

**The Relationship of Capital Investment and Capacity Utilization with Prices
and Labor Productivity**

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Introduction

Capital investment is extremely important to the long-run growth of any modern economy. Inter-country comparisons have generally found that investment is a significant determinant in differences in labor productivity, and hence, real income.¹ Differences between Japan and the U.S. are often suggested to support these findings, as Japan has had a consistently higher level of investment to GDP than the U.S. for the past 35 years, and has enjoyed higher rates of productivity growth.²

However, success at finding a significant impact of capital investment on labor productivity at the industry level has been mixed. For example, Baily (1981) found that the slowdown in labor productivity growth occurring in the U.S. between 1969 and 1973 is correlated with a slowdown in capital investment in the aggregate, but finds some puzzling discrepancies at the industry level. Several attempts at finding a reasonable capital to labor productivity link have been tried at INFORUM, particularly the studies by Meade (1990, 1993), but these equations have not been incorporated into the INFORUM model, due to unsatisfactory simulation properties.

The level of capital stock also serves to determine the optimal short-run productive capacity. The concept of capacity, and the related concept of capital utilization also play a role in the pattern of sectoral price growth. In the face of increasing demand for its goods or services, a firm may decide to invest in more capital, or it may increase capital (and labor) utilization. Since capital takes time to build or install, in the short run capacity utilization should increase under demand pressure. Increasing labor utilization in the short run is shown by the observed phenomenon of short run increasing returns to labor, which is the part of the reason for the cyclical pattern of labor productivity. Theory and evidence both suggest that while the demand pressure relative to capacity is strong, price growth should accelerate.

This paper explores a way of determining capital utilization at the industry level that is consistent with observed investment behavior, which can be used to relate capacity pressure to the growth rate of sectoral prices, as well as to determine labor-output ratios, or inverse labor productivity. This model, based on a Generalized Leontief (GL) cost function, explicitly relates the demand for labor to the capital stock. Before discussing this model, some preliminary investigations of the relationship of capacity utilization to inflation and industry output prices are presented.

¹ Delong and Summers (1991,1992), Christensen, Cummings and Jorgenson (1995).

² See in particular the studies by Jorgenson and Kuroda and by Morrison in the Hulten (1990) volume, and the earlier paper by Norsworthy and Malmquist (1983).

The Effects of Capital and Capacity Utilization on Prices

In a typical input-output model, prices are modeled according to one of the fundamental Leontief identity:

$$\mathbf{p}' = \mathbf{p}'\mathbf{A} + \mathbf{v} \quad (1)$$

Where \mathbf{p} is the vector of domestic prices, \mathbf{A} is the intermediate coefficient matrix, and \mathbf{v} is a vector of unit value added, or value added divided by real output.³ Since \mathbf{v} includes items such as interest, depreciation allowances and profits (or operating surplus), part of the determinants of price are returns to capital. The rest of value added consists of labor compensation and indirect taxes. Depreciation and interest directly represent the user cost of the capital input used in production for each period. Profit income is partly a reward to risk taking, innovation or imperfect competition and is by far the most volatile of the larger components of value added.

One insight of the theory of investment is that the shadow value of capital is the amount by which it reduces the cost of variable factors, such as labor, materials and energy. Investments should be made only when the full cost of extra investment is less than the reduction of these variable costs. This cost is uncertain, but includes depreciation, and the opportunity cost of interest plus some “reasonable” rate of profit. The corollary to this rule is that it is not obvious that more capital investment is always desirable, even if it increases labor productivity, since more than the optimal amount is more costly, will raise prices, reduce profits, and reduce total factor productivity.

In addition to its role as a component of overall costs, capital also plays a role in the cyclical movements of prices.⁴ Once a firm has committed to a certain level of capital stock (and other fixed factors), it has also defined an optimal level of production. Even if the long-run cost curve of a firm is flat or falling, the short-run curve will be U-shaped. To produce an output greater than this level, average costs must rise, and marginal cost will rise more steeply. These extra costs consist of additional maintenance and repair expenditures, the costs of bringing less efficient equipment and plant into production, and higher costs for overtime pay.

Such reasoning has motivated the use of capacity utilization measures in aggregate and sectoral price change equations. Klein’s seminal paper on capacity measurement was motivated in part by the need for a definition of capacity utilization that would be useful for forecasting prices.⁵ Perry used capacity utilization to explain the markup of manufactured goods prices over labor and materials costs. Eckstein and Fromm (1968) experimented with using the Federal Reserve Board (FRB) capacity utilization index in price change equations for two-digit manufacturing industries, and found this variable useful for some industries as a demand pressure variable. Popkin has also made extensive use of capacity utilization in his models of sectoral inflation.⁶ The DRI Cost Forecasting Service uses a price change equation based on the difference between industry supply, which is determined by capacity and employment, and industry demand, which is output as determined by an

³ Actually, import prices are usually weighted with domestic prices to obtain the unit cost of intermediate inputs.

⁴ To the extent that labor also has properties of a quasi-fixed factor, it also contributes in this role. This is especially true of non-production workers and highly trained production workers.

⁵ Klein (1960).

⁶ For a typical example, see Popkin (1974).

Figure 1

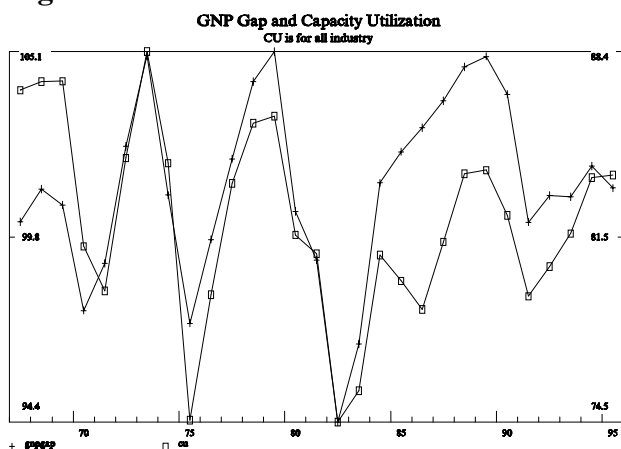
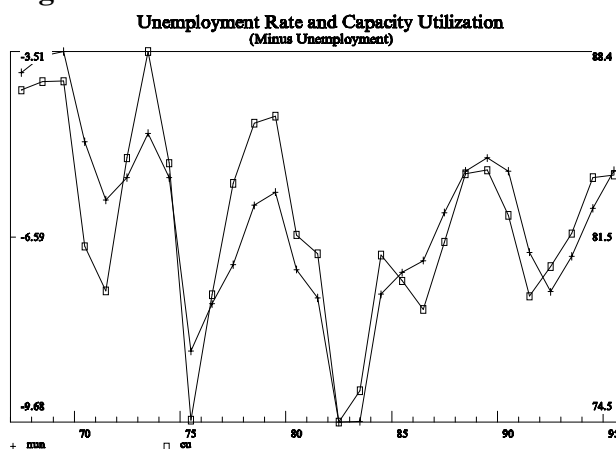


Figure 2



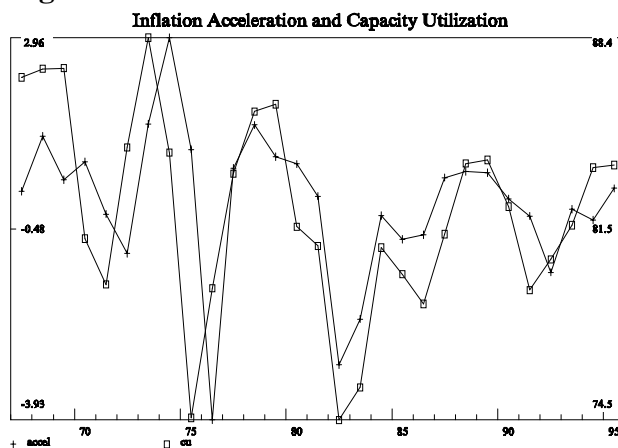
input-output solution. The FRB MPS model uses a degree of resource utilization variable in a price equation which is a markup over unit materials costs, labor costs and indirect business taxes.⁷

In studies of aggregate inflation, there are various measures of “tightness” that are used to determine what Sachs (1980) called the “disequilibrium” component of inflation. The “equilibrium” component of inflation in this framework is the expected component, based on observations on recent inflation as well as expectations of money supply growth. The “disequilibrium” component responds to supply-demand disequilibrium. The three main measures of tightness used are: 1) the unemployment rate, or some function of the unemployment rate; 2) the output or GNP gap, measured as a difference from peak or average output or GNP; and 3) some measure of capacity utilization. In the aggregate, these variables are quite similar, as can be seen from figures 1 and 2. Figure 1 compares the GNP gap with the capacity utilization for all industry constructed by the FRB, from 1967 to 1995. The GNP gap is constructed by taking the ratio of actual GNP over “potential GNP”, which is defined as a function of trend aggregate labor force growth and productivity growth. The GNP gap is equal to 100 when actual GNP equals potential GNP. The scale for the GNP gap is on the left axis, and the scale for capacity utilization is on the right axis. In figure 2, the negative of the unemployment rate is plotted with capacity utilization, and the left scale indicates unemployment.

