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Intermediate Inputs and Sectoral Comovement in the Business Cycle

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Intermediate inputs and sectoral comovement in the business cycle*

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Abstract

The postwar U.S. business cycle is characterized by positive comovement of employment and output across sectors. It has been argued that multi-sector growth models are inconsistent with this observation when changes in relative productivities are the main source of fluctuations. We suggest that the input-output structure of an economy, in particular the pervasive use of intermediate inputs, can induce positive comovement in sectoral employment and output following changes in relative productivities. We calibrate a model of the U.S. economy for the durable and nondurable goods producing sectors, and show that sectoral employment and output move together if intermediate inputs are used in production. The model is also consistent with the observation that the relative price of nondurable goods is procyclical.

Keywords: Real business cycles; Multi-sector growth model; Co-movement
JEL Classification: D24; E23; E32

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1. Introduction

A defining characteristic of the business cycle is the comovement of macroeconomic time series. In particular, employment and production across broadly defined industrial sectors move together. It has been argued that multi-sector extensions of the basic neoclassical growth model are inconsistent with this observation when changes in sectoral productivities are independent of each other, e.g. Lucas (1977). We suggest that the neoclassical growth model is indeed consistent with the observed positive comovement across sectors if one accounts for the input-output structure of the economy.

The properties of the U.S. business cycle have been documented as early as Mitchell (1913) and Burns and Mitchell (1947).[1] In our study we focus on the comovement of employment, output, and investment between the durable and nondurable goods producing sector of the U.S. economy. Figure 1 displays the percentage deviations from trend for aggregate value-added and sectoral data of employment, value-added, and investment.[2] Like other studies, we find that employment, value-added, and investment in the two sectors are strongly procyclical and move together, and household investment leads business investment. We also find that the durable goods producing sector is more volatile than the nondurable goods producing sector.

Current studies of the business cycle at a disaggregated level usually assume that a sector uses only primary factors of production: capital, labor and land. In this case sectoral output is measured by value-added. Input-output tables, however, show that in any sector payments for intermediate inputs are a substantial fraction of total payments made to inputs. These intermediate goods are produced and used up in production during the accounting period. Unlike labor, intermediate goods are reproducible, and unlike capital, they depreciate completely within the accounting period. In Table 1, we have aggregated the industries of the 1982 U.S. input-output table to a durable and a nondurable goods producing sector. Nondurable goods which are used as intermediate inputs in the durable goods producing sector make up 26 percent of total payments to inputs in this sector. Conversely, payments

[1] An influential review of this literatuer has been Lucas (1977), and recent work with an emphasis on sectoral comovement includes Murphy et al.(1989) and Cooper and Haltiwanger (1990).

[2] The data are described in the appendix, and they are detrended using the Hodrick-Prescott (1981) filter.

for durable goods which are used as intermediate inputs in the nondurable goods producing sector are about four percent of total payments made to inputs in that sector.[3]

A complete study of the role that intermediate inputs play in the business cycle requires observations on gross output and all inputs, including intermediate inputs, for each sector. There is no such complete and consistent data set available.[4] National Income Accounts (NIA) at the sectoral level contain information on value-added and primary factors of production, but they do not contain information on gross output and all inputs. At the current stage of our research we therefore concentrate on the implications of intermediate inputs for the comovement of value-added and primary factors of production.

In standard multi-sector growth models where a sector's production depends only on primary inputs, a change in relative productivity tends to lead to a reallocation of resources towards a sector whose relative productivity has increased and away from a sector whose relative productivity has declined, e.g. Rebello (1987). In our two-sector economy a productivity increase in either sector increases the economy's ability to produce capital goods. For standard intertemporal consumption smoothing reasons investment, that is the production of durable goods, increases. This in turn increases employment in the durable goods sector, and it increases the demand for intermediate inputs, that is nondurable goods. The higher demand for nondurable goods then increases employment in the nondurable goods sector, and employment in both sectors moves together.

