Intermediate Input Channel and the Sectoral Comovement along Business Cycle: analysis based on the intertemporal optimization approach

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Abstract

This paper investigates both analytically and quantitatively the role of intersectoral linkages in explaining the sectoral employment comovement over the business cycle. We use a multisector dynamic stochastic general equilibrium model calibrated to the 2-digit SIC level intermediate input-use and capital-use tables and sectoral productivity shocks. With indivisible labor implying constant marginal utility of leisure, the intersectoral linkages at the disaggregated level are sufficient to generate the strong business cycle comovement across sectors. With divisible labor, however, the procyclical marginal utility of leisure can dominate intersectoral linkages, implying a negative comovement. It further requires some form of the difficulty in reallocating labor across sectors, such as worker's reluctance to substitute hours worked across sectors. Referring to some micro-level studies on the low wage elasticity of labor supply, a low substitution of labor hours is shown to generate strong employment comovement over the business cycle.

1 Introduction

It is well known that, over the business cycle, most sectors of the economy move up and down together. This comovement is a central part of the definition of the business cycle. Under the National Bureau of Economic Research's (NBER) definition, for example, "a recession is a period of decline in total output, income, employment, and trade, usually lasting from six months to a year, and marked by widespread contractions in many sectors of the economy." Hornstein (2000) document industry comovement for employment, capital service, and output (or value added) in the US. Christiano and Fitzgerald (1998) also document business cycle comovement of hours worked acorss industrial sectors, most of which has remained a puzzle since Lucas (1981).

It has been argued that the observed comovement is inconsistent with independent industry specific shocks (e.g. Lucas 1981). The effect of uncorrelated industry specific disturbances may tend to wash out since, by the law of large numbers, negative variations in some sectors offset positive variations in other sectors. Instead many researchers conjectured that industry comovement was due to the presence of common aggregate disturbances (e.g. aggregate monetary or productivity shock) to which all industrial sectors of the economy respond in a similar fashion. However, it has turned out that this conjecture is not right. As shown by Benhabib, Rogerson, and Wright (1991), Christiano and Fisher (1998), and Hornstein (2000), multisector interpretation of the standard real business cycle model implies that employment in the consumption good sector should move countercyclically. The common aggregate shocks can yield the comovement of output in different sectors, but not necessarily the comovement of sectoral employment.

In the presence of industry specific productivity shocks, recent attempts to explain sectoral employment comovement have focused on the use of an industry's output as intermediate inputs in other sectors (Hornstein and Praschnik 1997) or the production function with a constant elasticity of substitution (Huffman and Wynne 1999). In particular, Hornstein and Praschnik (1997) is motivated by the observation that some of the output of the consumption good sector is also used as intermediate goods in the production of the investment goods, and they modify a standard real business cycle model to accommodate this intermediate input channel. During the boom, this has the effect of increasing the value of output in the consumption good sector with the increased need for its output for use in the investment good sector. With perfectly mobile labor across the two sectors, their model generates strong contemporaneous correlation for sectoral employment. This is claimed to be true of both divisible and indivisible labor specification for preferences. With common aggregate productivity shocks, Boldrin, Christiano, and Fisher (2001) also explain the industry comovement by way of limited labor mobility across sectors.

However, these works have the following limitations. First, their results were obtained in the two sector models which consist of consumption and investment good sectors. As will be explained below, the two sector specification, despite its simplicity, yields some misleading implications such as the role of indivisible labor in generating employment comovement. Second, the industry comovement in general depends not only on the specification of technology with the use of intermediate goods, frictions in reallocating labor across sectors, or the form of production function, but also on the specification of preferences with divisible or indivisible labor. However, the current literature has ignored their joint implications by considering each factor separately.

The goal of this paper is to investigate, both analytically and quantitatively, the relative importance of the production technology with intersectoral linkages and the specification of preferences with divisible or indivisible labor in explaining the industry comovement. To do so, we use a multisector dynamic stochastic general equilibrium model with more disaggregated production sectors whose productivity shocks are not perfectly correlated each other. Horvath (1998, 2000) recently developed a generalized version of Long and Plosser (1983).[1] Calibrated to the 2-digit Standard

[1] Long and Plosser (1983) adopt several simplifying assumptions such as a complete depreciation of

Industrial Code (SIC) level of disaggregation using the intermediate input-use and the capital-use matrices which represent the uses of a sector's output as intermediate inputs and/or capital inputs in the production of other sectors, it shows that the model can match aggregate fluctuations in the US with independent sectoral shocks only.

However, Horvath (2000) emphasizes the persistence and volatility in aggregate fluctuations driven by independent sectoral productivity shocks, paying less attention to the synchronized nature of economic activity (e.g. employment comovement) across sectors.[2] In fact, Horvath (2000) which assumes divisible labor, noted that as labor hours become perfect substitutes across sectors, wage differences between two sectors due to sector specific productivity shocks cause large but opposite movements in employment in the two sectors as the worker allocates more time to the sector paying higher wages. This paper shows that, in addition to intersectoral linkages, the specification of preferences with divisible or indivisible labor plays a crucial role in generating the industry comovement as well as the persistence and volatility in aggregate fluctuations.

We first examine an indivisible labor version of Horvath (2000) calibrated to the 2-digit SIC level (e.g. 36 sectors) of the intermediate input-use and the capital-use tables. With perfectly substitutable labor hours across sectors, the model simulations yield both aggregate volatility and strong sectoral employment comovement over the business cycle. This is in a contrast to Horvath (2000). With indivisible labor which implies a constant marginal utility of leisure, sectoral employment depends largely on its output which can be potentially allocated to the following three uses: intermediate

capital stock within a time period (e.g. a quarter). Despite analytical tractability, these assumptions make their model economy unsuitable for quantitative empirical analysis.

[2]In the presence of the independent sectoral shocks, Horvath (2000) stresses a delayed application of the law of large numbers in generating the volatility of aggregate output. This is due to the propagation mechanism of the sectoral shocks via the "sparse matrices" form of the intermediate-input use and the capital-use tables in the US.

inputs in the industrial sectors, investment goods built into the capital stocks of the sectors, and final consumption goods. Therefore, as long as both the intermediate input-use and the capital-use matrices at a disaggregated level indicate sufficiently strong intersectoral linkages, sectoral employments tend to comove over the business cycle. The model simulations also show that the intersectoral linkages in the actual data are significant enough to generate positive sectoral comovements in both capital services and value added, with several exceptions where their size of comovement is below the actual one.

Although these findings are qualitatively similar to those in Hornstein and Praschnik (1997), the sectoral comovement in employment depends crucially on the indivisible labor specification of preferences. With divisible labor, procyclical marginal utility of leisure makes sectoral employment move countercyclically, whereas the intermediate input channel enables procyclical comovement for sectoral employment. Hence, for those sectors whose output is used small amount for the inputs in other sectors, the intersectoral linkages can be dominated by the procyclical marginal utility of leisure, yielding negative employment comovement. The importance of procyclical marginal utility of leisure did not show up in the two-sector model of Hornstein and Praschnik (1997). This is because the intermediate input share of nondurables (consumption sector) in the production of durable goods (investment sector) is sufficiently high that the effect of procyclical marginal utility of leisure with divisible labor is always dominated by the intersectoral linkages, yielding a positive employment comovement regardless of labor divisibility in preferences.