One way of measuring the disequilibrium component of inflation is to regress inflation on a distributed lag of past inflation, and then to subtract the actual inflation for each period from the value that would be predicted from this regression. Another way is to view the disequilibrium part as simply the first difference, or “acceleration” of inflation. According to this notion, there is some degree of “core inflation” that obtains momentum from workers including expected inflation in their wage demands. The acceleration of aggregate GNP inflation is plotted with capacity utilization in figure 3. From this graph it is apparent that capacity utilization (marked with squares) is highly correlated with the acceleration of inflation, and tends to lead acceleration anywhere from a few quarters to over a year. In fact, both the GNP gap and the unemployment rate also follow this pattern, but the simple correlation of lagged capacity utilization with acceleration of inflation is .738 for the interval from 1968 to 1995, whereas the correlation of the lagged GNP gap is .615, and that of the lagged unemployment rate is only .569. This tallies with the findings of Franz and Gordon (1993),

⁷ See Stekler (1990) for a description of the DRI model, and Brayton and Mankopf (1985) for in-depth documentation of the FRB MPS model.

Figure 3



who find that inflation depends more closely on capacity utilization than on unemployment in both the U.S. and Germany. Franz and Gordon also find a “nonaccelerating inflation rate of capacity utilization” or NAICU, for the U.S. of about 82 percent, using the FRB measure. McElhattan (1985) had also determined this same figure for the aggregate economy, and inferred from her regressions that for each percentage point that all industry capacity utilization exceeded 82 percent, inflation would accelerate by about .15 percentage points. Furthermore, she tried these regressions over several intervals and found the relationship to be quite stable, unlike the corresponding NAIRU for the unemployment rate. Garner (1994) investigates whether the increased openness of the U.S. economy to trade has weakened the relationship between capacity utilization and acceleration of inflation and finds that it has not. He also verifies the 82 percent aggregate capacity utilization as the acceleration point.

Judging by these findings, it seems logical to expect that an excellent way to model the patterns of price change at the industry level would be to use an industry capacity utilization measure as an explanatory variable, along with other variables for money supply growth relative to GDP, and perhaps a supply shock variable. However, this path is not as straightforward as it seems. First, the FRB does not publish capacity utilization measures for all industries, but only for mining, manufacturing and utilities, which comprise 45% of total output and 29% of total employment in 1994. Second, to use capacity utilization in a forecasting framework, one needs to be able to forecast capacity as well. Although the FRB uses the capital stock of equipment and structures as one of the inputs to their capacity estimates, they also combine this information with surveys of businessmen, as well as data from The Bureau of Economic Analysis (BEA) on operating rates. The way in which they combine this information is somewhat *ad hoc*, and has been criticized for not being well-grounded in economic theory.⁸ Third, a consistent finding in the literature is that capacity utilization is not as powerful in forecasting prices at the industry level as it is in the aggregate. Yoo (1995), presents some regressions of inflation on distributed lags of inflation and capacity utilization, and only finds significant coefficients on

⁸ Corrado and Matthey (1997) provide an excellent discussion of many of the issues and controversies surrounding the FRB capacity utilization figures. Corrado, Gilbert and Raddock (1997) discuss the construction of both the capacity and the utilization indexes in more detail. Shapiro (1989) undertakes a detailed look at the FRB capacity and utilization estimates, relating them to capital stocks and testing how well they forecast production and prices. Berndt and Morrison (1981) provide an alternative approach to defining capacity utilization, discussed in more detail below.

capacity utilization in 6 of 23 industries. Using a vector autogression, Shapiro (1989) found that industry capacity utilization does not add much to explaining movements in industry prices, after lagged prices have already been included in the equation. Eckstein and Wyss (1972) found capacity utilization significant in only 8 of 15 industries that they investigated.

These objections notwithstanding, the strength of the relationship between capacity utilization and aggregate inflation suggests that experiments with industry capacity utilization in industry price equations should be fruitful. It may be possible to forecast capacity by relating it to industry level capital stock of plant and equipment. Furthermore, one could feasibly construct independent estimates of capacity for the services and other non-manufacturing industries, using data on plant and equipment. Finally, it would be interesting to verify in a simple structural equation whether or not capacity utilization does work well in understanding short-term price movements. The next section summarizes some experiments using capacity utilization in several variants of price equations, and using industry capital stock to explain the FRB measures of capacity

Some Preliminary Price Regressions

A data set for 54 industries was constructed to develop some preliminary regressions relating price change, acceleration of price change, markups, and accelerations of markups to the level of capacity utilization by industry. This data set consists of equipment and structures capital investment and stocks, capital user costs, hours worked, average wage indexes, estimated intermediate and energy consumption, prices for intermediate and energy, output and output price. At this level of industrial detail, a direct match with the FRB's capacity utilization indexes can be made for 24 of the 54 industries, and a many-to-one mapping for 14 more industries, for a total of 38 industries comprising mining, manufacturing and utilities.⁹

The first objective was to determine whether capacity utilization was a significant variable determining price change, whether the contribution to price change was positive, as it is in the aggregate, and whether the relationship held up better for price change, or acceleration of price change. Since the ultimate aim is to develop a forecasting framework that estimates prices based partly on known unit materials and labor costs, markup change and markup acceleration equations were also tried. Markups here are defined as the difference between industry output price and unit variable costs:

$$MU = P_Q - \frac{P_M M}{Q} - \frac{P_L L}{Q} \quad (2)$$

Change in price or markup is defined as the simple percent change, and acceleration is defined as the first difference of percent change. In each regression, the dependent variable was regressed on a three year distributed lag of capacity utilization (CU).

⁹ The FRB indexes are more aggregate than our industry classification in Chemicals, Machinery, Electrical machinery and Other transportation equipment.

Using this simple regression, I was pleased to obtain more positive results than described in much of the literature. The best fitting equations were the price acceleration equations, and this fact corresponds to the findings at the aggregate economy level. These equations had the best fit in 16 of the 38 industries, and CU appeared fairly significant and with a positive sign in 27 industries. The second place winner in terms of number of best fits was the price change equation, which fit best in 14 industries, and in which CU appeared significant and with a positive sign in 18 industries. The markup change equation fit best in only 3 industries and the markup acceleration equation in 5 industries. However, these last two forms were tied with the price change equation in the number of industries for which CU was significant and had a positive coefficient. In all four types of equations, capacity utilization lagged once seemed to most consistently come in with a strong contribution to the fit and the right sign. The markup change and markup acceleration equations tended to favor the current period value of capacity utilization in more industries.

Figures 4 to 7 show regression plots for four selected industries, of the equation type that gave the best results for that industry. The fits are good, for a variable with as much volatility as price change or price acceleration, but they are not spectacular. The best fitting equations are the price change and price acceleration equations, but they do not make it possible to relate changes in unit materials or labor costs to industry price. The markup

Figure 4 -Markup Acceleration Equation

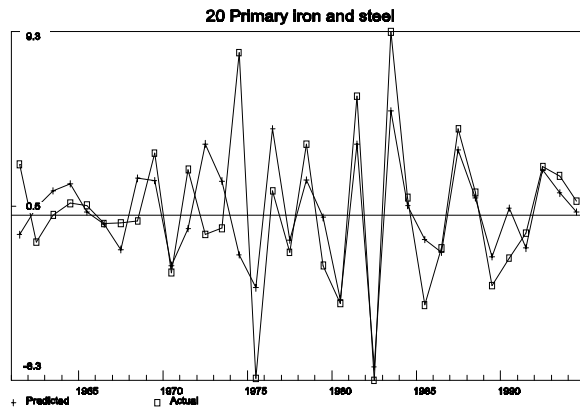


Figure 5 -Price Acceleration Equation

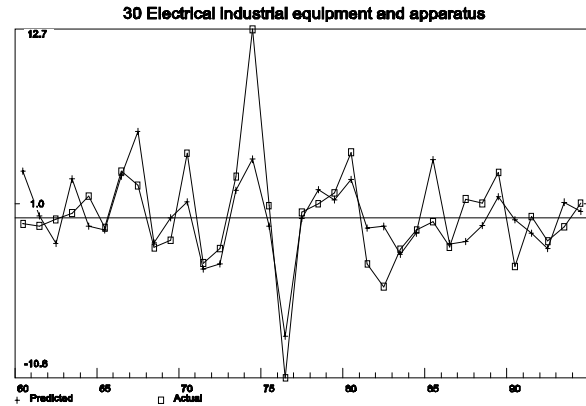


Figure 6 -Markup Change Equation

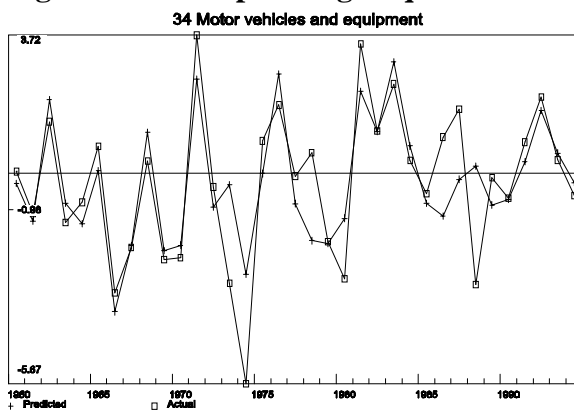
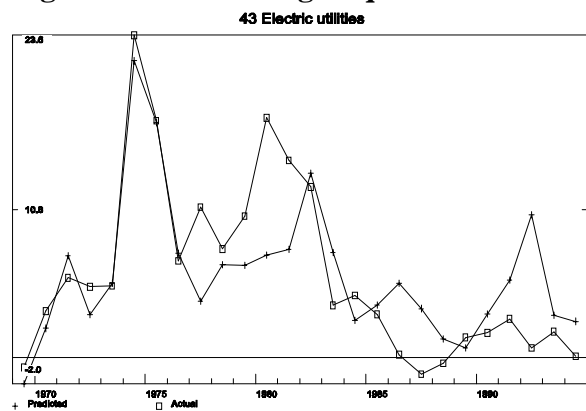


Figure 7 -Price Change Equation



equations do allow this, but they are harder to fit, and in many industries, capacity utilization comes in as insignificant, or with a negative sign. Examining the plots of some of the markup equations, it appears that markups are sometimes falling at the same time that prices are rising. This suggests that in those industries,

profits are smoothing price change, absorbing some of the shock when input costs are rising, but then expanding when input costs become cheaper with respect to output price. In other industries, output price change seems to be more volatile than input price change, and it is in these industries that capacity utilization works well in the markup equation.