The role of the input-output structure in the business cycle has been emphasized before by Long and Plosser (1983). They provide a disaggregated model of the U.S. economy where the output of one sector is an input to other sectors. In their work Long and Plosser do not distinguish between capital and intermediate inputs, and the equilibrium of their economy is characterized by constant employment in each sector over the business cycle.

The economy's input-output structure is not the only possible explanation for the observed comovement of employment and output across sectors. A partial list of alternative explanations includes aggregate monetary disturbances, Lucas (1977), demand spill-overs,

[3] The separation of the economy into durable and nondurable goods producing sectors is not perfect. Since durable goods are capital goods they should not appear as intermediate goods in the nondurable goods sector, also since nondurable goods are perishable they should not appear as final investment demand.

[4] An exception is Jorgenson et al.(1987).

Cooper and Haltiwanger (1990) and Murphy et al.(1989), nonconvexities in production, Cooper and Haltiwanger (1992), home production, Benhabib et al.(1991), or intratemporal adjustment costs to investment, Huffman and Wynne (1995).

The paper is organized as follows. In section two we describe our model economy where nondurable goods serve as intermediate inputs in the production of durable goods. In section three we calibrate the economy, that is we choose parameter values for the economy which are consistent with the long run properties of the U.S. economy. In section four we analyze the dynamic properties of the model economy. In section five we summarize our results and relate them to other work on multi-sector models of open and closed economies.

2. The Economy

Our economy is a two-sector stochastic neoclassical growth model in discrete time. There is a nondurable goods producing sector and a durable goods producing sector. The nondurable good can be consumed or used as an intermediate input in the production of the durable good. The durable good becomes capital and can be used for production in the two sectors or it can provide a direct flow of consumption services in the household sector. Total factor productivity in the two sectors is labor augmenting, has a common deterministic trend and deviations from trend follow a bivariate Markov process. There is also a government which imposes proportional taxes on capital and labor income. These taxes are rebated in a lump-sum fashion.

The use of intermediate inputs is not the only nonstandard feature of our model economy, we also distinguish between household and business capital formation. We make this distinction because we want to focus on the production structure of the economy, and NIA measures of the service flow from household capital are not always available.[5] Therefore we exclude the services provided by household capital from our definition of output in the model economy. On the other hand, we cannot disregard household capital formation because it represents half of all investment expenditures. Thus we offer a model of household

[5] The NIA do contain measures of the service flow from residential housing, but not from household durable goods.

investment.

2.1. The Environment

There is an infinitely lived representative agent which maximizes expected life time utility

$$E\left[\sum_{t=0}^{\infty}\beta^{t}\mathcal{U}\left(c_{t},k_{ht},h_{t}\right)\right], \tag{2.1}$$

with $0<\beta<1$. Period utility $\mathcal{U}$ is increasing in the nondurable consumption good c and the services from the stock of the durable good k_h, decreasing in work effort h, and concave.

There are two production sectors, the nondurable goods $(s=n)$ and the durable goods $(s=d)$ producing sector. Both sectors use capital k_s and labor h_s as inputs. The durable goods sector also uses the nondurable good as an intermediate input m. Each sector's production technology is constant returns to scale in all inputs, and depends on some productivity parameter z_s,

$$\begin{aligned} q_{nt} &= F_{n}\left(k_{nt},z_{nt}h_{nt}\right), \\ q_{dt} &= F_{d}\left[G\left(k_{dt},z_{dt}h_{dt}\right),m_{t}\right]. \end{aligned} \tag{2.2}$$