Finally, in order to examine the potential role of difficulty in adjusting employment across sectors, we consider Horvath (2000) where elasticity of substitution of labor supply is relatively low across sectors.[3] An interpretation of this specification is that the representative worker/consumer has a preference for diversity of labor hours

[3] Altonji (1982) and Ashenfelter and Altonji (1980) are examples of micro-level studies on the relatively low wage elasticity of labor supply.

despite wage differences across sectors. This modification is analogous to Boldrin, Christiano, and Fisher (2001) and Christiano and Fisher (1998) which assume limited labor mobility between industrial sectors.[4] We find that, as long as the elasticity of substitution of labor across sectors is sufficiently small, the multisector model calibrated to the 2-digit SIC level of disaggregation can generate the observed strong comovement of sectoral employment. Therefore, with divisible labor and a wide variation in the fraction of a given sector's output channeled (as intermediate inputs and capital goods) to many other sectors, the intermediate input channel is not sufficient to generate the industry comovement over the business cycle. It further requires some form of the difficulty in making intersectoral adjustment of labor such as worker's reluctance to substitute hours worked across sectors.

The paper is organized as follows. Section 2 describes the model economy and the definition of competitive equilibrium. In Section 3 we discuss analytically the role of preferences and technology in explaining employment comovement. Section 4 presents the model calibration and quantitative simulation results on the industry comovement of employment, capital services, and value added over the business cycle. Section 5 sums up the paper with a few remarks.

2 The Model

In order to examine the significance of the intersectoral linkages in the industry comovement, we consider a version of Horvath (2000) which generalizes Hornstein and Praschnik (1997)'s two-sector dynamic stochastic general equilibrium model to 36 sectors at the 2-digit SIC level of disaggregation.

[4]This is also the same way by which Huffman and Wynne (1999) impose the degree of difficulty in relocating labor across sectors by using a form with constant elasticity of transformation (CET). For example, a low elasticity of transformation across sectors is equivalent to a low substitutability of labor.

2.1 The Environment

The model economy consists of M (say, 36) sectors, indexed by $h = 1, 2, ..., M$, each producing a different good. The production technologies are distinct across the sectors, each requiring capital, labor, and intermediate inputs. Multifactor productivity in each sector is subject to stochastic innovations which are not perfectly correlated across sectors.

The output of each sector goes to potentially three different uses. First, some goods are used as intermediate inputs in the production of other goods. Sectors do not necessarily use the same intermediate inputs. Second, some goods are built into the capital stocks of the sectors in the economy and each sector has a distinct capital stock. Finally, a portion of output in each sector is supplied to a final consumption market. It is assumed that intermediate inputs are delivered and either used within one period or built into the capital stock of the purchasing sector. The production of each sector is controlled by firms which operate so as to maximize their expected present discounted value to shareholders.

An output, y_t^h, of good h is produced by combining sector specific capital, k_t^h, labor, n_t^h, and an index of intermediate inputs, M_t^h in a production process given by

$$y_t^h = A_t^h \left(k_t^h\right)^{\alpha_h} \left(n_t^h\right)^{\beta_h} \left(M_t^h\right)^{\gamma_h}, \tag{1}$$

where constant returns to scale implies $\alpha_h + \beta_h + \gamma_h = 1$. In (1), A_t^h represents the multifactor productivity or state of technology in sector h, which is assumed to follow a stochastic process given by

$$\ln(A_t^h) = \rho_h \ln(A_{t-1}^h) + \epsilon_t^h, \tag{2}$$

where ϵ_t^h is a serially uncorrelated and normally distributed random variable with mean zero and $E(\epsilon_t \epsilon_t^{'}) = \Omega$.

The index of intermediate inputs for sector h has a Cobb-Douglas form which implies a unitary elasticity of substitution between inputs:

$$M_t^h = \prod_{s \in B_h^M} (m_{t,s}^h)^{x_{sh}} \tag{3}$$

where $m_{t,s}^h$ denotes the quantity of good s purchased by sector h at period t for intermediate inputs and B_h^M denotes the set of sector indices which are inputs to the production of good h. The weights are normalized to satisfy: $\sum_{s \in B_h^M} x_{sh} = 1$ and $x_{sh} = \gamma_{sh}/\gamma_h$ where γ_{sh} is the sh^{th} element of Γ_m, the intermediate input-use matrix, denoting the cost share of total expenditure on intermediate goods in sector h due to purchases of intermediate goods from sector s. And γ_h denotes the sum of the h^{th} column in Γ_m.

Further, capital is accumulated through an investment process given by

$$k_{t+1}^h - (1 - \mu_h) k_t^h = \eta(i_t^h), \tag{4}$$

where $\mu_h \in (0, 1)$ is a sector specific depreciation rate. The (composite) investment good for sector h is created by combining inputs in a Cobb-Douglas form:

$$\eta(i_t^h) = \prod_{s \in B_h^I} (i_{t,s}^h)^{\tilde{x}_{sh}} \tag{5}$$

where $i_{t,s}^h$ denotes the quantity of good s purchased by sector h for investment purposes and B_h^I denotes the set of sectors from which sector h purchases intermediate goods for capital investment. And the weight $\tilde{x}_{sh}$ is derived from the capital input-use matrix, Γ_I, similarly to the weight x_{sh} in the index of intermediate inputs (3).

Now, in order to show that Hornstein-Praschnik (1997)'s two-sector (nondurables and durables) specification is a special case of the more disaggregated multisector specification, let N and D denote respectively the set of industrial sectors producing nondurable and durable goods. First of all, Hornstein and Praschnik (1997) assumes a reduced version of the production technology (1) such that the production of nondurable goods does not require intermediate input. That is, $[\gamma_N] = 0$ in (1) so that

$$y_t^h = A_t^h \left(k_t^h\right)^{\alpha_h} \left(n_t^h\right)^{1-\alpha_h} \quad \text{for all } h \in N.$$

Further, they simplified the sectoral intermediate input index (3) by assuming that the output of durable goods is not used as intermediate inputs in the production of both nondurable and durable goods: that is, $x_{sh} = 0$ for all $s \in D$ in (3), which implies

$$M_t^h = \prod_{s \in B_h^M} (m_{t,s}^h)^{x_{sh}} \quad \text{where } B_h^M \subseteq N.$$

The composite sectoral investment good is also simplified by assuming that the output of nondurable goods is not built into the capital stocks in the production sectors: that is, $\tilde{x}_{sh} = 0$ for all $s \in N$ in (5), and hence

$$\eta(i_t^h) = \prod_{s \in B_h^I} (i_{t,s}^h)^{\tilde{x}_{sh}} \quad \text{where } B_h^I \subseteq D.$$

In Hornstein and Praschnik (1997), the set of nondurable- and durable-goods sectors are respectively aggregated to a single sector each, which reduces the above specifications even further. That is, $y_t^h = A_t^h \left(k_t^h\right)^{\alpha_h} \left(n_t^h\right)^{1-\alpha_h}$ for $h \in N$ and $y_t^h = A_t^h \left(k_t^h\right)^{\alpha_h} \left(n_t^h\right)^{\beta_h} \left(M_t^h\right)^{\gamma_h}$, $M_t^h = m_{t,s}^h$ for $h \in D$ and $s \in N$. Further, $\eta(i_t^h) = i_{t,s}^h$ for $h \in N, D$ and $s \in D$ which simplifies the law of motion of capital accumulation (4) to $k_{t+1}^h - (1-\mu_h)k_t^h = i_{t,s}^h$ for $h \in N, D$ and $s \in D$.