In figures 8 to 11, the heavy solid line represents the annual percent change in price, the heavy dotted line is the percent change in unit intermediate costs, and the thin solid line is the percent change in unit labor costs. The Apparel and textile products industry is characterized by wide swings in the rate of growth of labor costs, that are not reflected in changes in output prices. This is the worst fitting industry using either of the four types of capacity utilization based equations. The pattern of price change in the Petroleum refining industry moves in step with the pattern of unit intermediate costs, and unit labor costs do not move as much. The Primary

Figure 8

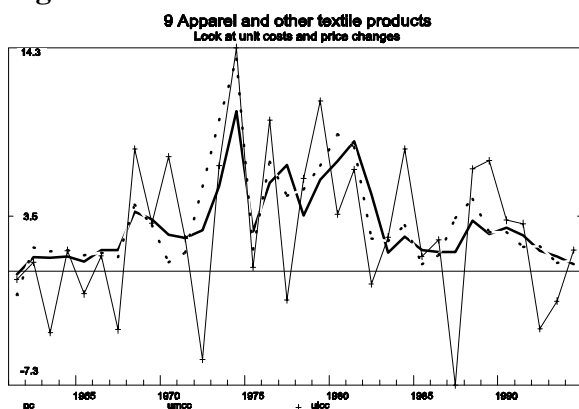


Figure 9

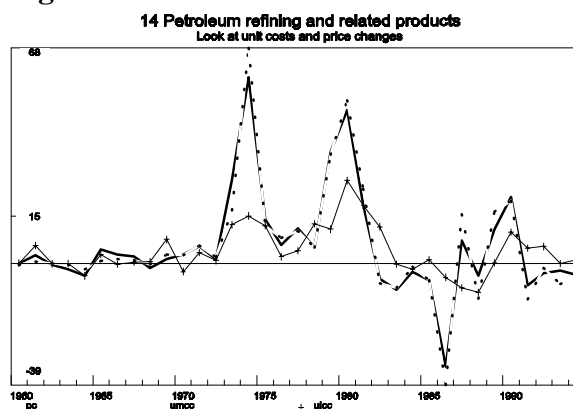


Figure 10

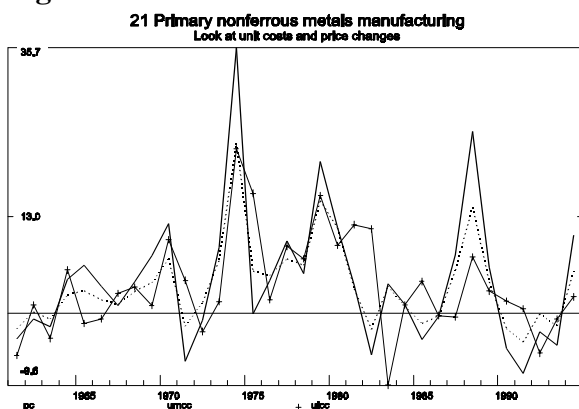
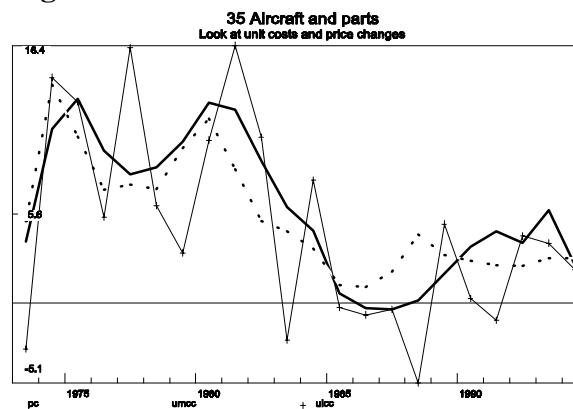


Figure 11



nonferrous metals industry is a case where output and input prices are quite volatile, but output prices change by more than input prices. Finally, the Aircraft and parts industry had high rates of price increases in the 1970s and early 1980s, and then went down to lower price growth in the late 1980s and early 1990s. Unit intermediate costs move very closely with output prices, but labor costs are more volatile.

Studying plots like this for all industries gives the impression that explaining markup behavior is a difficult task, and the results of using capacity utilization to explain markups directly do not look promising. At least, given the observed pattern of movements of input and output prices, it is not clear that capacity utilization should even necessarily have a positive sign in a markup equation. Since markups seem to be positively correlated with price change in some industries, and negatively correlated in others, it stands to reason that

capacity utilization may appropriately come into the equation with either a positive or negative coefficient, depending on the response of markups to increased activity and utilization.

The last set of industry price change equations I present here are an attempt to build a usable forecasting equation by relating price change to the change in unit intermediate and labor costs, and lagged capacity utilization. This equation should allow for different elasticities of output price change with respect to input price change by industry, but at least capture the effects of input prices. I observed what sign capacity utilization took in the equation, and tried to relate it to the relationship between output and input price change.

Figures 12 to 15 show the regression plots for the same four industries in figures 8 to 11. As would be expected, the fit of these equations is much improved from the preliminary equations using only capacity utilization. In these four industries, capacity utilization always comes in with a positive sign, although it was negative in 18 of 38 industries, about half. Notably, it is positive in the Apparel and other textile products industry, in which unit labor costs were much more volatile than output price. However, it must be that markups were slightly higher when capacity pressure was tight. Unit intermediate costs are by far the most significant variable, generally followed by unit labor cost. The marginal explanatory value of capacity utilization is much lower in these regressions, due to the strength of the other variables. Unit intermediate costs take a positive sign in every regression, and unit labor costs in all but 5 industries. The coefficients of capacity utilization are between $-.40$ in Electric utilities to $+.72$ in Food and tobacco products. In almost all of the other industries, this coefficient lies between $-.05$ and $+.15$. (The $.14$ coefficient on Petroleum refining implies that the rate of price increase in this industry will go up $.14$ percent with a one point increase in the measured capacity utilization rate.) A likely improvement to this regression equation would be to regress through the origin, which would make the response implications of the coefficients easier to interpret. A distributed lag on unit costs instead of the current value might be an improvement, although these equations already fit extremely well.

There are a number of drawbacks with equations of this type that could be anticipated in a simulation framework. For one, the equations make no allowance for the rate of change of the money supply with respect to the growth of real potential GNP. That variable was tried in these regressions, but always came in with a tiny marginal explanatory value, and frequently had the wrong sign. If the money supply variable is in the wage equations, that would help, but we still cannot be assured that the long-run property of constant average velocity will hold. Another problem is that there is no explicit accounting for the contribution of capital costs to total price. Perhaps a measure of the *ex ante* unit output cost of capital rental might be a good variable to try, but I expect it would not have high significance, since it changes slowly. Finally, since there are no lagged price changes in these regressions, there is no concept of a measure of *expected inflation* that could be used at the start of the iteration in the price calculation. Again, if this measure of expected inflation was in the wage equations, this would help, but the equations might be biased towards generating very low rates of price change. Further experimentation with price change equations is certainly warranted.

In order to use a price change equation which relies on capacity utilization, we need to forecast capacity. Moreover, we need to forecast capacity for all industries, not just those industries for which the FRB publishes capacity indexes. I have estimated some simple regressions relating capacity (using the FRB capacity utilization rate times INFORUM output measures) on estimates of equipment and structures capital stock by industry, with mixed success.

