjustment costs, and nonconstant returns to scale. They use data on nineteen two-digit U.S. industrial sectors and assume that sectoral markups can be expressed as a function of two demand variables, the first representing the current level of product demand relative to a normal level and the second representing the rate of growth of product demand relative trend growth rates. Chirinko and Fazzari (1994) also estimate the Euler equation for the capital stock with quadratic adjustment costs, a translog function to represent the non-adjustment cost part of the technology, and a log-linear output function.

In contrast to much of this literature, our analysis is based on the simple nonparametric measures of productivity that we introduced earlier. Equation (2.4) in Section 2 shows that the impact of allowing for time-varying markups introduces the percentage change of the sector-specific markup into the dual equation. We assume that the markup for sector i is a linear function of aggregate real value-added. Thus, we express μ_{it} as

$$\mu_{it} = \phi_i + \psi_i \Delta v_t, \tag{4.1}$$

where v_t is aggregate real value-added.

The results of estimating this specification are reported in Table 5. The median, mean, and weighted mean of the unrestricted primal and dual estimates of γ_i as well the mean and weighted mean of the estimates of γ_i that are constrained to be equal across the primal and dual equations are smaller than those reported in Table 2. However, there is more variation in the estimates of γ_i^P and γ_i with time-varying markups compared to Table 2. The estimates of ψ_i in the last two columns of Table 5 show that markups are more significantly related to changes in aggregate real value-added for the non-durable goods industries than for the durable goods industries. The p-values for the test of the hypothesis that $\gamma_i^P = \gamma_i^D$ imply that the number of rejections of the null hypothesis has declined relative to Table 2. In particular, allowing for time-varying markups reduces the number of rejections of the cross-equation restrictions for the durable goods industries by about half. By contrast, there is little or no change in the number of rejections for the non-durable goods industries. Thus, it appears that are factors other than time-varying markups that need to be considered for reconciling the primal and dual equation estimates of γ_i for the non-durable goods industries.

4.2 Quasi-Fixity of Capital

In an earlier paper, Shapiro (1987) argues that allowing for the quasi-fixity of capital suffices to reconcile the cyclical behavior of the primal and dual productivity measures for aggregate U.S. manufacturing industries. In this section, we extend his analysis to allow for non-constant returns and imperfect competition.

As in Shapiro (1987), we assume that changes in capital are decided at least one period in advance due to adjustment costs or time-to-build considerations. To obtain an analytic expression for the dual residual, we assume that the production function takes the form

$$Y_{it} = z_{it} K_{it}^{\alpha_i^1} M_{it}^{\alpha_i^2} L_{it}^{\alpha_i^3}, \quad \alpha_i^1 + \alpha_i^2 + \alpha_i^3 = \gamma_i. \tag{4.2}$$

We can derive an expression for the primal equation by logarithmically differentiating (4.2). However, the resulting expression depends on the parameters α_1, α_i^2, and α_i^3. Withe quasi-fixity of capital, we cannot proceed as in the derivation of (2.2) and rewrite this expression in terms of the cost shares of the inputs and the returns to scale parameter γ_i because capital is not valued at its rental cost. However, it is easy to show that cost minimization with the quasi-fixity of capital implies that $\alpha_i^2 = (\gamma_i - \alpha_i^1) c_{M,it}^{VC}$ and $\alpha_3 = (\gamma_i - \alpha_i^1) c_{L,it}^{VC}$. Substituting for α_2 and α_3 yields the version of the primal equation that is valid when the capital input cannot be adjusted instantaneously as

$$\Delta y_{it} = (\gamma_i - \alpha_i^1) \left[c_{M,it}^{VC} \Delta m_{it} + c_{L,it}^{VC} \Delta l_{it} \right] + \alpha_i^1 \Delta k_{it} + \Delta z_{it}. \tag{4.3}$$

To derive the dual equation, we note that the marginal cost function is given by

$$\mathrm{MC}_{it} = \frac{p_{it}^L L_{it} + p_{it}^M M_{it}}{(\alpha_i^2 + \alpha_i^3) Y_{it}}. \tag{4.4}$$