The production of durable goods is separable with respect to intermediate inputs. We will discuss this assumption in the following section. A nondurable good produced in the current period can be consumed or used as an input to the production of durable goods. The resource constraint for nondurable goods is

$$c_{t}+m_{t}=q_{nt}. \tag{2.3}$$

Durable goods can be invested in either of the two production sectors or the household sector and add to the respective capital stocks in the next period. Total investment is limited by the total production of durable goods,

$$i_{n,t}+i_{d,t}+i_{h,t}=q_{d,t}, \tag{2.4}$$

and the law of motion for capital in the different sectors is

$$k_{s,t+1}=\left(1-\delta_{s}\right)k_{st}+i_{st}, \tag{2.5}$$

where $s = n, d, h$ and $0 < \delta_s < 1$ is the depreciation rate of type s capital. Labor is perfectly mobile across the two production sectors, and total work effort is

$$h_t = h_{nt} + h_{dt}. \tag{2.6}$$

Sectoral productivity grows deterministically at the common rate γ and deviations from trend follow a bivariate AR(1) process with correlated innovations,

$$\ln \mathbf{z}_t = t \ln(1+\gamma) + \ln \tilde{\mathbf{z}}_t, \;\; \ln \tilde{\mathbf{z}}_t = \Lambda \ln \tilde{\mathbf{z}}_{t-1} + \epsilon_t, \tag{2.7}$$

with $\mathbf{z} = [z_n, z_d]$ and ϵ_t is iid normal with mean zero and covariance matrix Ω.

There is also a government which imposes proportional taxes on capital income (net of depreciation) originating in the business sector, and labor income. The tax rates are τ_k and τ_h. The tax revenue is rebated by a lump-sum payment Υ.

2.2. The Competitive Equilibrium

We now define a recursive competitive equilibrium, Stokey et al.(1989). The representative household owns all inputs and rents their services to firms. Firms produce nondurable and durable goods and sell the goods to the household. All markets are competitive. For the equilibrium definition we will differentiate between aggregate and individual state and decision variables. Bold faced letters denote aggregate variables. Aggregate state variables are $\mathbf{x} = [\mathbf{k}_n, \mathbf{k}_d, \mathbf{k}_h]$ and $\mathbf{z}$, and individual state variables are $x = [k_n, k_d, k_h]$. Aggregate decision variables are $\mathbf{y} = [\mathbf{i}_n, \mathbf{i}_d, \mathbf{i}_h, \mathbf{h}_n, \mathbf{h}_d, \mathbf{c}]$, and individual decision variables are $y = [i_n, i_d, i_h, h_n, h_d, c]$. Aggregate and individual state variables evolve according to the transition equations consistent with (**??**) and (**??**), $[\mathbf{x}_{t+1}, \mathbf{z}_{t+1}] = \mathbf{H}(\mathbf{x}_t, \mathbf{z}_t, \mathbf{y}_t)$ and $x_{t+1} = H(x_t, y_t)$.

In a recursive competitive equilibrium prices and decision variables are functions of the relevant state of the world. Let $\mathbf{y} = \mathbf{Y}(\mathbf{x}, \mathbf{z})$ be the aggregate and $y = Y(x, \mathbf{x}, \mathbf{z})$ be the individual decision rule. Normalize the price of the durable good at one. Let $p = [u_n, u_d, w, p_n]$ denote period prices, where u_s is the rental rate of capital in production sector s, w is the wage rate, and p_n the price of the nondurable good. Let $p = P(\mathbf{x}, \mathbf{z}) = [U_n, U_d, W, P_n](\mathbf{x}, \mathbf{z})$ denote prices as functions of the aggregate state, and $\Upsilon(\mathbf{x}, \mathbf{z})$ the lump-sum tax rebate as function of the aggregate state of the economy.

The representative agent's dynamic optimization problem is now defined as follows

$$
\begin{aligned}
V(x, \mathbf{x}, \mathbf{z}) \quad &= \quad \max \quad \{\mathcal{U}(c, k_d, h_n + h_d) + \beta E[V(x', \mathbf{x}', \mathbf{z}')|x, \mathbf{x}, \mathbf{z}]\} \\
&\quad\quad \text{s.t.} \quad P_n(\cdot)c + i_n + i_d + i_h \\
(PH) \quad &\quad\quad\quad\quad \leq [(1-\tau_k) U_n(\cdot) + \tau_k \delta_n] k_n + [(1-\tau_k) U_d(\cdot) + \tau_k \delta_d] k_d \\
&\quad\quad\quad\quad + (1-\tau_h) W(\cdot) [h_n + h_d] + \Upsilon(\cdot), \\
&\quad\quad\quad\quad x' = H(x, y), \text{ and } \mathbf{x}' = \mathbf{H}[\mathbf{x}, \mathbf{z}, \mathbf{Y}(\mathbf{x}, \mathbf{z})].
\end{aligned}
$$

