Interest Rates and Capacity Utilization: An Empirical Assessment

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Abstract

Capacity utilization has always been central to understanding how monetary policy affects an economy. Surprisingly, however, the quantitative importance of the capacity utilization channel of monetary policy has not yet been adequately established in the literature. This study examines the empirical link between movements in interest rates and capacity utilization, using 2SLS fixed effects estimations in a panel setting of 21 U.S. manufacturing industries for the period 1975 to 2011. The baseline results show that there is considerable cross-industry heterogeneity in the sensitivity of capacity utilization to changes in interest rates. The study arrives at three main findings: (a) In most industries a cut in the interest rate does not simultaneously stimulate capacity utilization. Among industries, food manufacturing is the only one that responds to an increase in the interest rate with a decrease in capacity utilization, during the same period; (b) in contrast to previous studies, the results do not show evidence that durable-goods industries are more sensitive to interest rate changes than other industries are; and (c) in many industries, when the interest rate and capacity utilization move in the same direction this suggests that manufacturers initially respond to interest-rate shocks by adjusting the utilization of their current capital stock.

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1 Introduction

The importance of including the topic of capacity utilization in discussions on monetary policy has long been recognized. Policymakers and economic agents consider changes in capacity utilization as a signal of future changes in the economic environment. Capacity utilization is one of several factors that determine why the effectiveness of monetary policy could vary over a business cycle. Capacity utilization features prominently in descriptions of monetary policy's transmission mechanism for at least two reasons. First, it factors in the conventional view of how monetary policy affects the economy. In this case, monetary policy transmission happens through the conventional interest rate/cost –of-capital channel.[1] Changes in the cost of borrowing lead businesses to adjust their investment and spending and, as a result, either their capital stock or their capital-utilization rate. Changing the utilization or the quantities of the different factors employed implies different adjustment costs. These different adjustment costs have different implications for profits and, consequently, for manufacturing output and capacity utilization. In the short term, movements in the capacity-utilization rate primarily reflect changes in manufacturing-industry output. In the long run, however, the growth rate of capacity utilization (of industries) changes in response to changes in business investment and technological progress (Garner (1994)). Second, even when monetary policy is constrained by a zero lower bound (as at present in the U.S., Japan, and many other countries) and unconventional channels, such as large-scale asset purchases and forward guidance on long-term interest rates, capacity utilization continues to play an important role in how these unconventional monetary policies are viewed as affecting the economy. Wu and Xia (2016) argue that following the Great Recession, the Fed has used unconventional policy measures to successfully lower the shadow rate, which has led to increases in industrial production and capacity utilization and, consequently, decreases in the unemployment rate.

There is a large literature that explores the macroeconomic effect of business cycle-fluctuations on capacity utilization, mostly using a dynamic stochastic general equilibrium (DSGE) model.[2] There are also many studies that investigate the relationship between capacity utilization and

[1] See, for example, García-Schmidt and Woodford (2016).

[2] See, for example, Greenwood et al. (1988), Boileau and Normandin (2003), Krüger (2008), and Wu and Xia (2016).

inflation, using Phillips curve.[3] However, much less empirical work has been done based on microeconomic evidence and there is little evidence that establishes the empirical relationship between interest rates and capacity utilization. The principal goal of this paper is to fill this gap by providing a framework for understanding the link between these two factors.

The capacity-utilization rate is quite different across industries. This cross-industry heterogeneity can be due to individual industry characteristics, such as the sensitivity of the capital intensity of production or the degree of openness which captures exchange rate fluctuations. Individual industry characteristics also play an important role in the transmission of monetary policy. For example Alvarez-Lois (2005) has argued that these differences are related to production inflexibilities and idiosyncratic demand uncertainties. Production inflexibilities mean firms cannot immediately modify their production possibilities in response to changes in the business environment. For instance, many firms cannot adjust their capacity to produce more goods, in the short-run, in response to an increase in excess demand. There are also cases wherein the existence of uncertainty at the time firms are making their capacity choices leads them to underutilize equipment. Low capacity-utilization rates suggests that firms have idle or excess capacity. The idle capacity reflects the shortage demand in manufactured goods. In this case firms try to cut their costs and do not invest any more in plant and equipment so as to expand production. As Figure 1 shows, after the 2008 crisis, slack in production was the highest and capacity utilization the lowest in nonmetallic minerals, wood, textiles, and printing, according to Federal Reserve data. This raises the questions as to which U.S. manufacturing industry policy makers should be most anxious about.

Most previous studies on capacity utilization have concentrated on the manufacturing sector as a whole without providing a more disaggregated view of the problem.[4] This paper provides quantitative results on the connection between interest rates and capacity utilization at the industry-level. There are two reasons for exploring this disaggregated analysis: First, each of these industries behaves differently in response to changes in interest rates over time. Second, in theory, interest rates can have either a positive, negative, or no effect on capacity utilization. Therefore, studying the manufacturing sector at the aggregate level can obscure our understanding of how interest rates

[3] See, for example, Garner (1994), Finn (1996), Emery and Chang (1997), Belton and Cebula (2000), and Dotsey and Stark (2005).

[4] See, for example, Berndt and Morrison (1981), Garofalo and Malhotra (1997) and Kim (1999).

affect capacity utilization. From a policy perspective, however, it would be useful to know the capacity utilizations of the industries that are more sensitive to fluctuations in interest rates. Some studies, such as Peersman and Smets (2005), show that the durability of the product produced by the industry has a highly significant and positive effect on its sensitivity to changes in monetary policy. It is for this reason that a rise in interest rate has more impact on demand for durable goods than the demand for non-durables. The second question this paper asks is whether the capacity utilization of durable-goods industries is more sensitive to changes in interest rates. To answer this question, I conduct a disaggregated analysis of manufacturing industries.

The main objective of this paper is to contribute to the literature by analyzing cross-industry heterogeneity on the basis of the sensitivity of capacity utilization to changes in the interest rate. For this reason I distinguish between the direct and indirect effects of interest rates on capacity utilization. Interest rates have both a direct and an indirect effect through the cost-of-capital channel. Most of the previous literature on capacity utilization considers capital stock as an exogenously given variable; however, this approach can bias the estimated parameters. Another contribution of this paper is to correct this problem by using a sample that includes manufacturing industries with different levels of capital utilization. In contrast to the concept of capacity utilization, capital utilization may be defined as the ratio of the desired stock of capital (given the quantity of the output and the input prices) to the actual stock of capital (Berndt and Fuss (1989)). Capital utilization is different from capacity utilization. The former measures the intensity with which capital operates, and the latter measures the actual output relative to the firm or industry's potential. The capital-utilization rate affects the user's cost of capital by changing the depreciation rate and it gives the firm flexibility in responding to a shock to demand and/or cost. In this case, the level of output is determined by the firm's choice of inputs and their utilization of these inputs. Shapiro (1986) argued that firms may respond to temporary shocks by adjusting the utilization of their inputs; they can respond to permanent shocks by adjusting the stock of their inputs. Therefore capital utilization is an indirect transmission channel of monetary policy that cannot be ignored.

In this paper I identify the main factors that affect capacity utilization. I also present a framework in which elasticities of capacity utilization are measured with respect to changes in economic conditions; I do so by using the 2SLS fixed effects estimation in a panel setting for 21 U.S. manufacturing industries for the period 1975 to 2011. The main findings are as follows: (a) In most industries, a cut in the interest rate does not simultaneously stimulate their capacity utilization. Interest-rate changes only have an immediate negative influence on the capacity utilization of food industries, which capture less than ten percent of total manufacturing production. (b) In contrast to previous studies, I do not find evidence regarding more sensitivity of durable-goods industries to interest-rate changes. In terms of magnitude, leather and allied products from non-durable manufacturing industries and computer and electronic products from durable manufacturing industries, respectively, show the greatest sensitivity to interest rate changes. (c) In many industries, interest rates and capacity utilization move in the same direction. This suggests that, in response to a raise in the interest rate and a consequent increase in the cost of capital, many firms increase their capacity utilization by using their current level of capital more intensively.

In conceptualizing the channels through which monetary policy affects capacity utilization, we must keep in mind that the contemporaneous elasticity is not high; also, it is quite different across industries. Policymakers need to consider that capacity utilization is more sensitive to policy in certain sectors than it is in others; therefore, they should pay more attention to these interest-rate-sensitive industries. This means that knowledge about which sectors are more responsive to federal interest-rate changes is very important and is provided by the current research.

The rest of the paper is organized as follows. Section 2 shows how the theory predicts how the relationship between capacity utilization and interest rates should work in principle. Section 3 is devoted to an empirical analysis, including a discussion of the data sources, some descriptive statistics about the data sources, an empirical specification, industry effects, and robustness checks. The final section of this study provides a brief summary and conclusions.