Logarithmically differentiating the expression in (4.4) and using the form of the production function in (4.2) to substitute for ΔL_{it} in the resulting expression yields

$$\Delta \mathrm{MC}_{it} = c_{L,it}^{VC} \Delta p_{it}^L + c_{M,it}^{VC} \Delta p_{it}^M + \left[c_{M,it}^{VC} - \frac{\alpha_i^2}{\alpha_i^3} c_{L,it}^{VC} \right] \Delta m_{it}$$

$$+\left[\frac{c^{VC}_{L,it}}{\alpha^3_i}-1\right]\Delta y_{it}-c^{VC}_{L,it}\left(\frac{\alpha^1_i}{\alpha^3_i}\right)\Delta k_{it}-\frac{c^{VC}_{L,it}}{\alpha_3}\Delta z_{it}. \tag{4.5}$$

Making use of the fact that $\Delta\mathrm{MC}_{it}=\Delta p_{it}-\Delta\mu_{it}$ together with the expressions for α^2_i,α^3_i, and $\gamma_i-\alpha_1$ implied by cost-minimization yields

$$\Delta p_{it}=c^{VC}_{L,it}\Delta p^L_{it}+c^{VC}_{M,it}\Delta p^M_{it}+\left(\frac{1-(\gamma_i-\alpha^1_i)}{\gamma_i-\alpha^1_i}\right)\Delta y_{it}-\frac{\alpha^1_i}{\gamma_i-\alpha^1_i}\Delta k_{it}+\Delta\mu_{it}-\frac{1}{\gamma_i-\alpha^1_i}\Delta z_{it}. \tag{4.6}$$

The expression in (4.6) shows that correcting the dual equation for the quasi-fixity of capital has several effects. First, the percentage change in the product price depends only the share-weighted change in the prices of the variable inputs, with the shares denoting the cost share of each variable input in total variable cost. Second, the quasi-fixity of capital implies that instead of changes in the cost of capital, the product price depends on changes in the marginal product evaluated in terms of quantities. Finally, we note that with constant returns to scale (γ_i), the expression in (4.6) simplifies to the expression in Shapiro (1987).

To show the effects of the quasi-fixity of capital, we could proceed as before and derive estimates of the returns to scale parameter γ_i from the primal and dual equations defined in (4.3) and (4.6). Since α_1 is unknown, we would need to estimate this parameter. Unfortunately, this approach proved infeasible due to the well-known problems in estimating the elasticity of output with respect to capital, α_1. Instead, we test for the effects of the quasi-fixity of capital by equating the values of Δz_{it} from the primal and dual equations to each other. This approach is equivalent to testing for the equality of the modified primal and dual Solow residuals with the quasi-fixity of capital. The resulting expression is given

$$\Delta y_{it}=\Delta x_{it}+\Delta p^x_{it}-\Delta p_{it}, \tag{4.7}$$

where $\Delta x_{it}=c^{VC}_{M,it}\Delta m_{it}+c^{VC}_{L,it}\Delta l_{it}$ and $\Delta p^x_{it}=c^{VC}_{L,it}\Delta p^L_{it}+c^{VC}_{M,it}\Delta p^M_{it}$. Thus, we can regress the changes in output on the expresison on the right-side of (4.7) and test whether the slope coefficient is equal to one.

The results of this estimation are reported in Table 6. There we see that the null hypothesis that the modified primal and dual Solow residuals are equal to each other is rejected for all the non-durable goods industries in our sample. The coefficient estimates are all less than one and the marginal significance levels associated with the null hypothesis are zero or close to zero. By contrast, we cannot reject the hypothesis that the modified primal and dual Solow residuals are equal to each other for the durable goods industries aside from Lumber, Instruments, and Miscellaneous Manufacturing at conventional significance levels. Thus, it appears that allowing for the quasi-fixity of capital is useful for reconciling the cyclical behavior of the primal and dual Solow residuals for the durable goods industries. Our results provide partial confirmation of the results in Shapiro (1987) but they also show that there are significant differences in productivity movements for the non-durable versus durable goods industries.