Figures 16 to 19 show INFORUM output as a heavy line, the implied capacity as suggested by the capacity utilization index as the line marked by squares, and the fit from the regression on capital stocks as the line marked with '+'s. Four industries are shown which give an indication of the correspondence of movements in the Fed capacity estimates with our measures of capital stock. Figure 16 shows the results for Crude petroleum and natural gas extraction, which is one of the worst fitting industries.¹⁰ The FRB uses a different source to estimate capital inputs than we do, although the methodology they use is very similar to ours. However, they adjust these estimates of capital input by survey information which includes questions about discards, closings of plants or the resuscitation of shuttered plants. In the Oil and gas industry as well as in

Figure 12

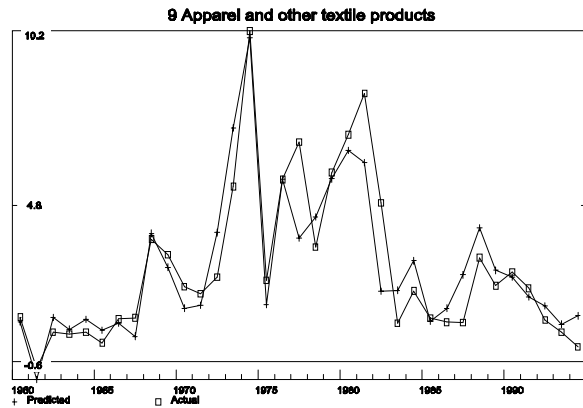


Figure 13

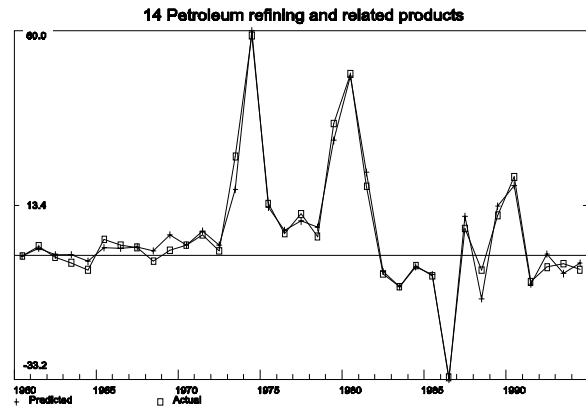


Figure 14

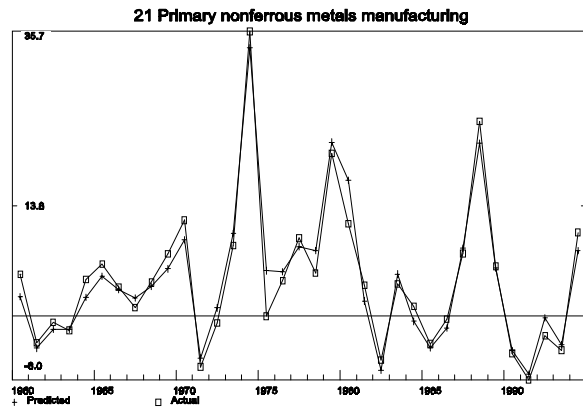
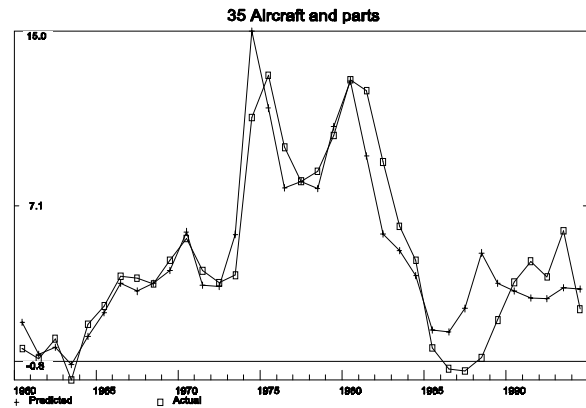


Figure 15



¹⁰ Other particularly bad fits were in Metal mining, Coal mining, Petroleum refining, Machinery, and Gas utilities. All other industries but these had R^2 of at least .6

Figure 16

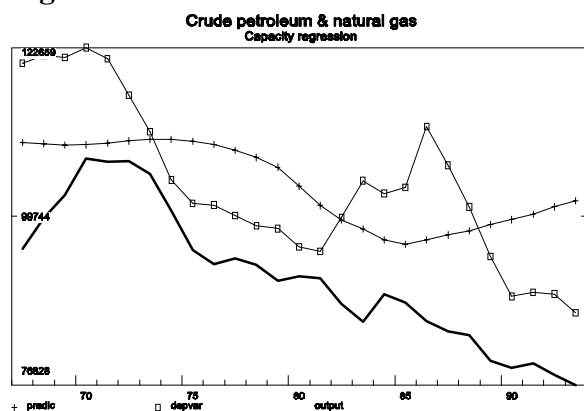


Figure 17

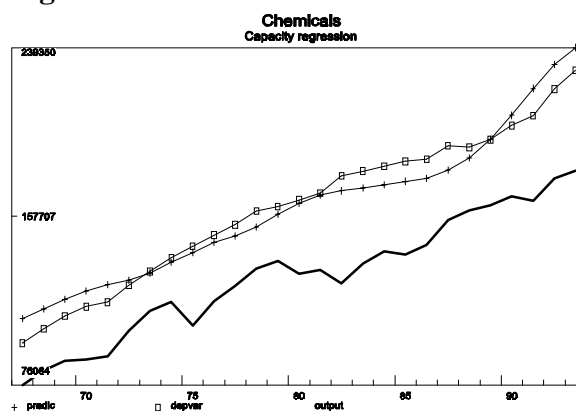


Figure 18

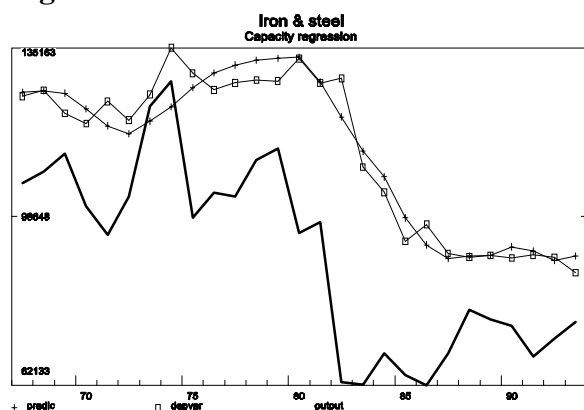
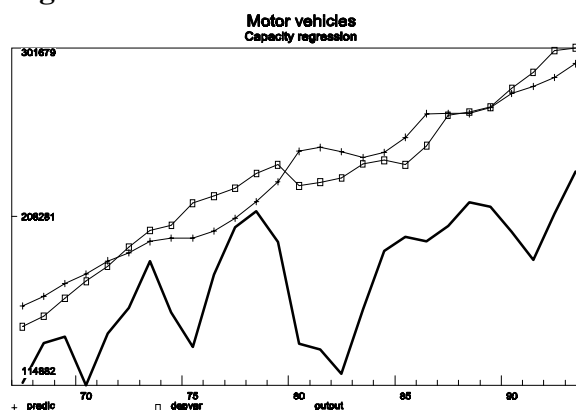


Figure 19



the mining industries, this factor is likely to be quite important. Figure 17 shows the estimates for the Chemicals industry, where our regression is able to fit the Fed capacity number quite well. Also in the Iron and Steel industry (figure 18), the estimates of capital stock constructed from investment data fit the capacity estimates surprisingly well. Finally, figure 19 shows the results for Motor vehicles, where a slowly growing capacity can be compared to an extremely cyclical production figure, resulting in wide swings in reported capacity utilization.¹¹

A question remains as to how to handle the industries outside of mining, manufacturing and utilities, where the FRB does not publish capacity utilization figures. For these industries, it might be possible to borrow some results from the current INFORUM investment equations. These equations model the investment process as an attempt to maintain an optimal capacity. The ratio of added capacity to new investment in each period is estimated as a function of a time trend and relative prices of capital, labor and energy. Replacement needs are estimated in relation to depreciation of *capacity*, not depreciation of capital stocks *per se*. Estimates of capacity calculated in this way are available in the forecasting model for the set of 54 industries we have now

¹¹ The capacity utilization index for Motor vehicles has ranged from a low of 52.8 in 1982 to 91.6 in 1973. In 1995 it was 76.9.

been examining.¹²

In the beginning of this section, I alluded to the criticism of the FRB capacity utilization measures as being *ad hoc*, and not soundly based in economic theory. In the next section I will review an alternative method that has been suggested to estimate capacity utilization.

An Alternative Approach to Measuring Capacity Utilization

The three major published sources of capacity utilization have been the Federal Reserve Board (FRB), the McGraw-Hill survey, and the Wharton index. All three measures formulate capacity utilization as an index, where 100 represents full utilization, in the sense of the maximum attainable level. However, the determination of this “capacity” level of output has not been based on explicit theoretical analysis. Cassels (1937) and Klein (1960) formulated capacity as the point on the minimum of the short-run average cost curve, as being the point where a firm or industry would minimize costs, given the current level of fixed stocks. Berndt and Morrison (1981) have followed up on this line of reasoning, and formulated a more exact notion of capacity using duality theory.¹³

In this formulation, concepts of capacity output and capacity utilization are essentially short-run concepts, conditional on a firm's current stock of fixed inputs. The capacity level is not an engineering maximum which cannot be exceeded. Rather, in a dynamic growing economy, firms may more often be producing at higher than optimal capacity, which then provides an incentive to invest in more fixed factors, thus shifting the short-run average cost curve to the right, and reducing average cost for that level of output. In fact, much of the investment literature has been implicitly based on this notion, deriving the concept of an optimal capital stock, and then developing an investment function which adjusts capital towards that desired stock in each period.