2 Theory

Assume that each manufacturing industry has a production function for gross output as follows:

$$Y_{it} = F(K_{it}u_{it}, L_{it}, E_{it}, M_{it}, T_{it}),$$

where Y_{it} denotes the level of output in manufacturing industry i, at time t. K_{it} is the capital stock and u_{it} is an index of its utilization rate. L_{it} is the services provided by labour. Variables E_{it} and

M_{it} represent the inputs of energy and materials, respectively, that are used to produce Y_{it}. T_{it} represents the state of technology. In the short run, capital is generally fixed; that is, plant size and equipment cannot be increased or decreased. The capacity utilization ratio in manufacturing industry i, at time t is

$$CU_{it} = Y_{it}/Y_{it}^{*}, \tag{1}$$

where Y_{it} and Y_{it}^{*} are the actual and capacity level of output, respectively, in manufacturing industry i, at time t. Output (Y_{it}) is chosen by firms that are using the short-run profit maximization rule, which in this case, this is defined as the point at which marginal revenue is equal to short-run marginal cost (*SRMC*). Cassels (1937) defines a capacity level of output (Y^{*}) as the level of output where the firm's long-run average cost curve reaches a minimum. However, a firm that is experiencing constant returns will also have constant long-run average cost which is horizontal and does not have a minimum point. Klein (1960) provides an alternative measure of capacity output that also works under constant returns to scale. He defines the capacity level of output as the point where the short-run average cost curve (*SRAC*) is tangent to the long-run average cost curve (*LRAC*). This is the point at which the *SRMC* is equal to the long-run marginal cost (*LRMC*). The capacity-utilization ratio can be less, equal to, or greater than one indicating under-utilized, fully utilized or over-utilized capacity, respectively.

The short-run variable cost function (*SRVC*) is defined as a function of labour (L), energy (E), and materials (M) as follows:[5]

$$SRVC = WL + P_E E + P_M M = f(Y, P, g(K))$$

$$g(K) = uK. \tag{2}$$

For notational convenience, the subscripts have been dropped. Y is the output level, P is a vector of input prices, and $g(K)$ is the flow of capital services, which is defined as a function of the capital-utilization rate (u) and the capital stock (K). Previous studies have generally treated capital stock as being exogenous to the estimation of capacity utilization or the *SRVC* function; however, capital

[5] Energy and materials are the intermediate inputs, purchased from domestic industries and foreign sources, that industries consume in producing gross output.

services (capital in use) is more relevant to these concepts. For instance, during slack periods, when firms operate at less than full capacity, measuring capital stock will overestimate the contribution of the capital input to the production and capacity utilization. Therefore, using the exogenous capital stock in the equations means that there will be errors in the estimations, which results in biased parameter estimates (Lovell (1968)). Capital utilization measures the speed or intensity with which a given stock of capital equipment operates. For instance, this could be referring to the capital's workweek.[6] When firms need more capital services than what they currently have, they may buy additional physical capital or they may use what they already have more intensively. Since most firms cannot adjust the level of capital stock in the short run, they try to choose the optimal utilization rate of their capital stock. Uncertainty about the future is also an important factor in firms' investment decisions. Firms respond differently based on their expectations about the permanency of shocks. Firms may respond to permanent shocks by adjusting their capital stock and they can react to temporary shocks by modifying the utilization of their capital stock (Shapiro (1986)). There are other factors such as existence of transaction costs and market imperfections which can affect on capital utilization (Durlauf and Blume (2008)). For these reasons it is important to include capital utilization in the estimation of capacity utilization.

In the literature, many researchers use the terms "capital utilization" and "capacity utilization" interchangeably. Berndt and Fuss (1989) show, however, that these two concepts are the same under two conditions: (a) if production has constant returns to scale; and (b) if there is only one fixed input. Most studies on capacity utilization consider only the first condition and treat capital stock as a given. However, the existence of only one capital input doesn't look realistic. For these reasons, I investigate the capacity-utilization function with a sample that includes industries with different utilization rates. This provides a better specification and a better estimation of capacity utilization.

I assume that the *SRVC* has regularity conditions as follows: it is increasing and concave in input prices; it is non-increasing and convex in K; it is linearly homogeneous in input prices; and it is non-decreasing in Y.[7]

[6] This is the main difference between the proposed *SRVC* functions in Appendix B and the conventional form which ignores capital utilization. In the conventional *SRVC* function, capital refers to capital stock, but in the proposed *SRVC*, $g(k)$ refers to capital services.

[7] See, for example, Morrison (1985), Kim (1999).

In this paper, I do a reduced-form estimation, according to the theory.[8] From the theoretical framework we know that

$$Y^* = Y^*(uK, W, P_E, P_M, P_K, T), \tag{3}$$

where uK is the current level of capital services, which in this case is equal to the optimal level of capital services, i.e. $uK = (uK)^*$. According to (3), the capacity level of output (Y^*) is the level of output at which the current capital stock is equal to the optimal long-run capital stock. From the production function, the current level of output is a function of the input prices, capital stock, capital utilization, and technology, that is,

$$Y = Y(uK, W, P_E, P_M, T).$$

Using (1), $CU = Y(uK, W, P_E, P_M, T)/Y^*(uK, W, P_E, P_M, P_K, T)$ (where CU is capacity utilization and all the other variables have been explained), the elasticities of capacity utilization with respect to the exogenous variables are as follows:

$$\frac{\partial\ lnCU}{\partial\ lnK} = \frac{\partial\ lnY}{\partial lnK} - \frac{\partial lnY^*}{\partial lnK} \gtreqless 0$$

$$\frac{\partial\ lnCU}{\partial\ lnP_K} = -\frac{\partial lnY^*}{\partial lnP_K} = -\left(-\frac{\partial\ lnK^*/\partial\ lnP_K}{\partial\ lnK^*/\partial lnY}\right) < 0 \tag{4}$$

$$\frac{\partial\ lnCU}{\partial\ lnP_j} = \frac{\partial lnY}{\partial lnP_j} - \frac{\partial lnY^*}{\partial lnP_j} \gtreqless 0 \qquad j = E, M \tag{5}$$

$$\frac{\partial\ lnCU}{\partial\ lnW} = \frac{\partial lnY}{\partial lnW} - \frac{\partial lnY^*}{\partial lnW} \gtreqless 0$$

$$\frac{\partial\ lnCU}{\partial\ lnT} = \frac{\partial lnY}{\partial lnT} - \frac{\partial lnY^*}{\partial lnT} \gtreqless 0.$$

These equations show that the elasticity of capacity utilization, with respect to an exogenous variable, is expressed by two terms: the effect on the current level of output given the output

[8] The empirical estimation of the model requires an explicit functional form for the variable cost function. Although the previous literature suggests a plethora of functional forms, I use a quadratic functional form in Appendix B to show the theoretical link between the interest rate and capacity utilization.

capacity, and the effect of the output capacity given the current level of output. In this case, whichever effect is greater will determine whether capacity utilization will increase or decrease (for more details, see Kim (1999)). It can also be shown that the semi-elasticity of capacity utilization with respect to capital utilization is as follows:

$$\frac{\partial\ lnCU}{\partial\ u} = \frac{\partial\ lnY}{\partial u} - \frac{\partial lnY^*}{\partial u} \gtreqless 0.$$

I formulate the user cost of capital using Gale and Orszag (2005) as follows:

$$P_K = \frac{r - \pi + \delta(u)}{1 - \tau}\ (1 - \tau z), \tag{6}$$

where r is the nominal interest rate and π is the expected rate of inflation. In this equation, τ and z are the statutory corporate tax rate and the present value of depreciation deductions on a one-dollar investment, respectively. I consider the depreciation rates (δ) as a function of capital utilization (u) following the theoretical results of Taubman and Wilkinson (1970). Their results show that capital utilization depends on factor prices which, in turn, affect the depreciation rate of capital. As such, whenever there is evidence of a shift in factor prices, the depreciation rate should not be constant. The logarithmic form of (6) is given by:

$$lnP_K = ln(r - \pi + \delta(u)) + ln(1 - \tau z) - ln(1 - \tau). \tag{7}$$

Differentiating (7) with respect to r can be written as

$$\frac{\partial\ lnP_K}{\partial\ r} = \frac{1}{r - \pi + \delta(u)} \gtrless 0. \tag{8}$$

Using (4) and (8) the semi–elasticity of capacity utilization with respect to the interest rate is

$$\frac{\partial\ lnCU}{\partial\ r} = -\frac{\partial lnY^*}{\partial lnP_K}\frac{\partial lnP_K}{\partial r} \gtrless 0. \tag{9}$$

This expression shows that an increase in interest rates can have either positive or negative effects on capacity utilization. I now turn to the data to determine these effects.

3 Empirical Analyses

3.1 Data

Time series data for U.S. industries on the NAICS (North American Industry Classification System) three-digit code list is drawn from different sources for the period 1975–2011. The annual industrial-production (IP) index and capacity-utilization data are obtained from the Board of Governors of the Federal Reserve. The IP index measures real output at the three-digit industry-level as a percentage of real output in a base year.[9] The Federal Reserve Board constructs estimates of capacity utilization in a given industry by dividing an output index by a capacity index.[10] Data on total real capital stock (in millions of USD) and total capital expenditure (in millions of USD) are obtained from the NBER-CES (National Bureau of Economic Research–Center for Economic Studies) Manufacturing Industry Database.[11] I calculate the values for total real investment by dividing the total capital expenditure by an investment deflator scale (1997=1). I calculate the depreciation rate for each industry, backing them out of the standard perpetual inventory equation as follows:

$$K_t = (1 - \delta(u_{Kt-1}))K_{t-1} + I_t, \tag{10}$$

where the net stock of fixed capital, at any given time, is the cumulative value of gross investment minus the aggregate value of past depreciation. Put differently, the machines that are available for production at time t are those that existed during the last period plus those that are producing and operating at t, minus those that are broken down.[12] Since the total real capital stock and the total capital expenditures are not available for the years that follow 2011, it was necessary to restrict the time period under study to 1975 to 2011. Rearranging (10), I calculate the depreciation rate as follows:

$$\delta(u_{K_{t-1}}) = 1 - \frac{I_t - K_t}{K_{t-1}}. \tag{11}$$

Nadiri and Prucha (1993) estimated the depreciation rate of physical capital in manufacturing, as a whole, at 0.059, which is close to the depreciation rates I calculated for different manufacturing industries, using (11). Applying (11) will recreate the missing values for the depreciation rates

[9] I calculate the IP index for Transportation Equipment industry as an average of IP index in Motor Vehicles and Parts industries and Aerospace and Miscellaneous Transportation industries.