5 Conclusion

In this paper, we have used the output-based primal and price-based dual equations implied by firms' cost-minimization problem to derive estimates of the degree of returns to scale under imperfect competition. While our findings from the primal equation are consistent with those of other studies such as Basu and Fernald (1995a,b,1997) and Burnside (1996), we find significant differences between the estimates obtained from the primal versus dual equations, especially for the non-durable goods industries. The primal equation estimates imply that returns to scale are constant or decreasing whereas the dual equation estimates provide evidence for constant or increasing returns. We find that allowing for time-varying markups reduces the number of rejections of the cross-equation restrictions for the durable goods industries by about half. By contrast, there is little or no change in the number of rejections for the non-durable goods industries. Thus, it appears that that are factors other than time-varying markups that need to be considered for reconciling the primal and dual equation estimates of the returns to scale parameter for the non-durable industries. We also find that the quasi-fixity of capital is useful for reconciling the cyclical behavior of the primal and dual Solow residuals for the durable but not non-durable goods industries.

Beginning with Hall (1988, 1990), the link between the industrial organization of markets and the study of cyclical movements in productivity has been emphasized in the macroeconomics literature. Our results suggest that deriving estimates of the degree of the returns to scale for U.S. manufacturing industries and explaining the cyclical behavior of primal and dual measures of productivity requires taking into account such links. In this paper, we have incorporated information based on the price-based dual equation for this purpose and considered the effects of time-varying markups and the quasi-fixity of capital. Other possible directions include introducing Keynesian demand effects due to labor hoarding or excess capacity and modelling the behavior of non-durable versus durable goods producing firms in explicitly dynamic environments.

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Table 1
Single Equation Estimates

	Single Industry Estimates		System Estimates	
Industry	γ_i^P	γ_i^D	γ_i^P	γ_i^D
Non-durables				
Food	0.669	0.822	0.718*	1,757*
Tobacco	0.657***	1.051	0.622***	5.331
Textiles	0.820	0.799	0.805**	0.719***
Apparel	0.999	1.034	0.761***	0.839***
Paper	0.917	1.003	0.763**	1.184*
Printing	1.113	1.154	0.882	1.200*
Chemicals	0.398***	1.074	0.414***	1.295
Petroleum Products	0.344***	0.867	0.349***	1.012
Rubber	1.092	1.104	1.181**	1.297***
Leather	0.777	1.425	0.981	0.910
Durables				
Lumber and Wood	0.826	0.631***	0.801**	0.819*
Furniture	1.109*	1.101**	1.069	1.044
Stone, Clay, and Glass	1.139	1.022	1.019	1.039
Primary Metal	1.091	1.036	0.991	1.131**
Fabricated Metal	1.354***	1.218**	1.233***	1.217**
Non-electrical Machinery	1.123	1.182*	0.951	1.274***
Electrical Machinery	1.119	0.970	1.063	0.989
Motor Vehicles	1.143***	1.091	1.165***	1.100***
Transportation Eqmt.	1.038	1.018	1.036	1.023
Instruments	0.740	0.916	0.742***	0.866**
Misc. Manufacturing	0.788	1.411**	0.489***	1.195**
Summary Statistics‡				
γ^{med}	0.999	1.036	0.882	1.100
$\bar{\gamma}$	0.917	1.044	0.859	1.297
$\bar{\gamma}^w$	0.964	1.038	0.898	1.198
σ_γ	0.253	0.181	0.242	0.928
σ_γ^w	0.258	0.440	0.233	0.443
Restricted Estimate				
	-	-	0.974	1.001

† γ^P and γ^D refer to the returns to scale estimates obtained from equations (2.2) and (2.4) with $\Delta\mu_{it} = 0$.