The consumers (or shareholders) allocate labor hours to the various industry sectors and make consumption-savings decisions. The representative consumer seeks to maximize discounted expected utility given by

$$E_0 \sum_{t=0}^{\infty} \delta^t U(C_t, L_t), \quad 0 < \delta < 1 \tag{6}$$

subject to:

$$\sum_{h=1}^{M} p_t^h c_t^h = \sum_{h=1}^{M} p_t^{n_h} n_t^h + \sum_{h=1}^{M} (d_t^h + q_t^h) s_t^h - \sum_{h=1}^{M} q_t^h s_{t+1}^h \equiv a_t. \tag{7}$$

In (6), $\delta \in (0,1)$ is a discount factor, C_t is an aggregate consumption index, L_t is an aggregate leisure index at period t, and $U(.)$ is the period utility function given by

$$U(C_t, L_t) = \begin{array}{ll} \log C_t + \chi \log L_t & : \text{divisible labor} \\ \log C_t - \chi(1 - L_t) & : \text{indivisible labor} \end{array}$$

where $\chi > 0$. We consider the two versions of the utility function with divisible or indivisible labor to investigate its role in explaining the industry comovement, in relation to the current literature such as Hornstein and Praschnik (1997). Given an initial share s_0^h for $h = 1, ..., M$, the consumer's budget constraint (7) shows that the sum of goods purchased, c_t^h, valued at their respective prices, p_t^h cannot exceed a_t, total income in period t. Other notations concerning sector h at period t are: $p_t^{n_h}$ hourly wage, d_t^h dividend paid per share held, q_t^h share price per unit, s_t^h share holdings at the beginning of t, and s_{t+1}^h shares purchased for period $t + 1$.

The aggregate consumption index has a Cobb-Douglas form:

$$C_t = \prod_{h=1}^{M} (c_t^h)^{\xi^h} \tag{8}$$

where ξ^h is the consumption expenditure share of sector h. Further, the representative consumer is endowed with one unit of time in each period and the aggregate leisure index takes the following form:

$$L_t = 1 - \sum_{h=1}^{M} n_t^h. \tag{9}$$

That is, labor hours are perfect substitutes for the consumer/worker, implying that the worker would devote all time to the sector paying the highest wage. Hence, at the margin, all sectors pay the same hourly wage.

2.2 Competitive Equilibrium

The competitive equilibrium consists of $(M \times 1)$ vectors of exogenous productivity shocks $\{\varepsilon_t\}_{t=0}^{\infty}$, $(M \times 3)$ price vectors $\{p_t, \pi_t, p_t^n\}_{t=0}^{\infty}$, and $(M \times 6)$ quantity vectors $\{k_t, n_t, M_t, c_t, i_t, y_t\}_{t=0}^{\infty}$ such that

1. productivity levels $\{A_t\}_{t=0}^{\infty}$ follow their laws of motion given by (2) subject to shocks $\{\varepsilon_t\}_{t=0}^{\infty}$;

2. firms maximize present discounted value of dividends $\{d_t\}_{t=0}^{\infty}$ subject to the sectoral production technology (1) and the sectoral law of motion of capital accumulation (4):

$$\max E_0 \sum_{t=0}^{\infty} \delta^t \left(\frac{a_t}{P_t}\right)^{-1} \left(\frac{d_t^h}{P_t}\right)$$

where $d_t^h = p_t^h y_t^h - p_t^{n_h} n_t^h - \pi_t^h \eta(i_t^h) - P_t^{M_h} M_t^h$,

$$P_t = \prod_{h=1}^{M} (p_t^h)^{\xi^h}, \quad \pi_t^h = \prod_{s \in B_h^I} (p_t^s)^{\tilde{x}_{sh}}, \quad \text{and} \quad P_t^{M_h} = \prod_{s \in B_h^I} (p_t^s)^{x_{sh}}$$

Real dividends (d_t^h/P_t) are discounted by $(a_t/P_t)^{-1} = 1/C_t$, which is the consumer-shareholders' marginal utility of consumption with the logarithmic per-period utility function as assumed here.

3. consumers maximize lifetime utility (6) subject to:

$$\sum_{h=1}^{M} p_t^h c_t^h = \sum_{h=1}^{M} \left[p_t^{n_h} n_t^h + r_t^h k_t^h - \pi_t^h \eta(i_t^h)\right] \equiv a_t$$

where the wage rate $p_t^{n_h} = \beta_h p_t^h y_t^h / n_t^h$ and the capital rental rate $r_t^h = \alpha_h p_t^h y_t^h / k_t^h$;

4. prices clear labor markets and goods markets:

$$n_t^h = \frac{\beta_h \xi^h}{\chi} \frac{y_t^h}{c_t^h} L_t^{\varpi},$$

$$y_t^h = c_t^h + \sum_{s=1}^{M} i_{t,h}^s + \sum_{s=1}^{M} m_{t,h}^s.$$

where $\varpi = 0$ for indivisible labor and $\varpi = 1$ for divisible labor. The labor market-clearing condition for sector h is obtained from equating the sectoral labor demand determined by the marginal product of labor with labor supply determined by the consumers' marginal rate of substitution between leisure and consumption.[5]

The competitive equilibrium in the two-sector model of Hornstein and Praschnik (1997) can be obtained from the above definition by imposing the appropriate restrictions as elaborated in the previous section. Except for a special case of the parameter set, analytical solutions are not possible. An approximate solution is computed by log-linearizing all equilibrium equations with a first-order Taylor series expansion around the model's steady state.

3 Employment Comovement

In this section we provide analytical characterizations on the relative importance of the intermediate input channel and the preference specification with divisible or indivisible labor in generating the sectoral employment comovement. For that purpose, we rewrite the equilibrium condition for sector h's employment as derived in the previous section:

$$n_t^h = \frac{\beta_h \xi^h}{\chi} \frac{y_t^h}{c_t^h} L_t^{\varpi} \quad \text{where} \quad L_t = 1 - \sum_{h=1}^{M} n_t^h. \tag{10}$$

[5]That is, the labor market-clearing condition for sector h can be written as

$$\frac{\partial y^h}{\partial n^h} = -\frac{\frac{\partial U}{\partial L}\frac{\partial L}{\partial n^h}}{\frac{\partial U}{\partial C}\frac{\partial C}{\partial c^h}}$$

which equates the sectoral labor demand determined by the marginal product of labor with labor supply determined by the consumers' marginal rate of substitution between leisure and consumption. From (1), (8) and (9) respectively, $\frac{\partial y^h}{\partial n^h} = \frac{\beta_h y^h}{n^h}$, $\frac{\partial C}{\partial c^h} = \xi^h \frac{C}{c^h}$ and $\frac{\partial L}{\partial n^h} = -1$. Further, $\left(\frac{\partial U}{\partial L}\right) / \left(\frac{\partial U}{\partial C}\right) = \frac{\chi C}{L}$ with divisible labor, whereas $\left(\frac{\partial U}{\partial L}\right) / \left(\frac{\partial U}{\partial C}\right) = \chi C$ with indivisible labor. This can be written as $\left(\frac{\partial U}{\partial L}\right) / \left(\frac{\partial U}{\partial C}\right) = \frac{\chi C}{L^{\varpi}}$ where $\varpi = 1$ for divisible labor and $\varpi = 0$ for indivisible labor.

3.1 On the role of indivisible labor

We first investigate the role of indivisible labor in generating the sectoral employment comovement, while ignoring the possible intermediate input channel. Further, for simplicity as well as comparison with the related studies such as Benhabib, Rogerson, and Wright (1991), Christiano and Fisher (1998), and Hornstein (2000), we consider the two-sector economy where consumption good ($h = c$) and investment good ($h = i$) are produced in each sector. There is no intermediate input channel in the sense that consumption good is not used as an input to producing investment good. Hence, $y_t^c = c_t^c$. Further, investment good is not used for consumption and hence is not part of consumption aggregate. Therefore, $\xi^c = 1$. Now, for the consumption sector, equation (10) is reduced to the following after y_t^c and c_t^c cancel out each other:

$$n_t^c = \frac{\beta_c}{\chi}(1 - n_t^c - n_t^i)^{\varpi} \tag{11}$$

This implies that employment in the consumption good sector should behave countercyclically if labor is divisible ($\varpi = 1$) and it should be a constant if labor is indivisible ($\varpi = 0$).

In the boom, aggregate employment rises and the amount of leisure falls. With divisible labor ($\varpi = 1$), smaller amount of leisure in the boom implies higher marginal utility of leisure. That is, with concave utility function with respect to leisure, marginal utility of leisure becomes procyclical over the business cycle. The necessary condition for optimality then requires that marginal product of labor in the consumption sector should rise. With the typical production function which has the property of diminishing marginal product of labor, an increase in the marginal product of labor can only be achieved through a fall in employment. Therefore, employment in the consumption good sector should behave countercyclically with the divisible labor specification.