[10] The Federal Reserve Board's capacity indices are associated to the sustainable maximum output which is the greatest level of output a plant can maintain within the framework of a realistic work schedule, after factoring in normal downtime and assuming sufficient availability of inputs to operate the capital in place.

[11] The data is from http://www.nber.org/nberces/ comes at six–digit manufacturing industries and I calculated the aggregate data at three-digit level.

[12] I do not use Capital Expenditure Survey because it does not include information about depreciation and includes just two–digit manufacturing industries.

in 2011. I estimate the imputed values for that year in order to have a balanced panel. Energy (E) and materials (M) are intermediate inputs that are purchased from domestic industries and foreign sources and consumed by industries in the process of producing gross output. Chain-type price indices for energy (P_E) and materials (P_M) are obtained from the Gross-Domestic-Product-by-Industry data series (including KLEMS data) from the Bureau of Economic Analysis (BEA).[13] Since KLEMS data are for the period 1997 to 2011, I use Dale Jorgenson's annual KLEMS data for the years prior to 1997. These data are based on the 2-digit standard industrial classification (SIC), which I cross-reference and match with the 3-digit NAICS industries in this study. Average annual pay (W) for industries are from the Bureau of Labor Statistics.[14] These data are available by ownership group.[15] I employed data that is related to the private sector and is calculated according to the real values of wages and capital stock by dividing the current values by the industrial-production index (1997). The effective federal funds rate (EFFR) (interest rate) and the inflation rate are obtained from Federal Reserve statistics.

Capital utilization (u) is another variable used in our estimation. Since u is not directly observable, some measure for u must be used. I used the proxy of Greenstone et al. (2010) for capital utilization, which is the ratio of the dollar value of energy usage to the capital stock. The dollar value of energy usage is a good measure for capital utilization, since it increases in the use in line with the use of capital stock. The total cost of energy was obtained from the NBER-CES manufacturing industry database. This cost includes the cost of electricity and fuel.

3.2 Descriptive Statistics

Table 2 shows the correlation between the variables. The unconditional correlations show that capacity utilization and the FFR move in the same direction with a moderate correlation (0.24). There is a positive correlation equal to 0.28 between capacity utilization and capital utilization. The price of energy shows the highest correlation with capacity utilization over the study period, and is negative. Table 3 shows the descriptive statistics for capacity utilization in each industry

[13] Based on BEA: "KLEMS (K-capital, L-labour, E-energy, M-materials, and S-purchased services) refers to broad categories of intermediate inputs that are consumed by industries in their production of goods and services.", http://www.bea.gov/industrygdpbyind˙data.htm

[14] http://www.bls.gov/cew/datatoc.htm

[15] Ownership group can be international, local, state, federal, total government or private.

over the sample period, sorted by their mean capacity utilization, from largest to smallest. The table denotes a remarkable heterogeneity in capacity utilization across industries. Paper industries and leather, and allied product industries have the highest and lowest capacity utilizations, with averages of 86.4 and 72.12, respectively. The data also show that the average capacity utilizations of nonmetallic mineral products, and leather and allied products industries have the highest variations from their means over the period, with standard deviations of 9.16 and 9.02, respectively. The food manufacturing industry has the lowest variation, during the period 1975 to 2011, with a standard deviation of 2.14.

3.3 Empirical Specification

In this section, I estimate the relationship between capacity utilization and interest rates, while controlling for a variety of other variables as discussed above. I use the variations across industries and over time to investigate the relationship between capacity utilization and interest-rate changes. There are a number of considerations that motivate the baseline specification, which is shown below:

$$lnCU_{it} = \begin{cases} \alpha_i + z'_{it}\alpha + \gamma_1 T + \eta_1 Dummy + u_{it} & \text{(12a)} \\ \beta_i + \phi r_t + z'_{it}\beta + \gamma_2 T + \eta_2 Dummy + v_{it}, & \text{(12b)} \end{cases}$$

where (12a) shows the baseline specification without interest rates, and (12b) shows the baseline specification with interest rates included as an additional explanatory variable. As it is shown in (7), there are four factors that affect user user cost of capital: fluctuations in the interest rate, the inflation rate, depreciation, or tax rates. For this reason, using user cost of capital by itself does not allow us to separate interest rate effect from other factors. Including the interest rate as an additional explanatory variable allows us to investigate the direct effect of interest-rate fluctuations on capacity utilization. The indirect effect of the interest rate fluctuation is through user cost of capital or utilization of capital which are included in the model. The dependent variable, $lnCU$, is the natural logarithm of capacity utilization. The subscript i refers to manufacturing industries (i=1, ..., 21) and t is time (t=1975, ..., 2011). α_i and β_i are simply the fixed- effects. z'_{it} is a K-dimensional row vector of the time-varying explanatory variables. α and β are K-dimensional column vectors of the parameters. Table 1 shows the explanatory variables of vector z_{it}.

Table 1: Explanatory Variables of vector z_{it}

Symbol	Desc.
IP_{it}	Industrial output
$P_{E\,it}$	Index price of energy
$P_{M\,it}$	Index price of material
$P_{K\,it}$	User cost of capital
W_{it}	Wages
K_{it}	Capital stock
u_{it}	Utilization rate of Capital

T shows the time trend. The *Dummy* variable captures the recessionary period and is equal to 1 for the years 2008 and afterward, and 0 otherwise. u_{it} and v_{it} are idiosyncratic error terms. I consider two different measures of the interest rate (r_t): the *FFR* for the baseline model and the treasury inflation-indexed security (*TIPS*) for the robustness check. Since businesses react to changes in the nominal interest rate and not just to changes in real costs, I initially estimate the model by adding the nominal interest rate (*FFR*) as a regressor and do a subsequent estimate by adding real costs (*TIPS*).[16]

To explore the relationship between capacity utilization and interest rates, I made use of variations across manufacturing industries, over time, by analyzing the two-stage least squares method (2SLS), using instrumental variables for output to address the endogeneity problem in the estimation. The instruments used are the industrial output with one lag, the dollar value of energy usage, and a time trend.[17]

As I previously mentioned, some values for the depreciation rate are missing, which leads to missing values for the rental price of capital (P_K) and an unbalanced panel. Since the panel has one continuous variable with missing values, I use a single-regression imputation. In this method, the imputed value is predicted from a regression equation. To decide which variables should be included in the imputation model, I follow the most common recommendation, which is that the imputation model should contain the same variables that are in the analytic model, including

[16] See, for example, Akhtar (1983).

[17] I test the validity of my instruments by checking week-, over- and under-identification using Kleibergen-Paap rk Wald F, Hansen J, and Kleibergen-Paap rk LM statistics, respectively. The results of these tests are available upon request.

the dependent variable. Otherwise, the relationships wherein variables are omitted will be biased toward zero. This is due to the assumption of non-correlation between the imputed values and the omitted variables.[18]

Table 4 indicates a robust estimation of the relationship between capacity utilization and the factors that underlie it, using a two-stage least squares (2SLS) regression for U.S. manufacturing industries.[19] The first column shows the estimation results, without the interest rate; the second columns shows the estimation results, using the interest rate as an explanatory variable to investigate how sensitive the capacity utilization ratio is to interest-rate changes. The semi-elasticity of capacity utilization with respect to the *FFR* appears to be very small (0.003). Both estimations suggest a positive and insignificant coefficient for industrial production. The results of both of the estimated equations indicate that the price of energy has an adverse and significant effect on capacity utilization. This is in contrast to Kim (1999) results, which find that energy prices have a stimulating effect on capacity utilization. However, earlier studies show that energy shocks had an adverse impact on capacity utilization during the 1970s. As it is shown in (5), there is no theoretical reason for predicting either positive or negative effects of input prices. However, Winston (1974) shows that an increase in wages tends to reduce capacity utilization. Obviously, this would not be the case if labour and capital were complements. The coefficient of wages is positive and significant under the specification with the interest rate, but insignificant under the specification without the interest rate. The price of capital has a correct sign but an insignificant impact on capacity utilization.

My results suggest that capital stock has a negative but insignificant effect on capacity utilization. On the contrary, a higher level of capital utilization will stimulate capacity utilization. The dummy variable, which captures the recessionary period (2008 to 2011), displays a negative and statistically significant effect.

[18]See Rubin (1996), Enders (2010).

[19]Robust estimation allows me to consider the effect of persistency of the capacity utilization on the estimated parameters.