Firms in the nondurable and durable goods sector solve the static profit maximization problems

$$
\begin{aligned}
(PF_n) \quad \pi_n &= \max P_n(\cdot) F_n(k_n, z_n h_n) - U_n(\cdot) k_n - W(\cdot) h_n \\
(PF_d) \quad \pi_d &= \max F_d[G(k_d, z_d h_d), m] - U_d(\cdot) k_d - W(\cdot) h_d - P_n(\cdot) m
\end{aligned}
$$

The durable goods sector's value-added is total payments to primary factors of production, capital and labor, $va_d = wh_d + u_d k_d$. Value-added is the product of a quantity index and a price index, $va_d = p_d^y y_d$. Our assumption with respect to the separability of inputs in the production of durable goods implies that a value-added aggregate exists for this sector, that is real value-added is a function of the primary factors of production and productivity only, e.g. Sato (1976) or Hulten (1978). Empirical work on production functions usually does not confirm the existence of a value-added aggregate, e.g. Berndt and Wood (1975) or Jorgenson et al.(1987). Existing work on sectoral models of the business cycle has proceeded on the assumption that such an aggregate exists. Our point is that even if such an aggregate exists, an explicit analysis of the environment including intermediate goods will improve our understanding of the business cycle.

We are now in a position to define a competitive equilibrium.

Definition 2.1. *A recursive stationary competitive equilibrium is a collection of functions* $Y, \mathbf{Y}, V, P, \Upsilon$ *such that (1) (utility maximization)* V *satisfies the functional equation* (PH)

and Y is the associated optimal policy function, given $\mathbf{Y}$, P, and Υ, (2) (profit maximization) $\mathbf{k}_n, \mathbf{h}_n$ is the optimal policy for (PF_n), and $\mathbf{k}_d, \mathbf{h}_d, \mathbf{m}$ is the optimal policy for (PF_d), given P, and (3) (market clearing) $\mathbf{Y}(\mathbf{x}, \mathbf{z}) = Y(\mathbf{x}, \mathbf{x}, \mathbf{z})$ and $F(\mathbf{k}_n, z_n \mathbf{h}_n) = \mathbf{m} + \mathbf{c}$.

3. Calibration

In this section we provide a parametric specification of our model economy and select parameter values such that the long-run properties of our model economy correspond to the growth path of the postwar U.S. economy. In the absence of stochastic productivity shocks the model economy has a balanced growth path for which employment is constant and consumption, investment, production, and the capital stock grow at the productivity growth rate γ. We are choosing parameter values such that certain ratios which are constant on the model's balanced growth path are equalized with their corresponding average values for the postwar U.S. economy from 1954 to 1992. A complete description of the data set is provided in the appendix. Here we just want to point out that our definition of GDP excludes two components from the usual NIA definition of GDP. First, we exclude rental payments for owner and tenant occupied housing from GDP. These payments are excluded because we do not model the market provision of services from residential housing, rather all housing capital is in possession of the household. Second, we exclude valued-added from the government sector from our definition of GDP, because our focus is on the production structure of the economy.

The preferences of the representative agent are

$$U(c, k_h, h) = \ln \left[\xi c^{\eta} + (1 - \xi) k_h^{\eta}\right]^{1/\eta} - \phi h, \tag{3.1}$$

with $\eta \leq 1$, $0 < \xi < 1$, and $\phi > 0$. We assume that the consumption of nondurable goods and services from the stock of durable goods provides a composite consumption good. The elasticity of substitution between the consumption of nondurable goods and the consumption of services from the durable good is $1/(1 - \eta)$. Following Hansen (1985) we assume that work-time is indivisible and agents can insure against income risk such that preferences are linear in work effort.