‡ γ^{med} , $\bar{\gamma}$, $\bar{\gamma}^w$ denote the median, mean, and weighted mean of the unrestricted estimates of γ_i. σ_γ and σ_γ^w are measures of dispersion of the estimates as defined in the text.

*, **, *** denote whether γ is significantly different from one at the 10%, 5%, 1% levels.

Table 2
Joint Estimates

Industry	**Estimates of $\gamma_i^{\dagger}$**			p-value for
	γ_i^P	γ_i^D	γ_i	$H_0 : \gamma_i^P = \gamma_i^D$
Non-durables				
Food	0.259***	0.400***	0.506***	0.159
Tobacco	0.853*	1.191	0.771***	0.048
Textiles	0.871	0.767***	0.663***	0.000
Apparel	0.734***	0.812***	0.752***	0.025
Paper	0.961	0.841*	0.693***	0.009
Printing	1.160	2.764*	1.653***	0.064
Chemicals	0.694***	0.789**	0.670***	0.094
Petroleum Products	0.959	1.239	0.761***	0.000
Rubber	1.091	1.070	0.969	0.152
Leather	1.335***	1.129	1.339***	0.000
Durables				
Lumber and Wood	0.845	0.615***	1.070	0.000
Furniture	0.968	0.942	0.909	0.018
Stone, Clay, and Glass	1.143*	1.036	0.886	0.000
Primary Metal	1.162	1.138	1.153	0.039
Fabricated Metal	1.356***	1.210*	1.096	0.040
Non-electrical Machinery	0.648***	0.725***	0.790***	0.002
Electrical Machinery	1.118	0.971	0.738***	0.000
Motor Vehicles	1.348***	1.158***	0.964	0.002
Transportation Eqmt.	1.022	0.982	0.783***	0.008
Instruments	1.062	0.787***	0.593***	0.005
Misc. Manufacturing	0.895	1.357*	1.132	0.003
Summary Statistics‡				
γ^{med}	0.964	1.004	0.838	-
$\bar{\gamma}$	0.975	1.044	0.900	-
$\bar{\gamma}^w$	0.943	1.011	0.871	-
σ_γ	0.254	0.447	0.264	-
σ_γ^w	0.304	0.488	0.268	-

† γ_i^P and γ_i^D denote the unrestricted estimates in the joint estimation of (3.1) and (3.2).
γ_i denotes the restricted estimate joint estimation of (3.1) and (3.2).

$^{\ddagger}\gamma^{med}$, $\bar{\gamma}$, $\bar{\gamma}^w$ denote the median, mean, and weighted mean of the estimates of γ_i.
σ_γ and σ_γ^w are measures of dispersion of the estimates as defined in the text.

*, **, *** denote whether γ is significantly different from one at the 10%, 5%, 1% levels.

Table 3
Regressions of the Primal versus Dual Residual

	(a) $SC_{it} = \alpha_i + \beta_i SPC_{it}$			(b) $SPC_{it} = \eta_i + \theta_i SC_{it}$			(c)
Industry	α_i	β_i	p-value for $H_0: \beta_i = 1$	η_i	θ_i	p-value for $H_0: \beta_i = 1$	$1/\beta_i$
Non-durables							
Food	0.001	0.867	0.156	0.000	0.903	0.290	1.153
Tobacco	0.007	0.766	0.086	-0.008	0.764	0.051	1.305
Textiles	0.004	0.677	0.001	0.001	0.930	0.625	1.477
Apparel	0.004	0.795	0.063	0.002	0.819	0.113	1.258
Paper	0.001	0.963	0.799	0.001	0.666	0.000	1.038
Printing	0.000	0.617	0.006	-0.002	0.550	0.007	1.621
Chemicals	0.000	1.038	0.762	0.003	0.696	0.000	0.963
Petroleum Products	0.001	0.872	0.024	0.000	1.061	0.079	1.147
Rubber	-0.002	1.124	0.358	0.004	0.698	0.000	0.890
Leather	0.000	1.058	0.558	0.000	0.767	0.000	0.945
Durables							
Lumber and Wood	0.003	0.561	0.000	-0.004	1.381	0.005	1.815
Furniture	0.001	0.980	0.921	0.004	0.451	0.000	1.020
Stone, Clay, and Glass	0.008	-0.516	0.000	0.008	-0.279	0.000	-1.938
Primary Metal	-0.002	0.854	0.189	0.002	0.769	0.049	1.171
Fabricated Metal	0.003	0.636	0.006	0.002	0.498	0.004	1.572
Non-electrical Machinery	0.001	0.840	0.162	0.006	0.622	0.002	1.191
Electrical Machinery	0.020	-0.075	0.000	0.020	-0.048	0.000	-13.333
Motor Vehicles	0.004	0.388	0.065	0.005	0.177	0.000	2.577
Transportation Eqmt.	-0.001	1.052	0.593	0.002	0.735	0.000	0.951
Instruments	0.004	0.546	0.009	0.011	0.307	0.000	1.832
Misc. Manufacturing	-0.002	1.286	0.318	0.006	0.413	0.000	0.778