3.4 The industry effects

Appendix A shows capacity utilization in each manufacturing industry. As the figures show, there is a considerable variation in capacity-utilization rates both across industries and over years within industries. To clarify the direct effect of interest rates, I next investigate its impact on each industry, separately. The first column of Table 5 shows the estimation results using the *FFR*. The results suggest that, interest-rate movements have a significant effect on the capacity utilization of fifteen industries. Looking at the industry effects, it is clear that the overall policy effects are significantly larger in leather and allied products, computer and electronic products, and beverage and tobacco products industries. Among all industries, the food industry is the only one wherein an increase in interest rates leads to a decline in capacity utilization. One possibility is that firms in this industry are capable of adjusting their production quickly in response to interest-rate changes. The results show that the contemporaneous semi-elasticity of capacity utilization with respect to the federal funds rate is not significant in apparel, chemical, primary metal, and fabricated metal products, machinery, and miscellaneous industries.

Following the results of Baghestani (2008) for the highly significant effect of the federal funds rate with lags of six and eight quarters on capacity utilization in the manufacturing sector, I investigate the lagged effects of the interest rate on capacity utilization. Table 5 (last two columns) shows the estimation results that use the federal funds rate as a regressor with one and two lags. The one-period lagged *FFR* specification shows significant effects on capacity utilization in fifteen industries, while under the two-period-lagged *FFR* specification, the number of industries with a significant coefficient goes up (sixteen industries). The estimation results show that a one-period-lagged *FFR* has a reverse significant effect on capacity utilization only in four industries, which include food, fabricated metals products, machinery, and transportation equipment. In the two-period-lagged *FFR* specification, the number of manufacturing industries wherein the *FFR* has a positive and statistically significant effect falls off. Under this specification, the interest rate has a depressing effect on the capacity utilization of six industries, including food manufacturing, primary metals, fabricated metal products, machinery, and electrical equipment, appliances and components, and transportation equipment. In terms of magnitude, changes in the interest rate have the greatest positive effects on capacity utilization in computers and electronic products, and beverages and tobacco products industries in both estimations, i.e. with one and two lags. The greatest reverse impact on capacity utilization with the one-lag estimation is on the food processing industry. Capacity utilization here and in machinery industries shows the greatest negative reaction to changes in the interest rate in the estimation with two lags, which is equal to -0.014 and highly significant. Figure 2 summarizes these results.

3.5 Robustness Checks

In this section, I examine the robustness of my results, using three different exercises. First, I apply two alternative imputation methods: predictive mean matching for continuous variables (PMM) and the monotone imputation for the missing data.[20] My estimations show that both of these imputation methods generate similar results. In the second exercise, I use the Wu–Xia shadow rate, instead of the *FFR*, for the years 2009 to 201l, and re-estimate the models. However, the results remain quite similar, since the data is changed for just three years.[21] In the last exercise, I use another regressor to analyze the direct effect of the interest rate changes on capacity utilization. Subsequently, I employ 5- and 10-year treasury inflation-indexed securities (*TIPS*) as extra explanatory variables. The *TIPS* protects investors against inflation. Since the rental price of capital is measured by the consumer price index (CPI), while the interest rate remains fixed, I define it as

$$P_K = TIPS_t + \delta(h_{Kt}). \tag{13}$$

Table 6 shows the estimation results using the *FFR*, the 5-year *TIPS*, and the 10-year *TIPS* for the period 2005–2011. Since the *TIPS* data are available from 2003, picking this period allows us to compare the results using different regressors with zero, one, and two lags. For the period 2005–2011, the *FFR*, the 5-year *TIPS*, and the 10-year *TIPS* show negative and highly significant effects on capacity utilization. In terms of magnitude, however, the effect is greater in the estimation

[20] PMM is an alternative way of imputing missing values of a continuous variable which identifies one or more neighbors with similar estimated values using regression methods (Roderick 1988). Monoton imputation is a non-iterative method which can be used when the missingness pattern is monotone (Rubin 1987).

[21] The results are available upon request.

that uses the 10-year *TIPS*. In contrast to the estimated results for the period 1975–2011, shown in Table 4, the price of energy does not show any significant impact on capacity utilization in all three estimated model. From the end of 2002 to the middle of 2008, the U.S. economy experienced a significant increase in oil prices. This increase is comparable in magnitude to the first two OPEC shocks, but Hooker 1996, 2002, Blanchard and Gali 2010 have shown that oil-price shocks have had smaller macroeconomic effects since the early 1980s. Their results show that the positive response of core inflation to oil-price shocks has sharply diminished over time; their results also show that the negative responses of output and employment to increased oil prices have almost vanished. This explains the insignificant effect of energy prices in my estimation model. In all specifications, the price of materials shows a positive and significant impact on capacity utilization. The results show that when capital stock is more expensive, this leads to lower capacity utilization. An increase in the amount of capital stock does not show a significant effect on capacity utilization in all cases. An increase in the price of labour causes a stimulating effect on capacity utilization for all specifications. A more intense utilization of the the existing capital stock causes higher levels of capacity utilization in all scenarios. The time trend, which captures the influences of changes in technology, shows negative coefficients that are statistically significant in the estimated models with the 5- and 10-year *TIPS*. The dummy variable, which captures the recessionary period (2008–2011), shows a negative and statistically significant effect in all of the estimated models. Overall, the results suggest a stronger effect of monetary policy in the estimated models with the 5- and 10-year *TIPS*.

Tables 7 and 8 show the results of the estimations for the period 2005–2011 with a one- and two-year lag, respectively. Comparing the estimations results suggests that the direct interest-rate effect is higher in the case of the 10-year *TIPS* as the regressor. However, the other coefficients are quite similar. The negative semi-elasticity of capacity utilization with respect to the interest rate is greater in the case that uses the related regressor with a 2-year lag. In both the 5-year *TIPS* and 10-year *TIPS* specifications with a one- or two-year lag, an increase in the price of materials or labour would encourage higher capacity utilization. In all specifications with a one- or two-year lag, an increase in the user cost of capital will decrease capacity utilization. An increase in the capital stock or in investment activity does not lead to a significant effect on capacity utilization in all cases. However, a more intense utilization of the existing capital stock causes higher levels of capacity utilization in all scenarios. A caution for this short series of 5- and 10-year *TIPS* is that estimating the models by industry and using these regressors can be very noisy. For this reason I do not provide estimations by industry, but rather across industries.

The theory suggests that a drop in the interest rate brings down the rental cost of capital which, in turn, encourages manufacturing industries to borrow more capital to increase production. However, my results show that, in most of the industries reviewed, an interest-rate cut does not encourage an increase in production and capacity utilization in the same time period; rather, it takes two periods for the effects of this policy to appear.

4 Conclusions

In this paper, I conducted an economic analysis of capacity utilization and its determinants, using the 2SLS fixed-effects estimation in a panel setting, for U.S. manufacturing industries, over the period 1975–2011. The results show that there is considerable cross-industry heterogeneity in the effects of interest-rate changes. Among industries, food manufacturing is the only one that reacts to a cut in interest rates with an increase in capacity utilization in the same period. Since this industry accounts for less than ten percent of total manufacturing production, a cut in the interest rate will only stimulate a small portion of manufacturing production in the short run. Capacity utilization in machinery, fabricated products, and transportation equipment industries shows a negative response to changes in the interest rate after one period. Primary and electrical equipment, appliance, and component industries negatively respond after two periods.

In contrast to previous studies, I find no evidence that differences in the sensitivity of capacity utilization to interest-rate changes can be explained by the durability of the goods produced in the industry. In terms of magnitude, the leather and allied products industries (which belong to the category of non-durable manufacturing industries), and computers and electronic products (which belong to durable manufacturing industries), respectively, show the greatest sensitivity to interest-rate changes. Regardless of which factor is used as the regressor for the interest rate, the semi-elasticity of capacity utilization with respect to interest-rate changes is negative and highly significant over the period 2005–2011. However, this sensitivity is positive in the estimation results for the period 1975–2011. Evidence from U.S. manufacturing industries shows that the price of energy has a depressing effect on the capacity utilization of manufacturing industries over the period 1975–2011. However, the estimation results for the period 2005–2011 do not show any significant effect of energy prices on capacity utilization. Comparing these results highlights that the role of energy prices on capacity utilization has sharply diminished over time. This suggests that policies that aimed to reduce the price of energy did not have any effect on capacity utilization in recent years.

The price of materials shows a stimulating effect on capacity utilization in almost in all of the estimated models. The estimation results also suggest that an increase in wages can result in an increase in capacity utilization. Capital utilization always has a positive effect on capacity utilization. In many industries, an increase in the interest rate has a stimulating effect on capacity utilization. This suggests that many firms make use of their current stock of capital more intensively in response to an increase in the user cost of capital and, consequently, increase their capacity utilization and production. Overall, my results show evidence that policy instruments that decrease interest rates will not always stimulate capacity utilization.