Formally, given a certain level of quasi-fixed factors x , there exists an average variable cost function:

$$c_v = g(Q, P_v, x, t) \tag{3}$$

where c_v = average variable costs
 Q = output
 P_v = prices of variable factors
 x = quantities of fixed factors
 t = an index of technological change

Total average cost is

$$c = c_v + c_f \tag{4}$$

¹² Perhaps these measures of capacity would also be useful for estimating price effects of capacity utilization in these industries. Some cursory preliminary experiments suggest that this is the case, but these will not be presented in this paper.

¹³ A more in-depth presentation can be found in Morrison (1993).

where c_f are average fixed costs. Then the level of capacity output Y^* is that level of output for which c is minimized, conditional on x :

$$Y^* = h(P_v, x, P_x) \quad (5)$$

and capacity utilization can be defined as

$$CU = Y/Y^* \quad (6)$$

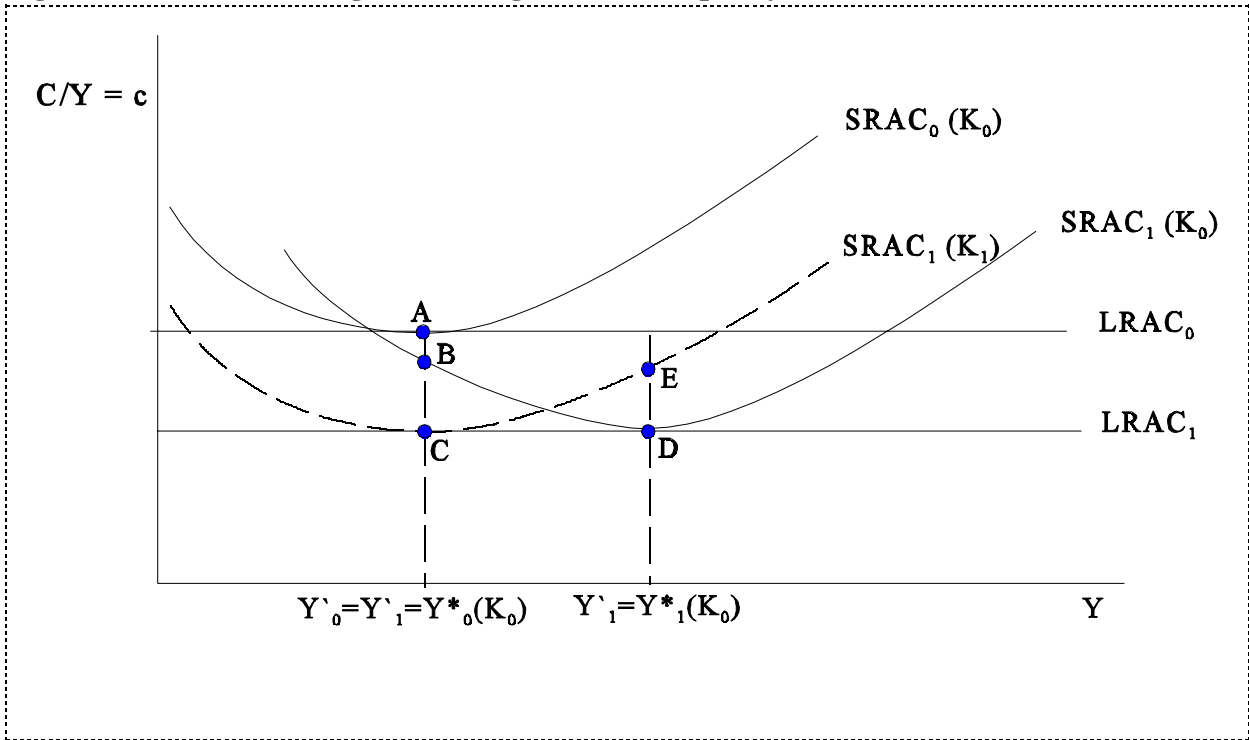
Berndt and Morrison approximate the cost function using a quadratic functional form, and proceed to estimate measures of capacity utilization for U.S. manufacturing, from 1958 to 1977. Their model has three variable factors: materials, energy and production workers, and two quasi-fixed factors: capital and non-production workers. They find capacity utilization greater than 1.0 for the entire period. They also compare their estimates to those of the FRB and Wharton. They find a correlation of .419 of their measure with the FRB treating only capital as a quasi-fixed factor, and .523 treating both non-production workers and capital as quasi-fixed. They find an even lower correlation with the Wharton index.

Figure 20 illustrates the concepts described above. At time period 0, the firm is in full equilibrium at point **A**, where the short-run average cost curve $SRAC_0$ is tangent to the long-run average cost $LRAC_0$. Only at this point is the given capital stock K_0 consistent with minimum long-run cost. Capacity utilization CU is equal to one here, defined as Y_0/Y_0^* . Assume that at time period 1 technology changes, and that the long-run average cost curve shifts down to $LRAC_1$. However, with capital level still at K_0 , the short-run cost curve shifts to $SRAC_1(K_0)$, which indicates that this technological change is *capital saving*. Therefore, if the firm is producing at the same level as before, it now has too much capital, and must produce at point **B**, since capital cannot adjust instantaneously. At **B**, capacity utilization is less than one. Now the firm stops investing, and lets capital depreciate to K_1 , shifting the short-run average cost curve to the left, to $SRAC_1(K_1)$. Eventually it can produce at point **C**, where short-run cost is at a minimum and it is back to full capacity utilization. If there were an exogenous increase in output demand to Y_1 , the firm could operate at **E**. However, this point is not minimum average cost, and the firm needs to increase its capital stock to move to **D**. Until then, it is operating with capacity utilization greater than one.

Another insight which emerges from this way of understanding capacity utilization is that productivity growth will be mismeasured unless adjustments are made to account for varying levels of capacity utilization. In the above example, technical change shifted the long-run cost curve all the way down to $LRAC_1$, which is the distance AC . However, the period to period measure of technical change will only pick up the difference AB , and productivity growth will be understated. The same underestimate will occur if technology shifts to a position where capacity utilization is greater than one. On the other hand, if we are at a suboptimal level of capital stock in one period, and move to the optimal level in the next period, measured productivity will increase, even if there has not been any shift in the underlying technology.

The notion of capacity utilization defined above can be expressed equivalently in terms of costs, and for econometric estimation, this is often more useful. We can write a restricted variable cost function analagous to the average cost function in (3):

Figure 20. Short- and long-run average cost and capacity utilization



$$C_v = G(Q, P_v, x, t) \quad (7)$$

with total costs equal to

$$C = G + \sum_k P_k x_k \quad (8)$$

where P_k = market asset rental prices of quasi-fixed factors
 x_k = quantities of quasi-fixed factors

The *shadow value* of a quasi-fixed factor x_k is

$$Z_k = -\partial G / \partial x_k \quad (9)$$

which can be interpreted as the potential reduction of variable costs per unit of investment in x_k . Therefore, *shadow costs*, or opportunity costs are

$$C^* = G + \sum_k Z_k x_k \quad (10)$$

The dual or cost side representation of capacity utilization is:

$$CU_c = C^*/C \quad (11)$$

and in subequilibrium (when capacity utilization is not exactly one) total revenue can be divided into returns to factors and utilization:

$$p_Y Y = C \cdot CU_c = C^* \quad (12)$$

A Model of Factor Demand, Capacity Utilization and Prices¹⁴

The theoretical model described above can be given empirical content by specifying a form for the restricted variable cost function G , deriving factor demand and other estimable equations, and estimating with aggregate or industry data. Using the INFORUM dataset of capital, labor, energy and materials for 54 industries, we can treat capital as the quasi-fixed factor, and labor, energy and materials as the variable factors.

Following Morrison (1990), I specify a Generalized Leontief (GL) functional form for the restricted cost function with long-run constant returns to scale imposed:

$$G = Y^{1/2} \left[\left(\sum_i \sum_j \beta_{ij} (p_i p_j)^{1/2} + \sum_i \alpha_{it} p_i t^{1/2} \right) Y^{1/2} + \sum_i \sum_k \delta_{ik} p_i x_k^{1/2} + 2 \sum_i \alpha_{kt} x_k^{1/2} t^{1/2} \right] + \sum_i p_i \sum_k \sum_l \gamma_{kl} x_k^{1/2} x_l^{1/2} \quad (13)$$

where p_i, p_j = prices of variable inputs i and j
 x_k, x_l = quantities of quasi-fixed factors k and l
 Y = output
 t = state of technology

Next I use Shephard's lemma with (13) to obtain the optimal input-output equations for the variable inputs. These equations are:

$$\frac{\delta G}{\delta p_i} \frac{1}{Y} = \frac{v_i}{Y} = \sum_j \beta_{ij} (p_j/p_i)^{1/2} + \alpha_{it} t^{1/2} + Y^{-1/2} \left(\sum_k \delta_{ik} x_k^{1/2} + 2 \sum_k \alpha_{kt} x_k^{1/2} t^{1/2} \right) + \sum_k \sum_l \gamma_{kl} x_k^{1/2} x_l^{1/2} / Y \quad (14)$$

Assuming competitive equilibrium, the output price equation can be added to the system, by setting $P = MC$,

¹⁴ This section borrows from the papers and book by C.J. Morrison cited in the references.