The production technology for nondurable and durable goods is described by the functions

$$
\begin{aligned}
q_{nt} &= k_{nt}^{\alpha_n} \left(z_{nt} h_{nt}\right)^{1-\alpha_n}, \\
q_{dt} &= \zeta \left[(1-\mu) \left[k_{dt}^{\alpha_d} \left(z_{dt} h_{dt}\right)^{1-\alpha_d}\right]^{\rho} + \mu m_t^{\rho}\right]^{1/\rho},
\end{aligned}
\tag{3.2}
$$

with $0 < \alpha_n, \alpha_d, \mu < 1$, $\zeta > 0$, and $\rho \leq 1$. We can derive real value-added and the price index for real value-added in the durable goods sector as

$$
\begin{aligned}
y_{dt} &= k_{dt}^{\alpha_d} \left(z_{dt} h_{dt}\right)^{1-\alpha_d}, \\
p_{dt}^{y} &= \left(r_{dt}/\alpha_d\right)^{\alpha_d} \left[w_t/z_{dt} \left(1-\alpha_d\right)\right]^{1-\alpha_d}.
\end{aligned}
\tag{3.3}
$$

The time period in our environment represents a year.[6] During the sample period the economy is growing at an average annual rate of somewhat more than two percent, total value-added was growing at 2.2 percent and value-added in the nondurable (durable) goods sector was growing at 2.2 percent (1.9 percent). We choose a balanced growth rate of 2 percent. The average ratio of investment expenditures to GDP is about 22 percent. Along a balanced growth path the relative price of nondurable goods is constant, and we normalize this relative price to one.[7] Of total investment 39 percent takes place in the nondurable goods sector, 6 percent in the durable goods sector, and 55 percent represents investment in household durables and residential housing. The capital stock in the nondurable (durable) goods sector is about 80 percent (10 percent) of annual GDP, and household capital is about equal to annual GDP. The implied annual depreciation rates for capital in the nondurable, durable and household sector are respectively 9 percent, 11 percent, and 10 percent.

These observations are not sufficient to determine all parameter values. For the time period 1977-92 we observe that the average factor income share of capital in the nondurable (durable) goods sector is about 35 (20) percent, and the business sector average is 27 percent. Although the capital income shares in the two sectors are different we decide to treat value-

[6] Our choice simply reflects the fact that most sectoral data is available only at an annual frequency. This limits our ability to compare our work directly with other related work on the aggregate U.S. business cycle which has focused on the dynamics at a quarterly frequency. In an earlier version of this paper, Hornstein and Praschnik (1994), we have provided an exhaustive analysis of the model at a quarterly frequency. The substantive conclusions are the same for the annual and quarterly model.

[7] We should however note that Greenwood et al.(1997) argue strongly that the relative price of nondurable goods has been increasing over time.

added in both sectors symmetrically and select a capital income share of 30 percent for both sectors. This procedure has the advantage that without intermediate goods there exists a standard one-sector aggregation of the model, Greenwood et al.(1997). We do not have reliable information on the elasticity of substitution between value-added and intermediate goods in the durable goods sector. Work by Jorgenson et al.(1987) appears to show that for most two-digit SIC industries the share of value-added in the value of gross output is independent of the price of intermediate inputs. This indicates an elasticity of one, which we choose. We view this as an upper bound on the elasticity of substitution since Berndt and Wood (1975) find less than unitary elasticity of substitution between capital and energy, which is confirmed by recent work of Woodford and Rotemberg (1996). We do not use information on the actual share of intermediate inputs in the value of gross output, which is about 40 percent, see Table 1. The value implied by our calibration procedure is remarkably close, about 45 percent.