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Table 2: Correlation

	CU	IP	P_E	P_M	W	P_K	K	u	FFR
CU	1.000								
IP	0.044	1.0000							
P_E	−0.332	0.269	1.000						
P_M	−0.085	0.140	0.745	1.000					
W	−0.111	0.809	0.331	0.124	1.000				
P_K	0.152	0.041	−0.341	−0.398	−0.003	1.000			
K	− 0.045	0.349	0.216	0.204	0.578	−0.104	1.000		
u	0.283	−0.104	−0.167	−0.047	−0.226	0.104	−0.019	1.000	
FFR	**0.239**	−0.238	−0.535	−0.447	−0.314	0.622	−0.142	0.147	1.000

Table 3: Descriptive Statistics of Capacity Utilization

Manufacturing Industries	Mean	Std. Dev.	Min	Max
Paper	86.362	3.840	77.149	92.120
Petroleum & coal products	85.132	5.765	71.206	95.164
Plastics & rubber products manufacturing	81.947	7.051	61.535	91.324
Food	81.927	2.144	77.901	85.567
Electrical equipment, appliance, & component	81.331	6.097	68.260	91.366
Textile product mills	80.728	8.399	58.746	93.551
Printing & related support activities	80.476	7.273	60.225	90.484
Textile mills	79.481	8.566	55.175	92.334
Apparel	79.018	5.001	66.372	86.703
Primary metal	78.235	8.826	55.168	90.898
Computer & electronic product	77.831	5.771	60.842	87.494
Beverage & tobacco product	77.248	5.573	66.594	85.827
Chemical	77.203	4.107	67.791	84.090
Machinery	76.956	7.275	60.487	90.136
Fabricated metal product	76.660	5.105	64.635	86.575
Wood product	76.312	8.251	51.180	86.022
Miscellaneous	76.035	3.064	67.658	81.881
Furniture and related product	75.665	6.191	58.381	86.024
Nonmetallic mineral product	74.837	9.597	45.758	86.520
Transportation equipment	74.108	6.156	55.883	83.089
Leather & allied product	72.120	9.016	48.400	83.905

Table 4: Baseline specifications with and without interest rate

Regressor	Without interest rate	With interest rate
Constant	3.650***	3.594***
	(0.762)	(0.754)
FFR		0.003*
		(0.002)
ln(P_K)	−0.010	−0.014
	(0.010)	(0.010)
u	0.034***	0.036***
	(0.010)	(0.011)
ln(IP)	0.019	0.012
	(0.039)	(0.039)
ln(P_E)	−0.130***	−0.155***
	(0.034)	(0.038)
ln(P_M)	0.192***	0.192***
	(0.036)	(0.037)
ln(W)	0.071	0.081*
	(0.048)	(0.048)
ln(K)	−0.015	−0.008
	(0.070)	((0.070)
T	−0.002	−0.001
	(0.002)	(0.002)
Dummy	−0.113***	−0.110***
	(0.018)	(0.019)

Notes: Dependent variable is $ln(CU)$. ***, **, * indicate statistical significance at the 1, 5, and 10 percent levels, respectively.
n=755

Table 5: Specification by Manfacturing Industries (1975–2011)

Regressor	*FFR*	FFR_{t-1}	FFR_{t-2}
Constant	3.667***	3.618***	3.052***
	(0.812)	(0.820)	(0.702)
ln(IP)	0.023	0.040	0.002
	(0.036)	(0.040)	(0.034)
$ln(P_E)$	−0.164***	−0.062**	−0.069**
	(0.033)	(0.030)	(0.027)
$ln(P_M)$	0.236***	0.222***	0.238***
	(0.048)	(0.044)	(0.041)
$ln(P_K)$	−0.014	0.001	0.005
	(0.010)	(0.009)	(0.008)
ln(K)	−0.066	−0.063	−0.010
	(0.073)	(0.072)	(0.067)
ln(W)	0.144***	0.105*	0.134***
	(0.051)	(0.055)	(0.052)
u	0.039***	0.030***	0.033***
	(0.011)	(0.010)	(0.010)
T	−0.002	−0.007	−0.009***
	(0.002)	(0.002)	(0.002)
Dummy	−0.104***	−0.109***	−0.100***
	(0.019)	(0.018)	(0.019)
FFR (Food)	−0.007***	−0.013***	−0.014***
	(0.003)	(0.002)	(0.002)
FFR (Beverage & tobacco product)	0.024***	0.021***	0.017***
	(0.002)	(0.002)	(0.002)
FFR (Textile mills)	0.020***	0.014***	0.012***
	(0.004)	(0.004)	(0.004)
FFR (Textile product mills)	0.018***	0.014***	0.013***
	(0.002)	(0.002)	(0.002)
FFR (Apparel)	0.005	0.003	0.003
	(0.005)	(0.006)	(0.005)
FFR (Leather & allied product)	0.025***	0.019***	0.016***
	(0.006)	(0.006)	(0.006)
FFR (Wood product)	0.016***	0.011***	0.008***
	(0.002)	(0.002)	(0.002)
FFR (Paper)	0.004**	0.004***	0.004**
	(0.002)	(0.002)	(0.001)
FFR (Printing & related support activities)	0.016***	0.014***	0.014***
	(0.002)	(0.002)	(0.002)

Regressor	FFR	FFR_{t-1}	FFR_{t-2}
FFR (Petroleum & coal products)	0.009*	0.003	0.004
	(0.005)	(0.004)	(0.004)
FFR (Chemical)	0.004	0.003	0.000
	(0.003)	(0.002)	(0.002)
FFR (Plastics & rubber products)	0.011***	0.007***	0.006***
	(0.001)	(0.001)	(0.001)
FFR (Nonmetallic mineral product)	0.015***	0.011***	0.006***
	(0.003)	(0.002)	(0.002)
FFR (Primary metal)	0.005	−0.003	−0.009**
	(0.004)	(0.004)	(0.004)
FFR (Fabricated metal product)	−0.000	−0.004***	−0.008**
	(0.001)	(0.001)	(0.001)
FFR (Machinery)	0.002	−0.005***	−0.014***
	(0.001)	(0.001)	(0.001)
FFR (Computer & electronic product)	0.024***	0.022***	0.017***
	(0.004)	(0.005)	(0.005)
FFR (Electrical equipment, appliance & component)	0.005**	0.000	−0.004*
	(0.002)	(0.002)	(0.002)
FFR (Transportation equipment)	0.002*	−0.003**	−0.005***
	(0.001)	(0.001)	(0.001)
FFR (Furniture & related product)	0.007***	0.002***	0.001
	(0.001)	(0.001)	(0.001)
FFR (Miscellaneous)	0.002	−0.001	−0.001
	(0.003)	(0.003)	(0.003)

Notes: Dependent variable is $ln(CU)$. FFR(.) shows the interaction between interest rate and each industry. ***, **, * indicate statistical significance at the 1, 5, and 10 percent levels, respectively.
n=755

Table 6: Estimation using different regressors (2005–2011)

Regressor	*Est. FFR*	*Est. 5-year TIPS*	*Est. 10-year TIPS*
Constant	−2.279	−0.506	−1.497
	(3.262)	(2.824)	(3.105)
FFR	−0.015***	−0.097***	−0.110***
	(0.005)	(0.027)	(0.033)
ln(IP)	0.143	0.190**	0.144
	(0.105)	(0.095)	(0.105)
$ln(P_E)$	0.095	0.086	0.119
	(0.179)	(0.148)	(0.162)
$ln(P_M)$	0.709***	0.490**	0.490**
	(0.233)	(0.225)	(0.229)
$ln(P_K)$	−0.039***	−0.069***	−0.074***
	(0.013)	(0.020)	(0.024)
ln(K)	−0.098	−0.088	−0.013
	(0.224)	(0.206)	(0.229)
ln(W)	0.583***	0.412**	0.449**
	(0.208)	(0.203)	(0.205)
u	0.049**	0.046**	0.049***
	(0.019)	(0.021)	(0.023)
T	−0.017	−0.055***	−0.041***
	(0.012)	(0.012)	(0.011)
Dummy	−0.194***	−0.134***	−0.128***
	(0.053)	(0.034)	(0.033)

Notes: Dependent variable is $ln(CU)$. ***, **, * indicate statistical significance at the 1, 5, and 10 percent levels, respectively.
n=147
FFR: $R^2_{within} = 0.80$
5-year $TIPS$: $R^2_{within} = 0.83$
10-year $TIPS$: $R^2_{within} = 0.81$

Table 7: Estimation using different regressors with one lag (2005–2011)

Regressor	*Est.* FFR_{t-1}	*Est. 5-year* $TIPS_{t-1}$	*Est. 10-year* $TIPS_{t-1}$
Constant	−1.682	−3.649	−3.967
	(2.964)	(3.655)	(3.749)
$\boldsymbol{FFR}_{t-1}$	−0.009***	−0.026**	−0.042**
	(0.003)	(0.011)	(0.018)
ln(IP)	0.185**	0.108	0.099
	(0.093)	(0.117)	(0.120)
$ln(P_E)$	0.096	0.324	0.337
	(0.161)	(0.213)	(0.218)
$ln(P_M)$	0.703***	0.568**	0.528**
	(0.229)	(0.226)	(0.230)
$ln(P_K)$	−0.035***	−0.078***	−0.070***
	(0.012)	(0.023)	(0.026)
ln(K)	−0.150	−0.001	−0.020
	(0.207)	(0.252)	(0.261)
ln(W)	0.568***	0.530**	0.544**
	(0.204)	(0.212)	(0.214)
u	0.045**	0.054**	0.055**
	(0.018)	(0.027)	(0.027)
T	−0.021*	−0.014	−0.012
	(0.011)	(0.009)	(0.010)
Dummy	−0.124***	−0.142***	−0.141***
	(0.035)	(0.037)	(0.037)