SC_{it} refers to the cost-based primal residual, and SPC_{it} refers to the cost-based dual residual;
*, **, *** denote whether γ is significantly different from one at the 10%, 5%, and 1% levels.

Table 4
Cyclical Properties of the Primal and Dual Residuals

Industry	$\text{SC}_{it} - \text{SPC}_{it} = a_i + b_i \Delta v_t$ a_i	b_i	p-value $H_0 : b_i = 1$	Corr. of SC_{it} with Δv_t	Corr. of SPC_{it} with Δv_t
Non-durables					
Food	0.003	-0.077	0.199	0.1268	0.2312
Tobacco	0.011	-0.076	0.716	0.0972	0.1421
Textiles	-0.010	0.292	0.002	-0.3290	-0.5744
Apparel	0.002	-0.037	0.461	0.1211	0.2004
Paper	-0.011	0.322	0.000	0.5521	0.2293
Printing	-0.006	0.217	0.006	0.5818	0.1985
Chemicals	-0.011	0.323	0.030	0.5130	0.3928
Petroleum and Coal Products	-0.003	0.060	0.371	-0.0507	-0.0901
Rubber	-0.008	0.183	0.017	0.3821	0.2476
Leather	0.001	-0.016	0.899	-0.5643	-0.6508
Durables					
Lumber and Wood	-0.019	0.595	0.000	-0.6016	-0.7070
Furniture	-0.005	0.167	0.058	0.5302	0.4268
Stone, Clay, and Glass	-0.019	0.473	0.000	0.6338	-0.2074
Primary Metal	-0.012	0.278	0.004	0.5657	0.3052
Fabricated Metal	-0.009	0.286	0.000	0.7005	0.2322
Non-electrical Machinery	-0.013	0.322	0.001	0.4635	0.1224
Electrical Machinery	-0.017	0.440	0.000	0.5559	-0.2255
Motor Vehicles	-0.023	0.617	0.002	0.5859	0.1037
Transportation Eqmt.	-0.002	0.035	0.676	-0.0223	-0.0695
Instruments	-0.019	0.448	0.000	0.5325	-0.0361
Misc. Manufacturing	-0.004	0.167	0.330	0.4355	0.5542

SC_{it} refers to the cost-based primal residual, and SPC_{it} refers to the cost-based dual residual; *, **, *** denote whether γ is significantly different from one at the 10%, 5%, and 1% levels.