The preference parameters are determined as follows. We select the time preference parameter such that it is consistent with an average annual after-tax rate of return on capital of 5 percent. Information on the elasticity of substitution between nondurable and durable consumption goods is scarce. Eichenbaum and Hansen (1990) suggest that the two goods are perfect substitutes, Benhabib et al.(1991) estimate an elasticity of 2.5. We follow Fisher (1997) who argues for a unit elasticity based on long run observations which show a constant expenditure share for durable goods in the face of a secular decline in the relative price of durable goods.

We now turn to government tax policy. Estimates of effective tax rates vary widely. Lucas (1990) suggests that the average tax on capital and labor income is 36 percent. McGrattan (1994) reports average values for the capital tax rate between 40 and 50 percent, and for the average labor tax rate values between 10 and 25 percent. For the labor income tax we choose a proportional tax of 30 percent. We do not fix the tax rate on capital, as an outcome of our calibration procedure its value is endogenously determined as 80 percent.[8]

[8] Note that in the model economy income on household capital is not taxed. This may be a questionable assumption for the following reasons. First, while there are no taxes on imputed rental income, there are property taxes, and second, we have included commercial rental housing in our definition of household capital and income from commercial rental housing is taxed. We have experimented with a tax rate on income from

Although this tax rate is quite large, it is within the range of 55 to 84 percent reported by Feldstein et al.(1983) for total effective tax rates on capital income in the U.S. from 1953-79. It is necessary to introduce such a high tax rate since we simultaneously want to match the sectoral capital-GDP ratios and the capital income shares. For example, if we set the tax rate to zero and leave all other parameter values unchanged, the implied capital-GDP ratios on the balanced growth paths are more than twice the values we observe for the U.S. economy. All parameter values are now determined except the ones for the productivity process. Table 2 summarizes the values of relevant steady state variables used in the calibration process and the implied parameter values for the model.

We construct total factor productivity measures for each sector using observations on value-added and primary inputs only. Total factor productivity is defined by

$$\ln z_{jt} = \left[\ln y_{jt} - \alpha \ln k_{jt} - (1-\alpha)\ln h_{jt}\right] / (1-\alpha)\,, \text{ and } j = n, d$$

where y_j is real value-added, k_j is the capital stock, h_j is labor, and α is the selected value for the share of value-added paid to capital in the two sectors.[9] In our framework this procedure is justified, since for each sector a value-added aggregate exists and changes in productivity affect only the value-added aggregate. In Figure 2 we plot the time path for the level of productivity in the two sectors and for the aggregate economy. Average productivity growth in the nondurable (durable) goods sector is 1.1 percent (1.8 percent). Figure 2 also shows that there is no obvious trend in relative productivity, and a common trend in sectoral productivity appears to be consistent with observations. Using ordinary least squares we estimate the stochastic process for the log of productivity after a linear trend has been

household capital, which is half the tax rate on business capital income. The results do not differ substantially from our no tax economy.

[9] The results are essentially the same when we use average sectoral capital share values from the sample.

removed as

$$\hat{\Lambda}_{U.S} = \begin{bmatrix} 0.859 & 0.003 \\ (0.070) & (0.035) \\ -0.390 & 0.927 \\ (0.166) & (0.083) \end{bmatrix} \text{ and } \hat{\Omega}_{U.S.} = \begin{bmatrix} 0.020^2 & 0.023^2 \\ 0.023^2 & 0.047^2 \end{bmatrix}$$

with standard deviations in parentheses. Total factor productivity in the durable goods sector is about two and a half times as volatile as in the nondurable goods sector, and the implied correlation coefficient between sectoral productivity innovations is 0.6. We select the following specification for the model's productivity process

$$\Lambda = \begin{bmatrix} 0.9 & 0.0 \\ 0.0 & 0.9 \end{bmatrix} \text{ and } \Omega = \begin{bmatrix} 0.020^2 & 0.025^2 \\ 0.025^2 & 0.050^2 \end{bmatrix}.$$