Notes: Dependent variable is $ln(CU)$. ***, **, * indicate statistical significance at the 1, 5, and 10 percent levels, respectively.
n=147
FFR_{t-1}: $R^2_{within} = 0.81$
5-year $TIPS_{t-1}$: $R^2_{within} = 0.79$
10-year $TIPS_{t-1}$: $R^2_{within} = 0.78$

Table 8: Estimation using different regressors with two lags (2005–2011)

Regressor	*Est.* FFR_{t-2}	*Est. 5-year* $TIPS_{t-2}$	*Est. 10-year* $TIPS_{t-2}$
Constant	-0.458	-1.054	0.647
	(2.700)	(2.823)	(2.674)
$\boldsymbol{FFR_{t-2}}$	-0.010^{***}	-0.048^{***}	-0.140^{***}
	(0.003)	(0.013)	(0.033)
ln(IP)	0.209^{**}	0.208^{**}	0.250^{***}
	(0.086)	(0.093)	(0.088)
$ln(P_E)$	-0.035	0.166	0.062
	(0.132)	(0.159)	(0.137)
$ln(P_M)$	0.653^{***}	0.528^{**}	0.491^{**}
	(0.234)	(0.222)	(0.232)
$ln(P_K)$	-0.028^{**}	-0.070^{***}	-0.066^{***}
	(0.012)	(0.020)	(0.021)
ln(K)	-0.152	-0.131	-0.180
	(0.198)	(0.202)	(0.196)
ln(W)	0.519^{**}	0.430^{**}	0.359^{*}
	(0.206)	(0.203)	(0.209)
u	0.042^{**}	0.046^{**}	0.042^{**}
	(0.017)	(0.021)	(0.019)
T	-0.024^{**}	-0.019^{**}	-0.031^{***}
	(0.011)	(0.009)	(0.009)
Dummy	-0.068^{***}	-0.063^{***}	-0.001
	(0.026)	(0.023)	(0.021)

Notes: Dependent variable is $ln(CU)$. ***, **, * indicate statistical significance at the 1, 5, and 10 percent levels, respectively.
n=147
FFR_{t-1}: $R^2_{within} = 0.83$
5-year $TIPS_{t-1}$: $R^2_{within} = 0.83$
10-year $TIPS_{t-1}$: $R^2_{within} = 0.83$

Figure 1: Capacity utilization before and after crisis

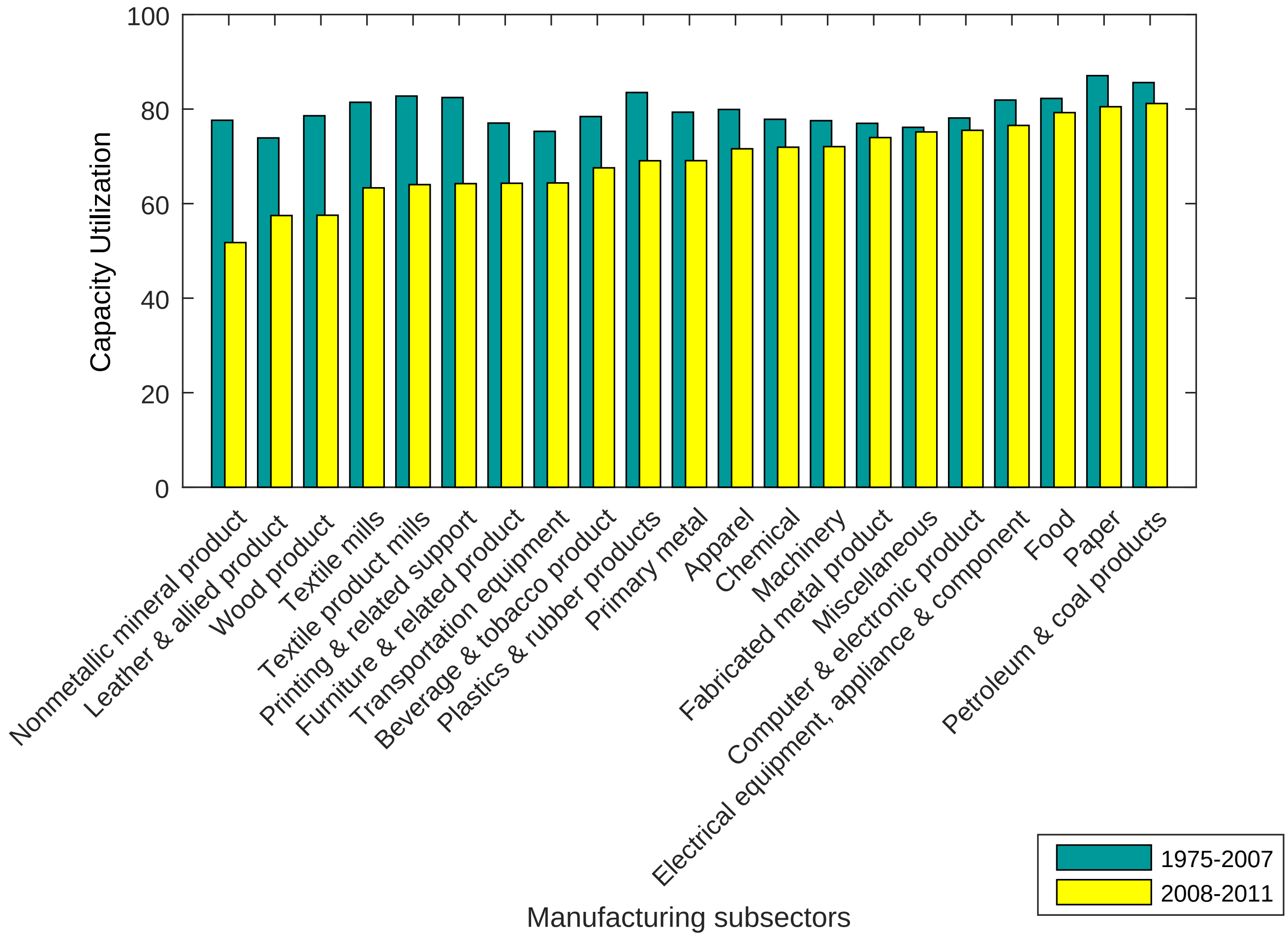
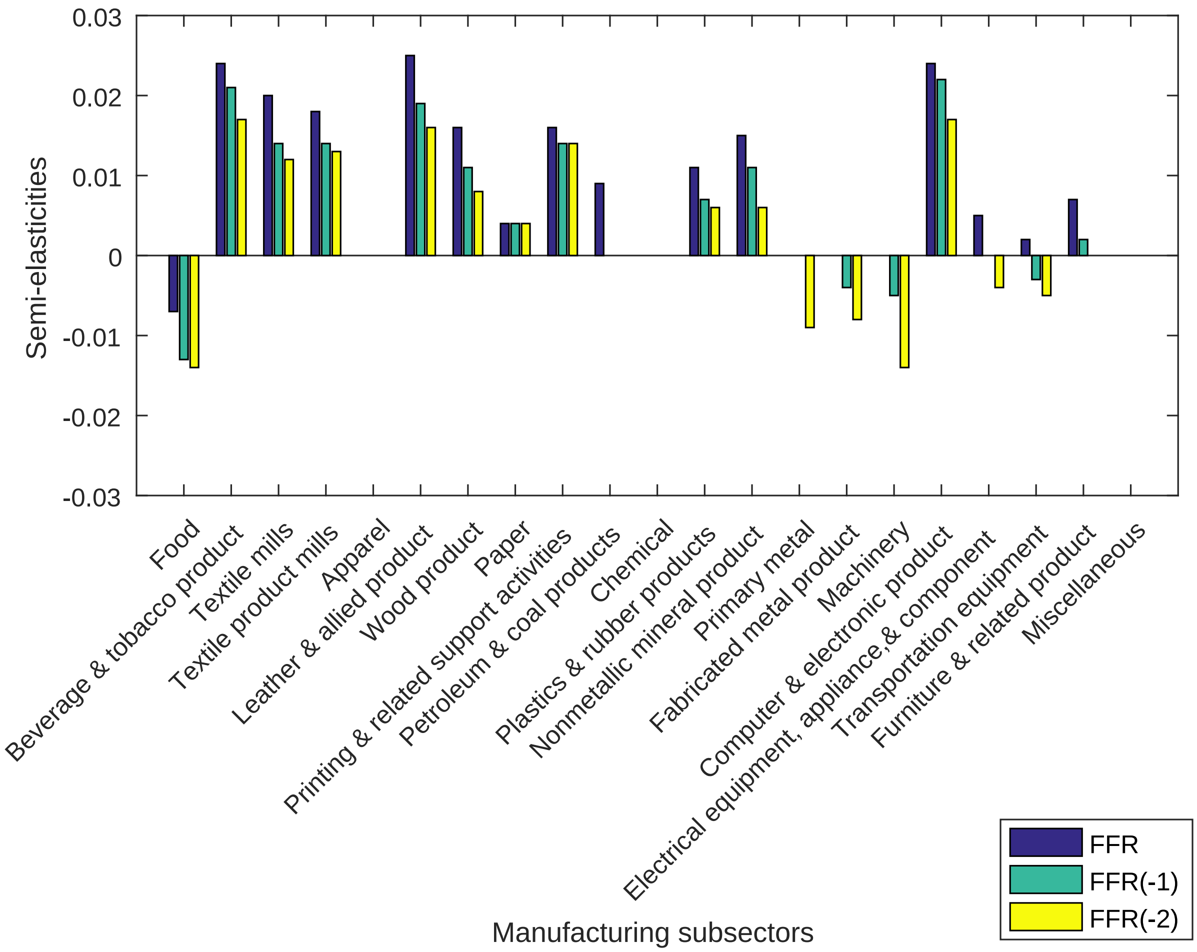
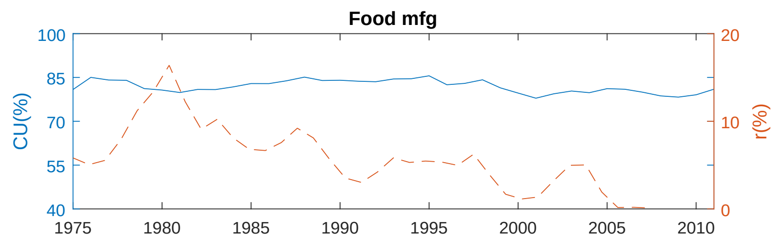