On the other hand, with indivisible labor ($\varpi = 0$), marginal utility of leisure is constant. Hence, smaller amount of leisure during the boom would have any effect on neither the marginal utility of leisure nor employment in the consumption sector. Therefore, employment in the consumption sector is constant over the business cycle with indivisible labor specification. These results are consistent with the findings in Benhabib, Rogerson, and Wright (1991), Christiano and Fisher (1998), and Hornstein (2000).[6]

3.2 On the role of intermediate input channel

In the presence of the intermediate input channel, each sector h's output is used not only for final consumption but also for intermediate input, which implies $y_t^h > c_t^h$ so that in equation (10) y_t^h and c_t^h do no longer cancel out each other. More specifically, sectoral output (y_t^h) can be used as intermediate inputs in the production sectors $(\sum_{s=1}^{M} m_{t,h}^s)$, or investment goods built into the capital stocks of the sectors $(\sum_{s=1}^{M} i_{t,h}^s)$, or final consumption goods (c_t^h). Let I^h denote the proportion of sector h's output that is either used as intermediate inputs for production or built into capital stocks. Then, the goods market-clearing condition for each sector's output implies

$$I^h = \frac{\sum_{s=1}^{M} i_{t,h}^s + \sum_{s=1}^{M} m_{t,h}^s}{y_t^h} = 1 - \frac{c_t^h}{y_t^h} \, . \tag{12}$$

According to equation (10), when all the possible intermediate input channels are considered, a constant employment with indivisible labor would be rather an exception in the sense that it occurs only to a sector whose output is never used as intermediate inputs. With indivisible labor ($\varpi = 0$), sectoral employment n_t^h is proportional to its output-to-consumption ratio y_t^h / c_t^h. That is, a given sector's employment is inversely related to the proportion of its output that goes for final consumption. With the productivity shock and consumption smoothing, output rises more than consumption in the economic boom. Hence, the proportion of sectoral output that

[6] In the absence of intermediate input channel, Christiano and Fisher(1998) have to rely on limited labor mobility for employment comovement.

goes for intermediate input use and capital formation increases relative to its use for final consumption. That is, y_t^h/c_t^h is procyclical, and therefore n_t^h becomes also procyclical without relying on additional restrictions such as limited labor mobility as in Christiano and Fisher (1998).

With divisible labor ($\varpi = 1$), the behavior of sectoral employment n_t^h over the business cycle is determined by the two factors. One is the intermediate input channel captured by y_t^h/c_t^h in equation (10) and the other is the procyclical movement of the marginal utility of leisure which is captured by L. As explained in the previous subsection, procyclical movement of the marginal utility of leisure makes sectoral employment move countercyclically, whereas the intermediate input channel makes sectoral employment move procyclically. Hence, in order to generate procyclical sectoral employment, intermediate input channel must be strong enough to dominate the effect from the procyclical movement of the marginal utility of leisure. For an industrial sector having relatively weak linkages to the other sectors, the procyclical sectoral employment due to the intermediate input channel is more likely to be dominated by the countercyclical sectoral employment caused by the procyclical marginal utility of leisure, yielding a low or even a negative comovement in sectoral employment.

Hornstein and Praschnik (1997) examine a two-sector (nondurable/consumption good and durable/investment good) model with indivisible labor where some of the output of the consumption good sector is used as intermediate inputs in the production of investment good. In the boom, for example, output in the consumption good sector increases with the increased need for use in the investment good sector. This is also claimed to be true of divisible labor specification for preferences. How would we then account for the essentially same positive sectoral employment comovement, irrespective of divisible or indivisible labor specification for preferences in the two-sector model of Hornstein and Praschnik (1997)? The key is the *two-sector* specification in which the intermediate input share of nondurables in the production of durable goods, is sufficiently high (e.g. 0.45) that the procyclical marginal utility of leisure with divisible labor is always dominated by the intersectoral linkages. Hence, the divisibility of labor appears to have no effect on sectoral employment comovement.

3.3 On the role of frictions in labor reallocation

In order to examine the potential role of difficulty in adjusting employment across sectors, we consider Horvath (2000) where elasticity of substitution of labor supply is relatively low across sectors. An interpretation of this specification is that the representative worker/consumer has a preference for diversity of labor hours despite wage differences across sectors. This modification is analogous to Boldrin, Christiano, and Fisher (2001) and Christiano and Fisher (1998) which assume limited labor mobility between industry sectors.

More specifically, the form of aggregate leisure index L_t in the preferences is now generalized to allow for less-than-perfect substitutability of labor hours across sectors:

$$L_t = 1 - \left[\sum_{s=1}^{M} (n_t^s)^{\frac{\tau+1}{\tau}} \right]^{\frac{\tau}{\tau+1}}, \qquad \tau > 0 \tag{13}$$

As $\tau \to \infty$, labor hours become perfect substitutes for the consumer/worker as in Hornstein and Praschnik (1997), implying that the worker would devote all time to the sector paying the highest wage. Hence, at the margin, all sectors pay the same hourly wage. For $\tau < \infty$, hours worked are not perfect substitutes for the worker. The worker has a preference for diversity of labor, and hence would prefer working a positive number of hours in each sector even when the wages are different among sectors. This is essentially the same way by which Huffman and Wynne (1999) impose the degree of difficulty in relocating labor across sectors by using a form with constant elasticity of transformation (CET). For example, a low elasticity of transformation across sectors is equivalent to a low substitutability of labor as represented by a low value of τ.

Now, sectoral employment is determined by the following equilibrium condition:

$$n_t^h = \left[\frac{\beta_h \xi^h}{\chi}\right]^{\frac{\tau}{\tau+1}} (1-L_t)^{\frac{1}{\tau+1}} \left(\frac{y_t^h}{c_t^h}\right)^{\frac{\tau}{\tau+1}} (L_t^{\varpi})^{\frac{\tau}{\tau+1}} \tag{14}$$

where $\varpi = 0$ for indivisible labor and $\varpi = 1$ for divisible labor.[7] Notice that, as $\tau \to \infty$, the above equilibrium condition for sectoral employment is reduced to equation (10). For $\tau < \infty$, sectoral employment is determined not only by the intermediate input channel $(y_t^h/c_t^h)^{\frac{\tau}{\tau+1}}$ or the procyclical movement of the marginal utility of leisure $(L_t^{\varpi})^{\frac{\tau}{\tau+1}}$, but also by aggregate employment $(1-L_t)^{\frac{1}{\tau+1}}$. With divisible labor ($\varpi = 1$), the procyclical aggregate employment and the intermediate input channel make sectoral employment move procyclically, whereas the procyclical marginal utility of leisure makes sectoral employment move countercyclically. Hence, as τ decreases so that the worker/consumer becomes more reluctant to substitute labor across sectors, the procyclical aggregate employment plays more dominant role in generating the observed sectoral employment comovement.

3.4 On the role of CES production function

According to Huffman and Wynne (1999) in which the intermediate input channel is absent, inclusion of adjustment cost for labor between the consumption good and investment good sectors does not significantly enhance the ability to explain employment comovement.[8] Instead, as a production function for the consumption good sector, they rely on the form with a constant elasticity of substitution (CES) rather than Cobb-Douglas production function. Noting the lack of the intermediate input channel in Huffman and Wynne (1999), we show below that, with a CES production function, the intermediate input channel is still crucial to explain the stylized facts of volatility as well as comovement for sectoral employment.

[7] This is derived similarly to (10), the details of which are in the footnote 6. The only difference is $\frac{\partial L}{\partial n^h} = -(1-L)^{-\frac{1}{\tau}} \left(n^h\right)^{\frac{1}{\tau}}$ with the aggregate leisure index L given by (13), instead of (9).