where MC is marginal cost:

$$P_Y = \frac{\delta G}{\delta Y} = \sum_i \sum_j \beta_{ij} (p_i p_j)^{1/2} + \sum_i \alpha_{it} p_i t^{1/2} + .5 Y^{-1/2} \left(\sum_i \sum_k \delta_{ik} p_i x_k^{1/2} + 2 \sum_i p_i \sum_k \alpha_{kt} x_k^{1/2} t^{1/2} \right) \quad (15)$$

After the parameters of this system have been estimated, we will have obtained variable input demand equations, a price equation, and the parameters of the short-run cost function. The shadow costs of each of the quasi-fixed inputs can be calculated as:

$$-Z_k = \frac{\delta G}{\delta x_k} = \frac{1}{2} x_k^{-1/2} \left[Y^{1/2} \left(\sum_i \delta_{ik} p_i + 2 \sum_i p_i \alpha_{kt} t^{1/2} \right) + \sum_i p_i \sum_l \gamma_{kl(k+l)} x_l^{1/2} \right] + \sum_i p_i \gamma_{kk} \quad (16)$$

Once Z_k has been calculated for each of the quasi-fixed inputs, we can then calculate cost-based capacity utilization from:

$$CU_c \equiv \frac{C^*}{C} = \frac{G + \sum_k Z_k x_k}{G + \sum_k P_k x_k} \quad (17)$$

The first results I will present with this model are for a data set for all manufacturing¹⁵. The data includes capital stock (K), labor (L), energy (E) and materials (M) inputs and prices, as well as output and output price, for the period 1947 to 1994. The model as described above was specified with three variable inputs (L,M,E) and one quasi-fixed input (K). Three input-output factor demand equations (14) were estimated for the variable factors, in conjunction with the cost function (13) and the output price equation (15).

Figure 21 shows a plot of the FRB measure of capacity utilization for all manufacturing for this period, compared with capacity utilization calculated by the model (multiplied by 100). The two axes have different scales, as the ranges of the two measures are different. Note that the relative movements of the two series are very close (the correlation between the series is .694), even though the parametric measure was based only on deviations of the constructed shadow price of capital from the index of the user cost of capital. Note also how the FRB measure defines 100 as the upper bound, and has a mean of about 82, whereas the model's output-based measure of capacity utilization has a maximum of 1.4, and a mean of about 1.1.

Figure 22 shows a plot of the estimated output price equation. Although the R^2 is high (.94) the equation misses the acceleration of manufacturing goods prices in the late 1960s. Figure 23 shows percentage changes

¹⁵ This data set was obtained originally from Berndt and Wood, and then updated to 1994 using aggregated INFORUM data.

of the fitted and actual values of output price. The fit is not nearly as close as the price change regressions examined earlier, but it is still remarkably good, considering that it is constrained to share parameters with other equations in the model.

Figure 21

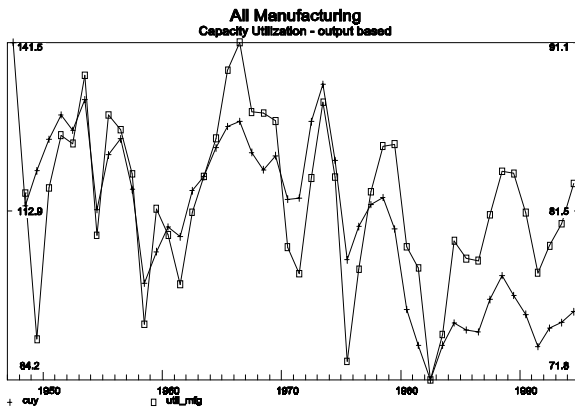


Figure 22

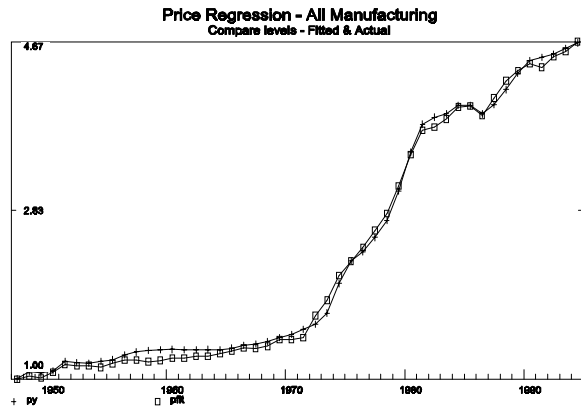


Figure 23

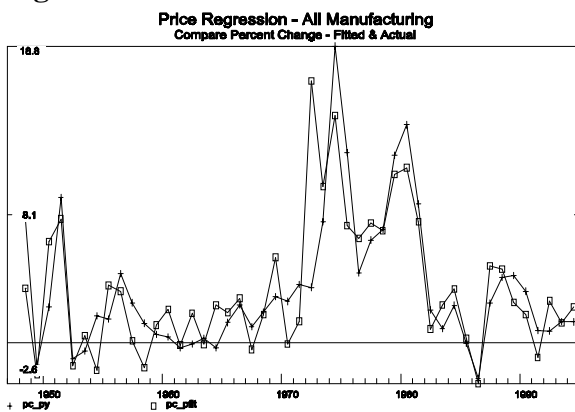


Figure 24

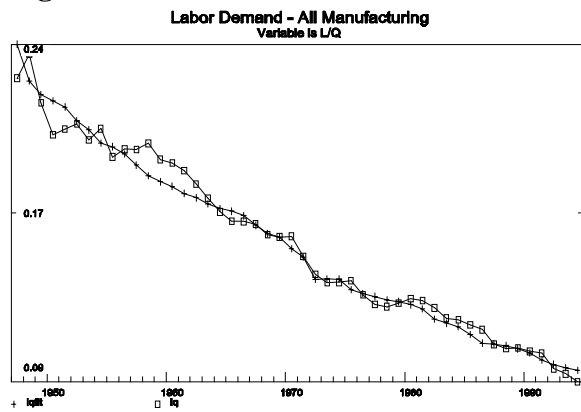


Table 2. Parameter Estimates from GL Model: 1947 - 1994
All Manufacturing

Parameter	Estimate	Parameter	Estimate
β_{LL}	0.3021	α_{Et}	-0.0053
β_{LE}	0.0029	α_{Mt}	-0.0237
β_{LM}	0.0895	α_{Kt}	0.0097
β_{MM}	0.7272	δ_{LK}	-0.9218
β_{ME}	0.0275	δ_{EK}	-0.6127
β_{EE}	0.0767	δ_{MK}	-1.281
α_{Lt}	-0.0214	γ_{KK}	1.541

Figure 23 shows the plot of the labor-output ratio equation. Like the price equation, this equation does not fit quite as well as a simple one equation model would, due to the cross-equation restrictions. However, this form of equation does have the property that it yields a response both to the level of capital stock, as well as to the price of labor.

Table 2 displays the estimated values of the 14 parameters of the model. They do not provide much interpretable information by themselves, except they are of the same sign and similar magnitude to results obtained by Morrison (1990) in a study comparing the U.S. and Japan. Table 3 shows calculated short-run price elasticities between the variable factors, and long-run price elasticities between the variable factors and the price of capital.

The long-run elasticities are defined by the situation that obtains when capital has adjusted to its optimal value K^* . This is solved by setting $p_K = Z_K$ in (16) and solving for K :

$$K^* = Y \left[\frac{\frac{1}{2} (\delta_{LK} p_L + \delta_{EK} p_E + \delta_{MK} p_M + 2(p_L + p_M + p_E) \alpha_{Kt} t^{1/2})}{p_K + (p_L + p_M + p_E) \gamma_{KK}} \right]^2 \quad (18)$$

Table 3. Estimated Short-run and Long-run Elasticities from GL CTRS Model: All Manufacturing, 1947-1994
(Values are calculated for 1994)

Parameter	Short-run	Long-run
ϵ_{LL}	-.254	-.288
ϵ_{LE}	.012	.031
ϵ_{LM}	.263	.243
ϵ_{LK}		.014
ϵ_{LY}	1.071	1.000
ϵ_{EE}	-.358	-.513
ϵ_{EL}	.057	.168
ϵ_{EM}	.301	-.195
ϵ_{EK}		-.120
ϵ_{EY}	-.135	1.000
ϵ_{MM}	-.177	-.195
ϵ_{ML}	.143	.131
ϵ_{ME}	.034	.052
ϵ_{MK}		.013
ϵ_{MY}	1.088	1.000

To calculate the long-run elasticities, we first calculate $\frac{\partial v_i}{\partial K}$ from the variable input demand function, and then calculate $\frac{\partial K^*}{\partial p_i}$ from (18). A long-run price elasticity is defined as:

$$\epsilon_{ij}^{LR} = \epsilon_{ij}^{SR} + \frac{p_j}{v_i} \frac{\partial v_i}{\partial K} \frac{\partial K^*}{\partial p_j} \quad (19)$$

Although the long-run elasticities are generally greater than the short-run in absolute value, and of the same

sign, they may be smaller, as is ϵ_{LM}^{LR} , or even of opposite sign, such as ϵ_{EM}^{LR} . The long-run elasticities show energy and capital to be complements for all manufacturing, and labor and materials to be weak substitutes with capital. In the short-run, all the variable inputs appear to be substitutes with each other, but energy and materials show long-run complementarity.