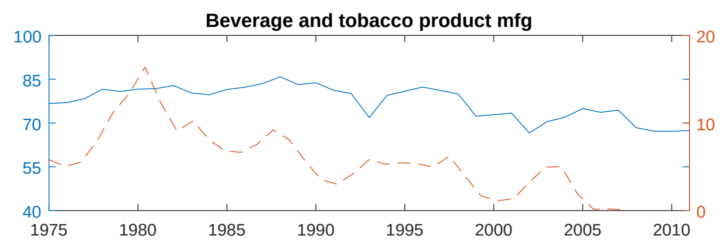
Figure 2: Semi-elasticity of CU respect to *FFR* with 0, 1 and 2 lags

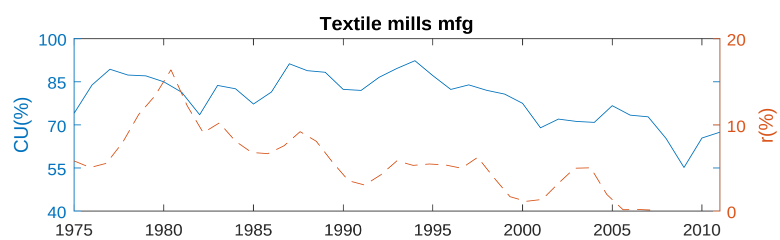


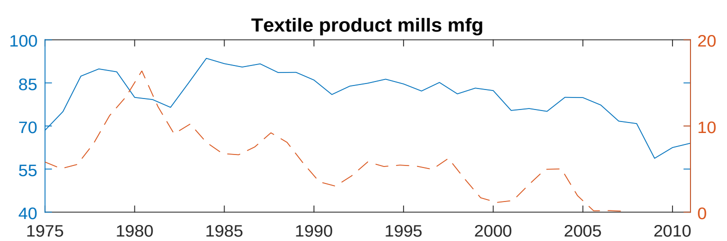
Appendix A CU and interest rates

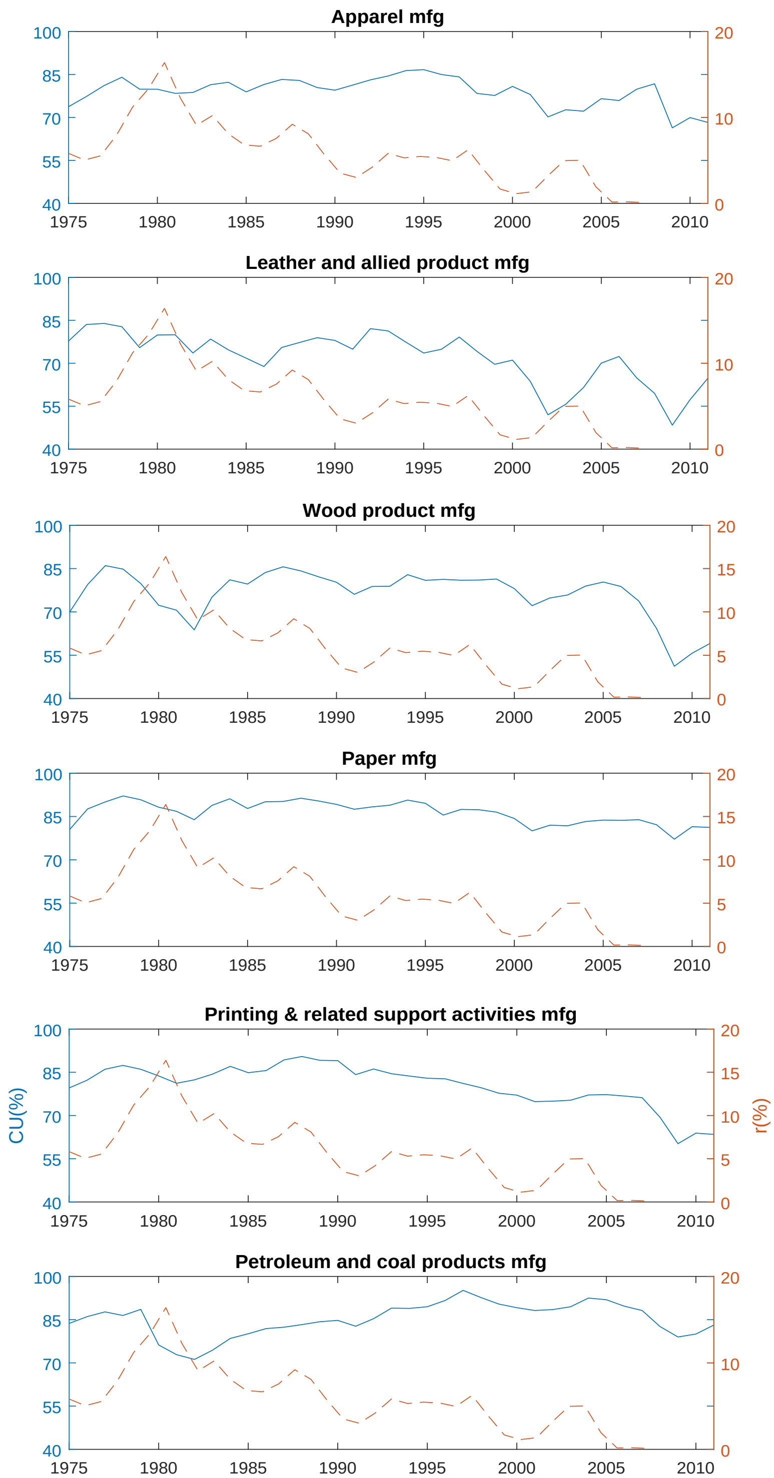
Graphs display capacity utilization in each manufacturing industry and federal funds effective rate as an indicator for interest rate over 1975–2011. The solid line in each graph shows capacity utilization over this period and the dashed line shows the interest rate. It reveals that the nature of fluctuations in capacity utilization differs across manufacturing industries.