[8] However, they find that adjustment costs for investment significantly increase sectoral investment comovement.

For instance, consider the following production function for the consumption good sector:

$$y_t^h = A_t^h \left[\alpha_h \left(k_t^h\right)^{\frac{\theta-1}{\theta}} + \beta_h \left(n_t^h\right)^{\frac{\theta-1}{\theta}} + \gamma_h (M_t^h)^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}}$$

where θ denotes the constant elasticity of substitution between k^h, n^h, and M^h. Now the equilibrium condition for a sector h's employment can be written as follows:

$$n_t^h = \left[\frac{\beta_h \xi^h}{\chi}\right]^\theta \left(\frac{y_t^h}{A_t^h}\right)^{1-\theta} \left(\frac{y_t^h}{c_t^h}\right)^\theta (L_t^\varpi)^\theta \tag{15}$$

With no intermediate input channel so that $y_t^h = c_t^h$ and indivisible labor ($\varpi = 0$), this becomes

$$n_t^h = \left[\frac{\beta_h \xi^h}{\chi}\right]^\theta \left(\frac{c_t^h}{A_t^h}\right)^{1-\theta}$$

Consumption smoothing implies that (c_t^h/A_t^h) is countercyclical, and hence with the reasonable assumption of $\theta > 1$, sectoral employment (n_t^h) is procyclical. For example, Huffman and Wynne (1999) calibrate $\theta = 1.02$. However, a crucial problem with this specification is that the implied volatility is extremely small.[9]

Christiano and Fitzgerald (1998) also consider a CES production function with divisible labor ($\varpi = 1$), in which case (15) is reduced to

$$n_t^h = \left[\frac{\beta_h \xi^h}{\chi}\right]^\theta \left(\frac{c_t^h}{A_t^h}\right)^{1-\theta} L_t^\theta$$

They point out that, with θ little above unity, (c_t^h/A_t^h) falls with a rise in A_t^h. Hence, if the resulting rise in $(c_t^h/A_t^h)^{1-\theta}$ is sufficiently large, it is possible for n_t^h to increase in response to an unexpected rise in A_t^h. However, they report that for various combinations of plausible parameter values, employment comovement does not occur.

It is worth noting that the problem of extremely small volatility of employment in the consumption good sector can disappear once we consider the intermediate input

[9] This can be seen by the log-linear approximation of the above equation $\hat{n}_t = (1-\theta)\left(\hat{c}_t - \hat{A}_t\right)$ where the variables are expressed as log-deviation from their respective steady states. With $(1-\theta) = 0.02$, volatility of n_t^h must be very small.

channel so that $y_t^h > c_t^h$. Now, with indivisible labor ($\varpi = 0$), (15) becomes

$$n_t^h = \left[\frac{\beta_h \xi^h}{\chi}\right]^\theta \left(\frac{y_t^h}{A_t^h}\right)^{1-\theta} \left(\frac{y_t^h}{c_t^h}\right)^\theta$$

As in the typical real business cycles, y_t^h and A_t^h tend to comove so closely that there is no noticeable pro- or countercyclical pattern for (y_t^h/A_t^h). On the other hand, (y_t^h/c_t^h) is strongly procyclical because the intermediate input use and capital formation is higher during the boom. Therefore, n_t^h is procyclical and, despite a small volatility of $(y_t^h/A_t^h)^{1-\theta}$, the reasonably large volatility of $(y_t^h/c_t^h)^\theta$ is likely to yield plausible volatility of sectoral employment. In short, even with a CES production function, the intermediate input channel plays an important role in generating comovement and volatility for sectoral employment.

Further, with divisible labor ($\varpi = 1$), (15) becomes

$$n_t^h = \left[\frac{\beta_h \xi^h}{\chi}\right]^\theta \left(\frac{y_t^h}{A_t^h}\right)^{1-\theta} \left(\frac{y_t^h}{c_t^h}\right)^\theta L_t^\theta \tag{16}$$

Again the procyclical marginal utility of leisure, as captured by L_t^θ, causes the countercyclical movement of sectoral employment. However, the procyclical intermediate input channel captured by $(y_t^h/c_t^h)^\theta$ would certainly help to make sectoral employment move procyclically. Finally, after setting $\theta \equiv \tau/(\tau+1)$, the above equation is closely related to (14) with the reluctance to substitute labor across sectors in the sense that both $(1 - L_t)$ in (14) and (y_t^h/A_t^h) in (16) are procyclical.

4 Quantitative Results

As for the calibrations of the model parameters, the level of sectoral disaggregation is set to $M = 36$, following the sectoral definitions used by Jorgenson, et. al. (1987) which has a mixture of 1- and 2-digit SIC industries. The production technology parameters, α_h, β_h, and γ_h are set respectively as the time-series average of cost shares for capital, labor, and intermediate inputs for 36 sectors using annual data from 1948 to 1985 (Jorgenson, et. al. 1987) by dividing the cost of inputs by the value of output both evaluated at producer prices. The mean value of α_h, β_h, and γ_h is respectively 0.16, 0.32, and 0.52. The "shocks" parameters, ρ_h and Ω, are also constructed using the Jorgenson data set. We consider the model economy where the productivity shocks are not independent across sectors: that is, off-diagonal elements from the estimated variance-covariance matrix of sectoral productivity residuals are not assumed to be zero.[10] The sectoral depreciation rates of capital stocks, μ_h, are those used in Jorgenson, et. al. (1987).

The time period considered is the year. Following the other business cycle models, the discount factor, δ, is set to be $(1.03)^{-1}$ implying an annual discount rate of 3%. The parameter χ is set so that total hours worked in steady state represent one-third of the worker's total time endowment. The share parameter ξ^h in the aggregate consumption index is obtained from the nominal consumption expenditure share of sector h in total consumption, $\xi^h = p^h c^h / \sum p^h c^h$, using consumption data from the National Income and Product Accounts.

Data for the capital-use matrix Γ_I and the intermediate input-use matrix Γ_m are based on the 1977 capital flow table described in Silverstein (1985) and the 1977 detailed intermediate input-use table, respectively. The capital-use and intermediate input-use tables are converted respectively to Γ_I and Γ_m by properly aggregating to 36 sectors and then dividing columns by their sums.

The simulation results are presented in Tables 1 through 6, along with the actual sectoral or industry comovement in employment, capital services, and value added in the US. In order to compare with the two-sector comovement results in Hornstein and Praschnik (1997), the disaggregated sectors are grouped under the nondurable and durable goods sectors following Hornstein and Praschnik (1997) definition of these two sectors.

[10]The simulation results under zero off-diagonal elements in Ω are very close to those with non-zero off-diagnoal elements.

The second column of each table reports the comovement between sectoral and aggregate series in the US. These are reproduced from Hornstein (2000) which used data from Jorgenson, et. al. (1987) after removing trend by a band pass filter.[11] The industry comovement is measured by the maximal correlation in absolute value of the contemporaneous, one-period lagged, and one-period led correlation between industry series and aggregate series. In Table 1, for example, the second column reports the maximal correlation between the industry employment and the corresponding aggregate employment: $corr[n_t^h, \sum_{h=1}^{M} n_{t+z}^h]$ with $z = 1, 0, -1$. A plus (minus) superscript denotes that the industry employment is leading (lagging) the aggergate employment, that is $z = 1 (z = -1)$. No superscript indicates that the contemporaneous correlation is maximal.

Further, in order to provide a measure of how tight the relation between the industry and the aggregate economy is, we also report the R^2 of the regression between the industry series and one lagged value, one leading value, and the contemporaneous value of the aggregate series. It captures the variation of the industry series explained by variation of the aggregate series. For example, in Table 2, the higher is the R^2, the tighter is the fit between the industry employment and the aggregate employment.