This model was also estimated using the INFORUM industry data described earlier. In general, the fitting of models such as this to industry data is more difficult than to the aggregate data. In the aggregate the cost function approximately satisfies constant returns to scale, and total revenue and total cost are roughly equal. Also, the aggregate data shows much less volatility than individual industries. In many industries, the use of an *ex ante* measure of capital cost yielded total cost significantly different from total revenue.¹⁶ The constant returns to scale version of the GL cost function used here assumes that total cost should equal total revenue.

In spite of these anticipated problems, the estimation results look promising. Figures 25 to 42 on the following pages show selected plots for 6 industries. The first plot for each industry compares capacity utilization as constructed from the cost function with the measure published by the FRB, where available. The second plot shows how well the price equation fits the actual data in percent change form. The third plot shows the fit of the labor-output ratio input demand equation. Note that in the capacity utilization plots, the measure based on the cost function is multiplied by 100, and the two measures are shown with separate scales. Most of the industry level capacity utilization estimates are highly correlated with the FRB measure, and track the turning points quite well. Furthermore, they generate reasonable estimates of capacity utilization in industries for which the FRB publishes no index, such as Air transportation. The fit of the price equations is in general very close, with R^2 higher than .98. That is why I present the percent change plots here, since they are more interesting. In most of the industries studied, the fitted price equation also tracks the changes in price quite well. Remember that the equation is based on an estimate of marginal cost, assuming constant returns to scale and no monopoly power. Although these assumptions may be unrealistic, the equations are picking up the changes in variable input cost, and the extra cost due to suboptimal capacity utilization. The labor demand equations fit fairly well, although in the Apparel and Air transportation industries, the fitted value is above or below the actual value for long periods. These equations are constrained by sharing parameters with the other equations in the system. However, they explicitly relate labor demand to the prices of the other variable factors, the quantity of capital, and the level of output.

Table 4 shows the labor-capital and energy-capital cross price elasticities for the industries in the graphs. In all cases, labor is a long-run substitute with capital. These elasticities seem reasonable, and imply that increasing the capital stock will increase labor productivity through substitution. In all cases but one, energy is complementary with capital. However, some of the energy elasticities are unreasonable, such as the energy-capital elasticity for Air transportation, which is much too high.

¹⁶ An *ex ante* measure of capital cost is based on a formula for capital user cost, which takes the capital cost index, rate of return, depreciation and tax factors into account. An *ex post* measure is constructed by subtracting variable costs from total revenue (less indirect taxes) and assigning the residual cost as the return to capital. Although satisfying constant returns to scale, this technique often yields a highly volatile capital cost variable when using industry data.

Table 4. Estimated labor-capital and energy-capital price elasticities

Industry	ϵ_{LK}	ϵ_{EK}
9. Apparel and other textile products	.084	-.175
18. Furniture	.676	-.916
21. Primary nonferrous metals	.525	-.117
29. Service industry machinery	.258	1.7
34. Motor vehicles and equipment	.100	-.006
40. Air transportation	.068	-4.7

Conclusions

The model used in this paper shows promise as a means to relate capital investment and capacity utilization to price change and labor productivity in an integrated framework. Although I encountered several industries where nonsense values of parameters were obtained, in general the results were reasonable, and the price and labor demand equations respond sensibly to relative prices, capital stock and output, all of which are variables commonly available in input-output models such as those in the INFORUM system. The model also yields independent estimates of capacity utilization by industry, which may be useful in other contexts.

The model needs to be extended to work better with industry level data. It is likely that at the industry level, the assumption of constant returns to scale is too restrictive, and one should also allow for some degree of imperfect competition in some industries. The cost function can be generalized, and prices can be estimated by adding an output demand curve to the system. The model should be extended to handle investment explicitly. Since the model solves for K^* , the optimal level of capital, we could also add an investment equation to the system, that would treat investment as the means of approaching to the optimal capital stock from the existing stock, subject to some lags or costs of adjustment. Once complete, the model would yield a consistent set of investment equations, labor demand equations and price equations for the INFORUM model.