Table 5
Joint Estimates with Time-varying Markups

Industry	**Estimates of $\gamma_i^\dagger$**			p-value for	**Estimates of $\psi_i^\dagger$**	
	γ_i^P	γ_i^D	γ_i	$H_0 : \gamma_i^P = \gamma_i^D$	ψ_i^D	ψ_i
Non-durables						
Food	0.551***	0.581***	0.547***	0.058	-0.158*	-0.169*
Tobacco	-0.451***	0.452***	-0.723***	0.000	-2.965***	-0.741***
Textiles	0.837*	0.718***	0.766***	0.004	-0.040	0.322***
Apparel	0.739***	0.687***	0.737***	0.006	-0.299	-0.117***
Paper	1.036	0.814	1.040	0.001	-0.305	0.191
Printing	-0.721***	0.459***	-0.748***	0.000	-1.602	0.136
Chemicals	0.533***	0.517***	0.522***	0.373	-2.525***	-2.467***
Petroleum Products	0.587***	0.646***	0.585***	0.000	0.420***	0.242***
Rubber	1.225*	1.188	1.207*	0.055	-0.023	0.084
Leather	0.987	1.070	0.986	0.005	0.522***	0.301***
Durables						
Lumber and Wood	0.814	0.630***	0.847	0.051	0.214	0.603**
Furniture	0.978	1.025	0.977	0.156	0.100	0.044
Stone, Clay, and Glass	1.143*	1.099	1.136*	0.119	0.144	0.151
Primary Metal	1.263***	1.144*	1.264***	0.006	-0.213	0.069
Fabricated Metal	1.260***	1.167	1.259***	0.109	-0.006	0.120
Non-electrical Machinery	0.617***	0.735***	0.625***	0.019	0.724***	0.138***
Electrical Machinery	1.099	1.016	1.097	0.619	0.084	0.216
Motor Vehicles	1.350***	1.151***	1.482***	0.000	0.282***	0.181***
Transportation Eqmt.	1.006	0.963	0.937	0.428	-0.088	0.206
Instruments	1.600	0.975	1.553***	0.000	0.143	0.988***
Misc. Manufacturing	0.886	2.582	0.854	0.000	0.758	-0.259
Summary Statistics‡						
γ^{med}	0.907	0.775	0.912	-	-	-
$\bar{\gamma}$	0.826	0.934	0.807	-	-	-
$\bar{\gamma}^w$	0.850	0.886	0.846	-	-	-
σ_γ	0.535	0.441	0.574	-	-	-
σ_γ^w	0.504	0.328	0.521	-	-	-

† γ_i^P and γ_i^D denote the unrestricted estimates in the joint estimation of (3.1) and (3.2) and γ_i denotes the restricted estimate in the joint estimation of (3.1) and (3.2) with $\Delta\mu_{it} = \psi_i \Delta v_t$.

$^\ddagger\gamma^{med}$, $\bar{\gamma}$, $\bar{\gamma}^w$ denote the median, mean, and weighted mean of the estimates of γ_i. σ_γ and σ_γ^w are measures of dispersion of the estimates as defined in the text.

*, **, *** denote whether γ is significantly different from one at the 10%, 5%, and 1% levels.

Table 6

Regressions of the Modified Primal versus Dual Residuals with the Quasi-Fixity of Capital

Industry	Estimate of $f^{\dagger}$	p-value for H_0: $f = 1$
Non-durables		
Food	0.187	0.000
Tobacco	0.21	0.000
Textiles	0.606	0.001
Apparel	0.313	0.000
Paper	0.575	0.000
Printing	0.187	0.000
Chemicals	0.591	0.000
Petroleum Products	0.565	0.000
Rubber	0.798	0.013
Leather	0.661	0.000
Durables		
Lumber and Wood	0.619	0.003
Furniture	0.828	0.084
Stone, Clay, and Glass	0.926	0.449
Primary Metal	1.036	0.601
Fabricated Metal	0.973	0.767
Non-electrical Machinery	0.966	0.526
Electrical Machinery	0.877	0.072
Motor Vehicles	1.039	0.554
Transportation Equipment	1.010	0.811
Instruments	0.664	0.000
Misc. Manufacturing	0.814	0.042

† The estimation equation is given by $\Delta y_{it} = e + f\,[\Delta x_{it} + \Delta p^{x}_{it} - \Delta p_{it}]$, derived from equation (4.7) in the text.