According to these two measures as displayed in the second column of Tables 1 through 6, with a few exceptions, industry employment, capital services, and value added are all positively correlated with the corresponding aggregate variables. This is also consistent with the previous works by Christiano and Fitzgerald (1998) which study the comovement of monthly two-digit industry employment, and Murphy, et. al. (1989) which study annual one-digit industry employment and value added.

[11] Jorgenson, et. al. (1987) provide annual series on inputs and outputs at the two-digit industry level. It covers annual prices and quantities for industry gross output and use of capital services, labor, materials, and energy for the years 1950-1991. For more details visit Jorgenson's Web page at http://www.economics.harvard.edu/faculty/jorgenson/data.html. All industries of the data set are included, except agriculture and government enterprises. For a description of band pass filters, see Hornstein (1998) and Christiano and Fitzgerald (1998).

The industry comovement in the model economy is measured similarly by taking averages of 100 simulated economies of length 40 years. Simulated data are band-pass filtered before they are used to estimate correlation coefficients or to regress the industry variables on the aggregate ones. As reported in the third column ("Indivisible") of Tables 1 and 2, the model simulations imply strong sectoral employment comovement over the business cycle in terms of both the maximal correlation and R^2.[12] This is in contrast to Horvath (2000) which has the divisible labor specification of preferences. With divisible labor which implies the procyclical marginal utility of leisure, wage differences between two sectors due to independent sectoral shocks cause the consumers to allocate more time to the sector paying higher wages, yielding opposite movements in sectoral employment.

At the disaggregation level of 36 industrial sectors, both the intermediate input-use and the capital-use matrices imply sufficient intersectoral linkages to explain the sectoral employment comovement over the business cycle. In the fourth column of Table 1, the sectoral averages of (over 100 simulations) the intersectoral linkages measured by I^h in equation (12) are reported next to the corresponding sectoral employment comovement. These linkage numbers are the same for both indivisible and divisible labor specification of preferences.

With divisible labor, as illustrated in the column ("Divisible") of Table 1, the model implies some negative employment comovement as well as positive ones. Notice that, with the procyclical marginal utility of leisure, the negative sectoral comovement tends to occur to those sectors having very low number for intersectoral linkages. This differs from the two-sector model of Hornstein and Praschnik (1997) where the procyclical marginal utility of leisure did not appear to play any role. The oversimplistic two sector specification (i.e. durables and nondurables) implies that the relatively strong intersectoral linkages tend to dominate the effect of the procyclical

[12] The standard errors of the correlation coefficients as reported in Tables 1, 3, and 5 are all close to zero.

marginal utility of leisure.

Christiano and Fitzgerald (1998) argue against the intermediate input channel by noting strong business cycle comovement in subsectors of the nondurable-goods sector, despite the wide variation in the strength of each nondurable subsector's intersectoral linkage (including zero) with the investment sector. The strength of the intermediate input channel is measured as the fraction of a nondurable sector's gross output which is allocated to intermediate goods sent directly or indirectly for the production of final investment goods.[13] However, the intersectoral linkages as considered here are much broader in the sense that the model allows for the potential uses of a sector's (nondurable or durable) output as intermediate inputs and/or capital inputs in the production of nondurables or durables (including final investment goods). The implied strength of intersectoral linkages are therefore much larger than those in Christiano and Fitzgerald (1998).

Further, as reported in the third column ("Indivisible") of Tables 3 through 6, model simulations also show that the intersectoral linkages generate positive sectoral comovements in both capital services and value added, although there are several exceptions where the size of industry comovement in capital services and value added is below that of the actual data.

Finally, we consider the potential role of difficulty in adjusting employment across sectors. Noting the empirical studies in labor economics which find a relatively low wage elasticity of labor supply (e.g. Altonji (1982) and Ashenfelter and Altonji (1980)) and persistent wage differences across sectors, we simulate the model economy where elasticity of substitution of labor supply across sectors is relatively low such as $\tau = 1$ in (13). This represents the worker's reluctance to substitute labor hours across sectors. As in the previous case of perfectly substitutable labor hours across sectors, the parameter χ is set so that total hours worked in steady state represent one-third of the worker's total time endowment. For example, $\tau = 1$ implies $\chi = 13.4$.

[13]See their Technical Appendix 3 for more details on the measure of the intermediate input channel.

The last column in Table 1 illustrates that a low elasticity of substitution of labor across sectors (e.g. $\tau = 1$) can generate the strong business cycle comovement of sectoral hours worked. Therefore, with divisible labor implying the procyclical marginal utility of leisure, the intermediate input channel alone is not sufficient to generate the employment comovement across sectors. It further requires some form of the difficulty in making intersectoral reallocation of labor, such as worker's reluctance to substitute labor hours across sectors or adjustment cost for labor.

5 Concluding Remarks

We have studied a multisector dynamic stochastic general equilibrium model calibrated to the 2-digit SIC level intermediate input-use and capital-use tables to investigate the determinants of employment comovement over the business cycle. In general, the business cycle comovement in employment depends on the specification of preferences with divisible or indivisible labor as well as technology with potential intersectoral linkages.

With indivisible labor on the part of consumers, the intersectoral linkages at a disaggregated level are sufficient to generate the employment comovement across sectors. With divisible labor, however, the procyclical marginal utility of leisure can dominate a sector's intersectoral linkage, implying a negative comovement. It further requires some form of the difficulty in adjusting labor across sectors, such as worker's reluctance to substitute labor hours across sectors. Referring to some micro-level studies on the low wage elasticity of labor supply, a low substitution of labor hours is shown to generate the comovement in sectoral hours worked.

Table 1: Sectoral Employment Comovement (Maximal Correlation)

Sector	US Data	Indivisible	Linkages	Divisible	$\tau = 1$
Nondurables & Services					
Agricultural products	-	0.96	0.93	-0.10^{+}	0.99
Agricultural services	-	0.92	0.53	0.07^{-}	0.99
Metal mining	0.44	0.89	0.60	0.76	0.99
Coal mining	0.30	0.98	0.63	0.92	0.99
Oil and gas extraction	-0.48^{+}	0.98	0.87	0.84	0.99
Nonmetallic mining	-0.31^{+}	0.85	0.48	0.50	0.99
Construction	0.70	0.71	0.96	0.55	0.96
Food	0.29^{+}	0.99	0.41	-0.08^{-}	0.99
Tobacco	0.19	0.79	0.19	-0.08^{-}	0.99
Textile mill products	0.66	0.93	0.85	0.31	0.99
Apparel	0.52	0.82	0.26	-0.03^{+}	0.99
Paper and allied	0.69	0.76	0.72	0.66	0.97
Printing	0.50	0.96	0.55	0.30	0.99
Chemicals	0.77	0.97	0.74	0.82	0.99
Petroleum & coal	0.37^{+}	0.96	0.62	0.77	0.99
Rubber & misc. plastics	0.85	0.98	0.69	0.94	0.99
Leather	0.46	0.85	0.29	-0.06^{+}	0.99
Transportation	0.84	0.97	0.67	0.83	0.99
Communication	0.55	0.95	0.56	0.87	0.99
Electric utilities	0.58^{-}	0.98	0.01	-0.08^{-}	0.99
Gas utilities	0.66	0.99	0.84	0.99	0.99
trade	0.81	0.99	0.27	-0.05^{-}	0.99
FIRE	0.24^{-}	0.77	0.96	0.61	0.97
Water & sanitary services	0.74	0.99	0.57	0.87	0.99
Other services	-	0.98	0.45	0.21	0.99
Durables					
Lumber & wood	0.77	0.83	0.78	0.68	0.98
Furniture & fixtures	0.84	0.76	0.05	-0.09^{-}	0.99
Stone, clay, glass	0.84	0.87	0.77	0.72	0.99
Primary metal	0.65	0.95	0.94	0.91	0.99
Fabricated metal	0.86	0.98	0.89	0.96	0.99
Machinery, non-electrical	0.86	0.44	0.94	0.34	0.91
Electrical machinery	0.88	0.66	0.80	0.51	0.94
Motor vehicles	0.79	0.78	0.51	0.76	0.94
Transportation equipment	0.62	0.93	0.63	0.80	0.99
Instruments	0.67	0.57	0.65	0.44	0.84
Misc. manufacturing	0.47	0.84	0.51	0.80	0.97