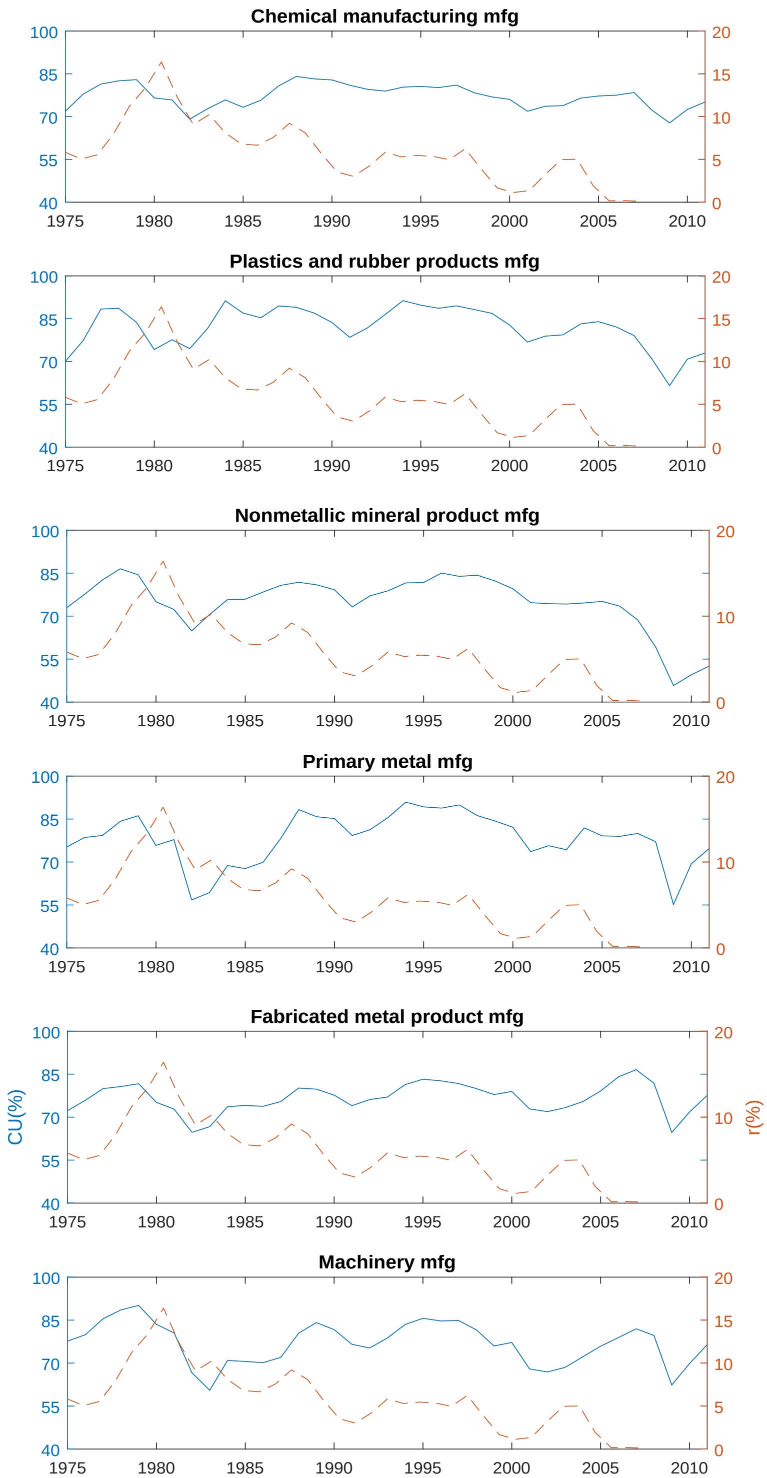


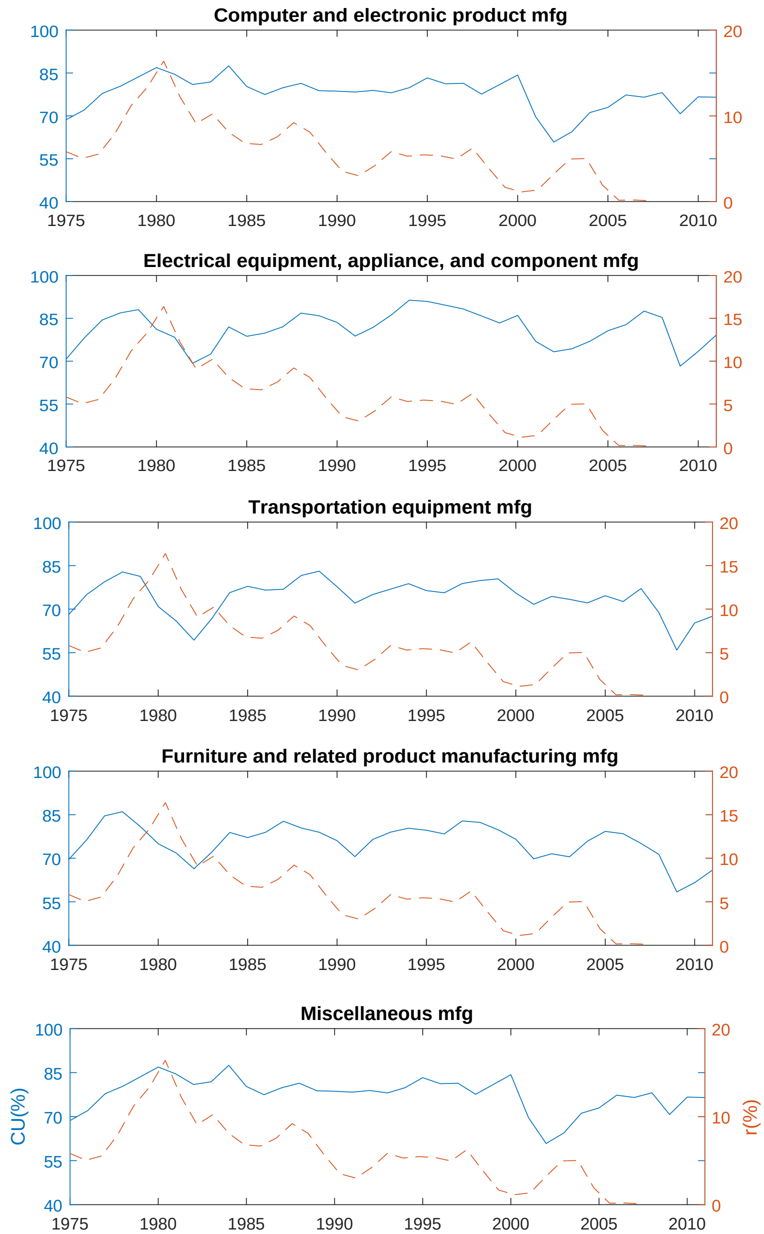







Apparel mfg
Leather and allied product mfg
Wood product mfg
Paper mfg
Printing & related support activities mfg
Petroleum and coal products mfg
CU(%)
r(%)
100
85
70
55
40
20
15
10
5
0
1975
1980
1985
1990
1995
2000
2005
2010


Chemical manufacturing mfg
Plastics and rubber products mfg
Nonmetallic mineral product mfg
Primary metal mfg
Fabricated metal product mfg
Machinery mfg
CU(%)
r(%)
100
85
70
55
40
20
15
10
5
0
1975
1980
1985
1990
1995
2000
2005
2010


Computer and electronic product mfg
Electrical equipment, appliance, and component mfg
Transportation equipment mfg
Furniture and related product manufacturing mfg
Miscellaneous mfg
CU(%)
r(%)
100
85
70
55
40
20
15
10
5
0
1975
1980
1985
1990
1995
2000
2005
2010

Appendix B Theoretical Link between r and CU

This part investigates the theoretical link between interest rates and capacity utilization using quadratic form of the cost function from Garofalo and Malhotra (1997). This form is a convenient way for presenting $SRVC$ function, because it provides a closed-form expression for Y^*. The $SRVC$ is given by

$$
\begin{aligned}
SRVC = \alpha_0 &+ G[\alpha_G + 0.5\gamma_{GG}\frac{G}{Y} + \gamma_{GL}P_L + \gamma_{GE}P_E + \gamma_{GM}P_M + \gamma_{GT}T] \\
&+ T[\alpha_T + 0.5\gamma_{TT}T + \gamma_{TL}P_L + \gamma_{TE}P_E + \gamma_{TM}P_M + \gamma_{TY}Y] \\
&+ P_L[\alpha_L + 0.5\gamma_{LL}P_L + \gamma_{LE}P_E + \gamma_{LM}P_M + \gamma_{LY}Y] \\
&+ P_E[\alpha_E + 0.5\gamma_{EE}P_E + \gamma_{EM}P_M + \gamma_{EY}Y] \\
&+ P_M[\alpha_M + 0.5\gamma_{MM}P_M + \gamma_{MY}Y] \\
&+ Y[\alpha_Y + 0.5\gamma_{YY}Y]. \qquad (14)
\end{aligned}
$$

The optimal level of capital services is the level of service flow from capital stock G^* under which the equilibrium condition or envelope condition is satisfied, which gives

$$P_K = -\frac{\partial SRVC}{\partial G^*}, \qquad (15)$$

where P_K is rental price of capital. Using (14) and (15), P_K is defined as

$$P_K = -[\alpha_G + \gamma_{GG}\frac{G}{Y} + \gamma_{GL}P_L + \gamma_{GE}P_E + \gamma_{GM}P_M + \gamma_{GT}T]. \qquad (16)$$

With rearranging (16), the optimal level of capital is given as

$$G^* = -\gamma_{GG}{}^{-1}Y[\alpha_G + \gamma_{GL}P_L + \gamma_{GE}P_E + \gamma_{GM}P_M + \gamma_{GT}T + P_K]. \qquad (17)$$

At the capacity level of output $SRMC = LRMC$. Then

$$\frac{\partial SRVC}{\partial Y} = \frac{\partial SRVC}{\partial Y} + \frac{\partial SRVC}{\partial G^*}\frac{\partial G^*}{\partial Y} + P_K\frac{\partial G^*}{\partial Y}. \qquad (18)$$

Simplifying (18) gives the envelope condition ($-\frac{\partial SRVC}{\partial G} = P_K$). Therefore, I can estimate capacity level of output (Y^*) by inverting (17) and solving for Y as

$$Y^* = -\gamma_{GG}G^*[\alpha_G + \gamma_{GL}P_L + \gamma_{GE}P_E + \gamma_{GM}P_M + \gamma_{GT}T + P_K]^{-1}. \qquad (19)$$

with substituting (2) and (7) in (19), the capacity level of output is

$$Y^* = -\gamma_{GG} u K [\alpha_G + \gamma_{GL} P_L + \gamma_{GE} P_E + \gamma_{GM} P_M + \gamma_{GT} T + r - \pi + \delta(u)]^{-1} \tag{20}$$

where $\gamma_{GG} > 0$ in order to ensure that I have a negative own price elasticity of demand for capital in long run. Substituting (20) in (1) gives capacity utilization equation as a function of the interest rate and all other variables discussed before.

$$CU = \frac{Y}{Y^*} = -\frac{Y[\alpha_G + \gamma_{GL} P_L + \gamma_{GE} P_E + \gamma_{GM} P_M + \gamma_{GT} T + r - \pi + \delta(u)]}{\gamma_{GG} u K} \tag{21}$$