Figure 25

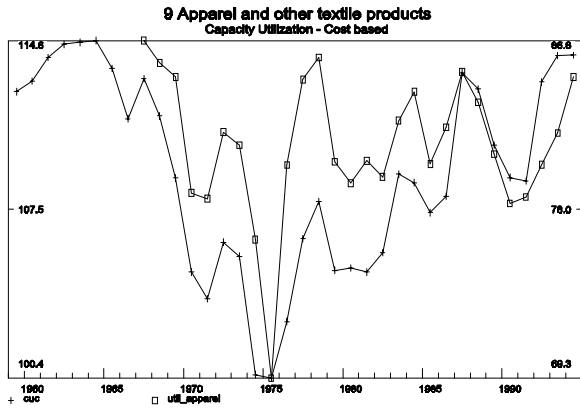


Figure 26

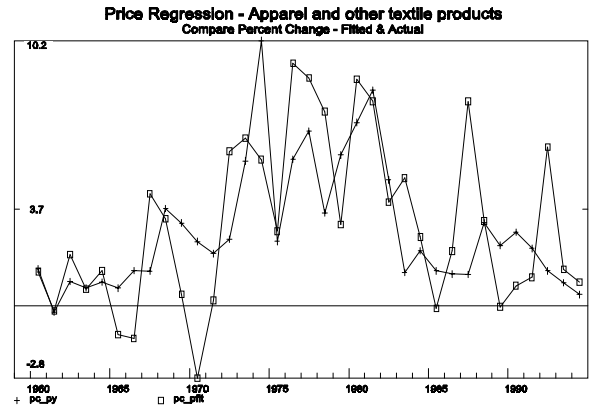


Figure 27

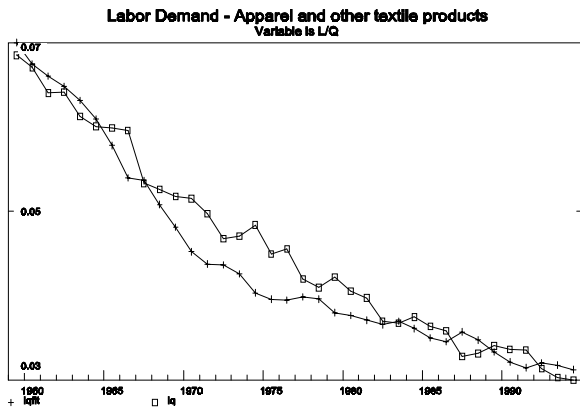


Figure 28

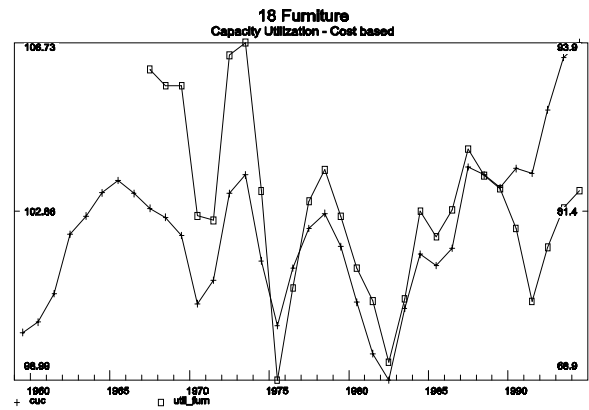


Figure 29

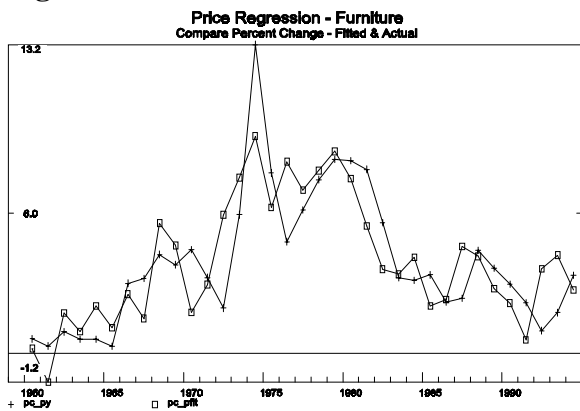


Figure 30

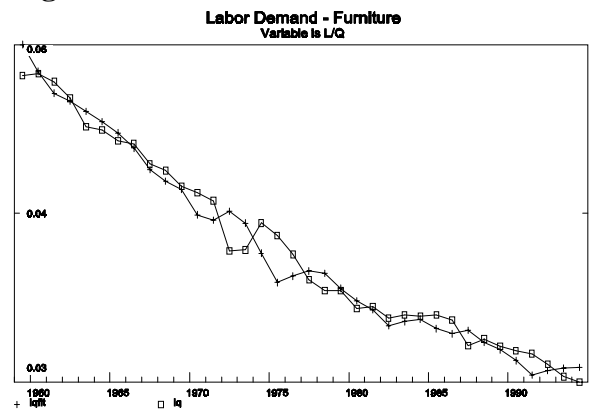


Figure 31

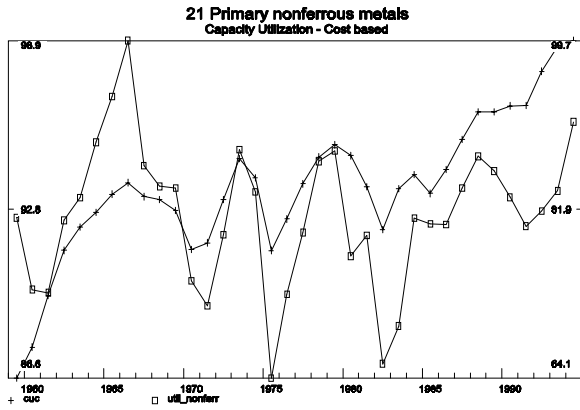


Figure 32

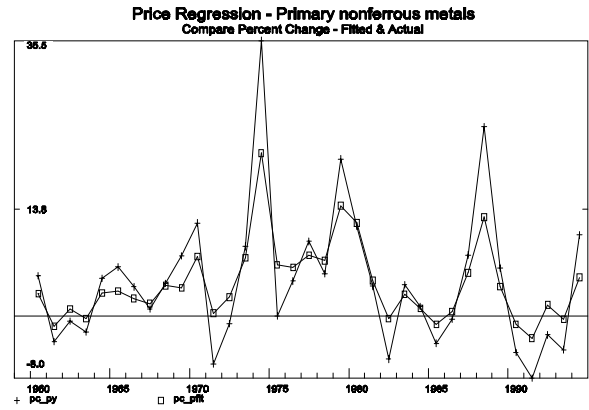


Figure 33

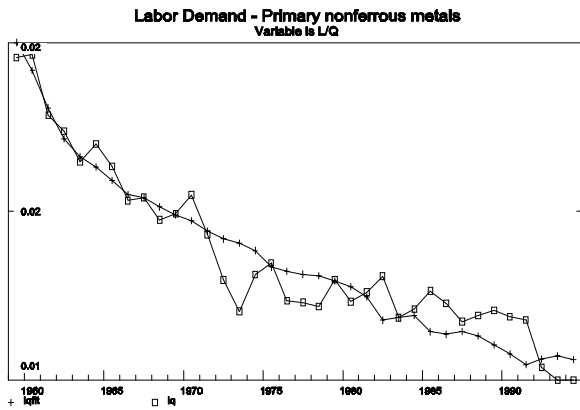


Figure 34

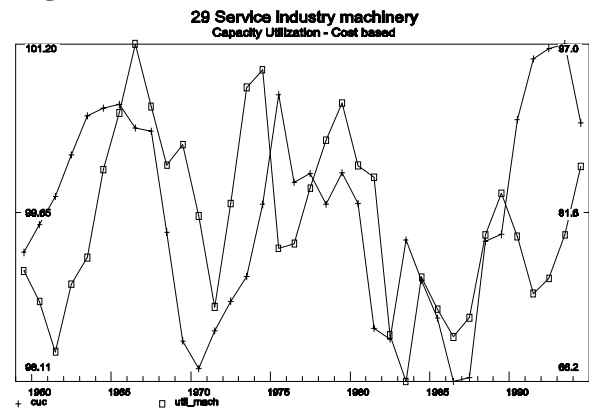


Figure 35

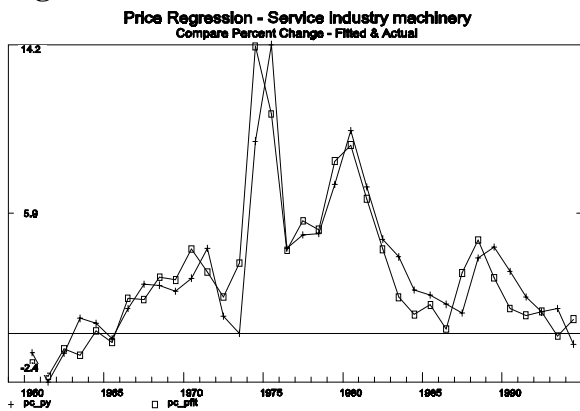


Figure 36

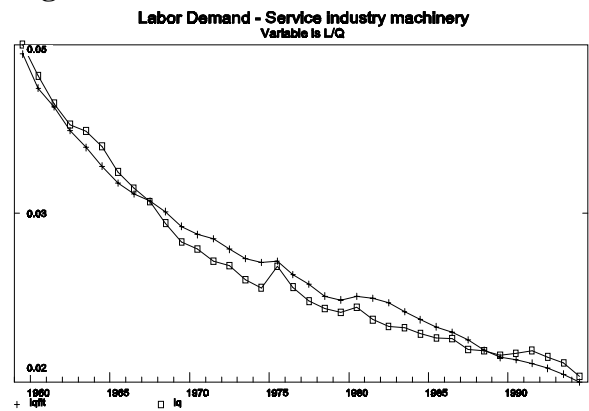


Figure 37

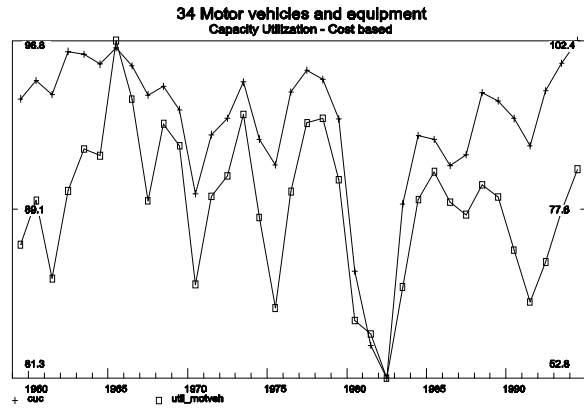


Figure 38

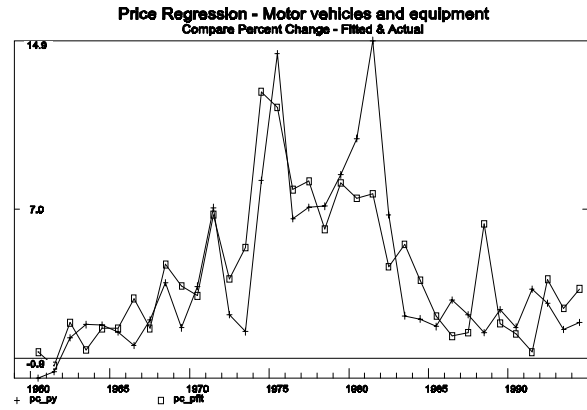


Figure 39

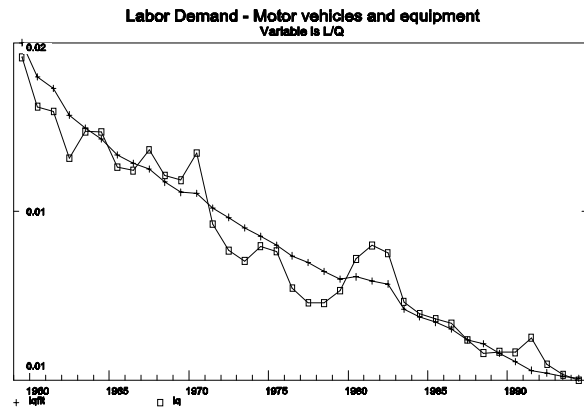


Figure 40

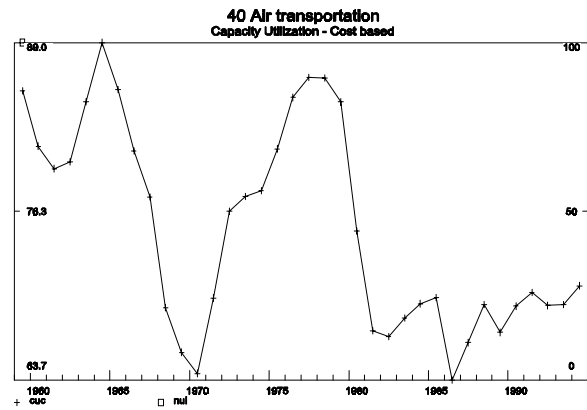


Figure 41

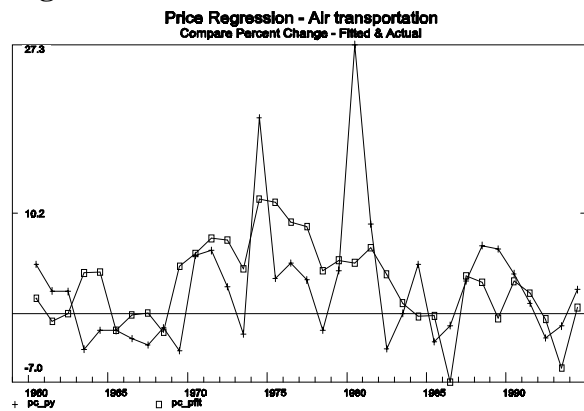
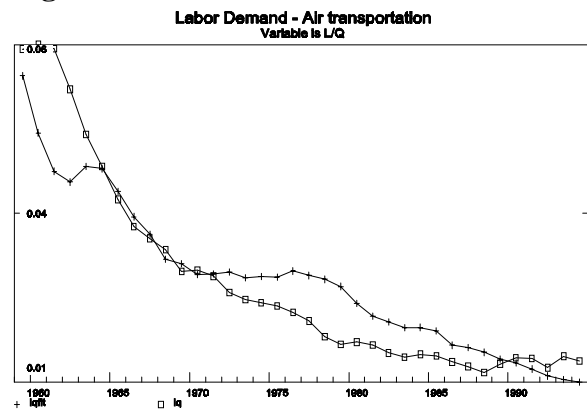


Figure 42



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