Table 2: Sectoral Employment Comovement (R^2)

Sector	US Data	Indivisible	Divisible	$\tau = 1$
Nondurables & Services				
Agricultural products	-	0.94	0.89	0.99
Agricultural services	-	0.86	0.08	0.99
Metal mining	0.23	0.89	0.70	0.98
Coal mining	0.18	0.96	0.85	0.99
Oil and gas extraction	0.35	0.97	0.73	0.99
Nonmetallic mining	0.14	0.76	0.30	0.98
Construction	0.58	0.56	0.34	0.93
Food	0.16	0.98	0.99	0.99
Tobacco	0.07	0.68	0.99	0.99
Textile mill products	0.57	0.92	0.43	0.99
Apparel	0.43	0.81	0.87	0.99
Paper and allied	0.57	0.84	0.73	0.96
Printing	0.25	0.93	0.12	0.99
Chemicals	0.74	0.95	0.69	0.99
Petroleum & coal	0.12	0.94	0.63	0.99
Rubber & misc. plastics	0.83	0.97	0.88	0.99
Leather	0.53	0.85	0.99	0.99
Transportation	0.75	0.95	0.71	0.99
Communication	0.59	0.96	0.88	0.99
Electric utilities	0.54	0.97	0.99	0.99
Gas utilities	0.60	0.99	0.98	0.99
trade	0.65	0.98	0.12	0.99
FIRE	0.16	0.64	0.41	0.94
Water & sanitary services	0.60	0.98	0.77	0.99
Other services	-	0.96	0.07	0.99
Durables				
Lumber & wood	0.70	0.74	0.52	0.97
Furniture & fixtures	0.80	0.62	0.83	0.99
Stone, clay, glass	0.74	0.78	0.54	0.98
Primary metal	0.44	0.91	0.84	0.99
Fabricated metal	0.76	0.97	0.93	0.99
Machinery, non-electrical	0.82	0.35	0.21	0.85
Electrical machinery	0.81	0.50	0.29	0.90
Motor vehicles	0.80	0.85	0.77	0.92
Transportation equipment	0.54	0.93	0.74	0.99
Instruments	0.60	0.51	0.34	0.74
Misc. manufacturing	0.33	0.88	0.82	0.96

Table 3: Sectoral Capital Comovement (Maximal Correlation)

Sector	US Data	Indivisible	Divisible	$\tau = 1$
Nondurables & Services				
Agricultural products	-	0.70^{-}	0.64^{-}	0.67^{-}
Agricultural services	-	0.69^{-}	0.66^{-}	0.68^{-}
Metal mining	-0.13^{+}	0.57	0.47	0.55
Coal mining	-0.13	0.41^{-}	0.31^{-}	0.38^{-}
Oil & gas extraction	0.30	0.28^{-}	0.18^{-}	0.24
Non-metallic mining	0.25^{-}	0.62^{-}	0.57^{-}	0.68^{-}
Construction	0.32	0.49	0.42	0.65
Food	0.31	0.76^{-}	0.71^{-}	0.69^{-}
Tobacco	-0.24^{+}	0.74^{-}	0.70^{-}	0.73^{-}
Textile mill products	0.58	0.68^{-}	0.61^{-}	0.67^{-}
Apparel	-0.43^{-}	0.74^{-}	0.71^{-}	0.72^{-}
Paper and allied	0.62	0.50^{-}	0.39^{-}	0.43
Printing	0.67	0.73^{-}	0.65^{-}	0.75^{-}
Chemicals	0.72	0.58^{-}	0.50	0.51
Petroleum & coal	0.50	0.51^{-}	0.45^{-}	0.26
Rubber & misc. plastics	0.31	0.70	0.63	0.66
Leather	0.60	0.61^{-}	0.48^{-}	0.53^{-}
Transportation	0.61	0.66^{-}	0.58^{-}	0.71^{-}
Communication	0.33	0.38	0.33	0.40
Electric utilities	0.17^{+}	0.66^{-}	0.56^{-}	0.60^{-}
Gas utilities	0.38	0.45^{-}	0.35^{-}	0.19^{-}
Trade	0.82	0.62^{-}	0.49^{-}	0.33^{-}
FIRE	0.75	0.32	0.29	0.59
Water & sanitary services	0.72	0.33^{-}	0.25^{-}	0.14^{-}
Other services	-	0.41^{-}	0.38^{-}	0.25^{-}
Durables				
Lumber & wood	0.43	0.49	0.43	0.61
Furniture & fixtures	0.70	0.78^{-}	0.74^{-}	0.77^{-}
Stone, clay, glass	0.75	0.57	0.50	0.61
Primary metal	-0.67^{+}	0.55	0.55	0.62
Fabricated metal	0.76	0.72	0.68	0.71
Machinery, non-electrical	0.75	0.28^{+}	0.25^{+}	0.54
Electrical machinery	0.72	0.32	0.26	0.53
Motor vehicles	0.66	0.27	0.26	0.38
Transportation equipment	0.64^{-}	0.47^{-}	0.41	0.50^{-}
Instruments	0.76	0.36^{+}	0.32^{+}	0.52
Misc. manufacturing	0.46	0.32	0.32	0.34

Table 4: Sectoral Capital Comovement (R^2)

Sector	US Data	Indivisible	Divisible	$\tau = 1$
Nondurables & Services				
Agricultural products	-	0.63	0.57	0.79
Agricultural services	-	0.60	0.56	0.76
Metal mining	0.04	0.55	0.36	0.64
Coal mining	0.05	0.24	0.12	0.24
Oil & gas extraction	0.15	0.29	0.15	0.20
Non-metallic mining	0.12	0.36	0.29	0.57
Construction	0.09	0.38	0.24	0.77
Food	0.06	0.69	0.62	0.73
Tobacco	0.08	0.70	0.65	0.83
Textile mill products	0.35	0.50	0.40	0.69
Apparel	0.31	0.71	0.67	0.83
Paper and allied	0.51	0.26	0.16	0.27
Printing	0.41	0.51	0.41	0.69
Chemicals	0.49	0.38	0.28	0.44
Petroleum & coal	0.20	0.31	0.21	0.19
Rubber & misc. plastics	0.33	0.60	0.53	0.58
Leather	0.43	0.44	0.27	0.48
Transportation	0.37	0.42	0.35	0.57
Communication	0.20	0.25	0.14	0.22
Electric utilities	0.06	0.65	0.54	0.63
Gas utilities	0.18	0.28	0.15	0.10
Trade	0.72	0.55	0.40	0.31
FIRE	0.56	0.59	0.52	0.65
Water & sanitary services	0.53	0.32	0.21	0.17
Other services	-	0.45	0.39	0.20
Durables				
Lumber & wood	0.19	0.33	0.25	0.48
Furniture & fixtures	0.60	0.65	0.60	0.81
Stone, clay, glass	0.61	0.39	0.26	0.64
Primary metal	0.50	0.71	0.63	0.84
Fabricated metal	0.53	0.56	0.44	0.76
Machinery, non-electrical	0.63	0.30	0.19	0.69
Electrical machinery	0.52	0.33	0.20	0.73
Motor vehicles	0.50	0.28	0.20	0.68
Transportation equipment	0.42	0.37	0.28	0.39
Instruments	0.57	0.60	0.50	0.68
Misc. manufacturing	0.32	0.17	0.07	0.17

Table 5: Sectoral Value-Added Comovement (Maximal Correlation)

Sector	US Data	Indivisible	Divisible	$\tau = 1$
Nondurables & Services				
Agricultural products	-	0.45	0.45	0.49
Agricultural services	-	0.48	0.47	0.51
Metal mining	0.44	0.38	0.38	0.39
Coal mining	0.51	0.52	0.48	0.50
Oil & gas extraction	0.73	0.64	0.63	0.64
Non-metallic mining	0.72	0.66	0.64	0.67
Construction	0.61	0.74	0.67	0.88
Food	0.44	0.68	0.68	0.73
Tobacco	0.38	0.15	0.15	0.23
Textile mill products	0.46^{+}	0.38	0.35	0.41
Apparel	0.67	0.55	0.47	0.65
Paper and allied	0.75	0.36	0.28	0.27
Printing	0.69	0.46	0.37	0.48
Chemicals	0.77	0.82	0.79	0.82
Petroleum & coal	0.62^{+}	0.76	0.73	0.76
Rubber & misc. plastics	0.78	0.81	0.79	0.81
Leather	-0.39	0.61	0.62	0.63
Transportation	0.75	0.62	0.55	0.60
Communication	-0.45^{+}	0.01^{-}	-0.009^{-}	-0.0005^{-}
Electric utilities	0.66	0.47	0.40	0.57
Gas utilities	-0.57^{+}	0.59	0.57	0.59
Trade	0.82	0.84	0.81	0.87
FIRE	0.22^{+}	0.25^{-}	0.24^{-}	0.13^{-}
Water & sanitary services	0.71	0.37	0.31	0.41
Other services	0.71	0.32	0.27	0.34
Durables				
Lumber & wood	-0.30	0.65	0.60	0.64
Furniture & fixtures	0.90	0.03	-0.005	0.07
Stone, clay, glass	0.89	0.85	0.81	0.86
Primary metal	0.75	0.87	0.84	0.85
Fabricated metal	0.88	0.87	0.82	0.84
Machinery, non-electrical	0.79	0.42	0.35	0.67
Electrical machinery	0.84	0.66	0.59	0.78
Motor vehicles	0.77	0.77	0.74	0.79
Transportation equipment	0.49^{-}	0.47	0.43	0.46
Instruments	0.73	0.41	0.31	0.43
Misc. manufacturing	0.65	0.76	0.73	0.74

Table 6: Sectoral Value-Added Comovement (R^2)

Sector	US Data	Indivisible	Divisible	$\tau = 1$
Nondurables & Services				
Agricultural products	-	0.22	0.12	0.15
Agricultural services	-	0.24	0.14	0.17
Metal mining	0.33	0.19	0.10	0.10
Coal mining	0.28	0.35	0.24	0.25
Oil & gas extraction	0.61	0.37	0.29	0.30
Non-metallic mining	0.68	0.49	0.43	0.46
Construction	0.60	0.60	0.47	0.79
Food	0.41	0.38	0.29	0.35
Tobacco	0.22	0.14	0.05	0.06
Textile mill products	0.21	0.18	0.07	0.09
Apparel	0.50	0.30	0.14	0.30
Paper and allied	0.61	0.27	0.12	0.08
Printing	0.55	0.33	0.19	0.29
Chemicals	0.65	0.63	0.56	0.60
Petroleum & coal	0.40	0.53	0.43	0.47
Rubber & misc. plastics	0.64	0.58	0.50	0.52
Leather	0.21	0.32	0.25	0.26
Transportation	0.62	0.43	0.31	0.36
Communication	0.25	0.17	0.15	0.12
Electric utilities	0.47	0.37	0.24	0.41
Gas utilities	0.36	0.38	0.31	0.33
Trade	0.79	0.61	0.50	0.62
FIRE	0.07	0.19	0.08	0.06
Water & sanitary services	0.60	0.18	0.07	0.13
Other services	-	0.23	0.11	0.15
Durables				
Lumber & wood	0.12	0.45	0.32	0.35
Furniture & fixtures	0.83	0.13	0.04	0.04
Stone, clay, glass	0.80	0.72	0.61	0.70
Primary metal	0.64	0.75	0.69	0.69
Fabricated metal	0.81	0.86	0.81	0.82
Machinery, non-electrical	0.82	0.38	0.27	0.64
Electrical machinery	0.83	0.51	0.37	0.64
Motor vehicles	0.73	0.77	0.70	0.73
Transportation equipment	0.37	0.35	0.26	0.28
Instruments	0.70	0.40	0.27	0.33
Misc. manufacturing	0.47	0.66	0.57	0.56

6 References

Altonji, J.G. (1982) "The Intertemporal Substitution Model of Labor Market Fluctuations: An Empirical Analysis," *Review of Economic Studies*, 49:783-824.

Ashenfelter, O. and Altonji, J.G. (1980) "Wage Movements and the Labor Market Equilibrium Hypothesis," *Econometrica*, 47:217-245.

Benhabib, J., Rogerson, R., and Wright, R. (1991) "Homework in Macroeconomics: Household Production and Aggregate Fluctuations," *Journal of Political Economy*, 99, 1166-1187.

Boldrin, M., Christiano, L.J., and Fisher, J.D.M (2001) "Habit Persistence, Asset Returns and the Business Cycle," *American Economic Review*, 91(1), 149-166.

Christiano, L.J. and Fisher, J.D.M (1998) "Stock Market and Investment Good Prices: Implications for Macroeconomics," Federal Reserve Bank of Chicago, working paper.

Christiano, L.J. and Fitzgerald, T.J. (1998) "The Business Cycle: It's Still a Puzzle," *Economic Perspectives*, Federal Reserve Bank of Chicago.

Hornstein, A. (2000) "The Business Cycle and Industry Comovement," Federal Reserve Bank of Richmond *Economic Quarterly,* 86: 27-47.

Hornstein, A. (1998) "Inventory Investment and the Business Cycle," Federal Reserve Bank of Richmond *Economic Quarterly,* 84: 49-71.

Hornstein, A. and Praschnik, J. (1997) "Intermediate Inputs and Sectoral Comovement in the Business Cycle," *Journal of Monetary Economics*, 40: 573-595.

Horvath, Michael T. K. (2000) "Sectoral Shocks and Aggregate Fluctuations," *Journal of Monetary Economics*, 45: 69-106.

Horvath, Michael T. K. (1998) "Cyclicality and Sectoral Linkages: Aggregate Fluctuations from Independent Sectoral Shocks," *Review of Economic Dynamics*, 1: 781-808.

Huffman, G. and Wynne, M. (1999) "The Role of Intratemporal Adjustment Costs in a Multisector Economy," *Journal of Monetary Economics*, 43, 317-350.

Jorgenson, D.G., Gollop, F.M., and Fraumeni, B. (1987) *Productivity and US Economic Growth*, Harvard University Press, Cambridge.

King, Robert G., Charles I. Plosser, and Sergio Rebelo (1988) "Production, Growth and Business Cycles: I. The Basic Neoclassical Model," *Journal of Monetary Economics*, 21.

Kydland, F. and Prescott, E.C. (1982) "Time to Build and Aggregate Fluctuations," *Econometrica*, 50, 1345-1370.

Long, John and Charles I. Plosser (1983) "Real Business Cycles," *Journal of Political Economy*, 91, 39-69.

Lucas, R.E. (1981) "Understanding Business Cycles," *Studies in Business Cycle Theory*, MIT Press.

Murphy, K.K., Shleifer, A., and Vishny, R.W. (1989) "Building Blocks of Market Clearing Business Cycle Models," in O.J. Blanchard and S. Fisher, eds., *Macroeconomics Annual 1989*, MIT Press, 247-287.

Silverstein, G. (1985) "New Structures and Equipment by Using Industries, 1977," *Survey of Current Business*, 65:26-35.