Our choice for the autocorrelation coefficients is conservative. It is well-known that for an AR(1) process with a high degree of persistence the OLS coefficient estimates are biased downwards in small samples, e.g. Hamilton (1994). This is confirmed by a simple Monte Carlo experiment with the parameterization described above. This experiment shows that while there is no substantial bias in the estimate of the covariance matrix of sectoral productivity innovations, the estimated own autocorrelation coefficients are substantially biased downwards and the coefficient of lagged non-durable productivity in the durable productivity equation is estimated very imprecisely.[10]

4. Findings

In the post-war U.S. business cycle employment, output, labor productivity, and investment in the durable and nondurable goods producing sectors move together, with the durable goods sector being much more volatile than the nondurable goods sector. Our model economy replicates this observed cross-sectoral comovement, and we show that intermediate inputs are crucial for this feature of the model. We also show that the model economy is

[10] The standard deviation on this coefficient is 0.6.

broadly consistent with the observed relative volatilities of the two sectors and the sectoral comovements with aggregate GDP.

A variable's business cycle is defined as the deviation from its long run trend as measured by the Hodrick-Prescott (1981) filter. For our model we solve for an approximation to the competitive equilibrium where decision rules are log-linear functions of the state variables, using an algorithm similar to that described in Hansen and Prescott (1995).[11] We then generate 100 random samples each consisting of 40 periods, that is 40 years, and apply the procedure we have used for the U.S. economy to the random sample.

4.1. Cross-Sectoral Comovement

In Table 3 we report cross-sectoral correlations for employment, value-added, labor productivity, and investment for the U.S. economy and the model. With two exceptions we match the observed cross-sectoral correlation patterns for the U.S. economy quite well. Our model replicates the observed strong contemporaneous correlation for sectoral employment and value-added, and it predicts that household investment leads business investment. The model does not capture the cross-sectoral correlations for labor productivity and investment in the business sector. In the U.S. economy labor productivity in the durable goods sector lags labor productivity in the nondurable goods sector, whereas in the model the contemporaneous correlation is highest. Sectoral investment in the U.S. economy moves together, whereas the model predicts that investment in the durable sector leads investment in the nondurable sector and that the contemporaneous correlation between investment in the business sectors is negative.

We can understand why intermediate inputs generate positive comovement of sectoral employment in our economy by looking at how employment responds to a change in productivity or a change in investment, that is durable goods production. Consider the labor market in the nondurable goods sector. Labor demand is given by the condition that the real wage in terms of nondurable consumption goods is equal to the marginal product of labor in the nondurable goods sector and labor supply is given by the condition that the real wage

[11] A complete description of the algorithm is provided in the appendix of Hornstein and Praschnik (1994).

is equal to the marginal rate of substitution between consumption of nondurable goods and work-time.[12] Figure 3 displays labor demand and supply in the nondurable goods market.

Consider a productivity increase in the nondurable goods sector and assume that production and productivity in the durable goods sector remain unchanged. In the nondurable goods sector this will shift up the labor demand and the labor supply curve, and the real wage increases, see Figure 3. Without intermediate inputs employment will remain unchanged and there will be no further repercussions, in particular employment in the durable goods sector does not respond. With intermediate inputs, nondurable goods employment declines, and the higher real wage means that durable goods employment also declines and the use of intermediate inputs increases. Increased use of intermediate inputs means that less is available for consumption and the labor supply curve shifts down. This dampens the wage and employment movements in the nondurable goods sector somewhat, but employment in both sectors continues to decline. A similar argument shows that without intermediate inputs higher productivity or lower production in the durable goods sector lowers employment in the durable goods sector only, whereas with intermediate inputs it also lowers employment in the nondurable goods sector.

The following sectoral employment elasticities with respect to productivity and investment changes summarize this argument,

$$\begin{aligned}
\hat{h}_n &= \frac{m}{c}\Delta \text{ and } \hat{h}_d = \frac{q_n}{c}\Delta \text{ where} \\
\Delta &= \left[\hat{q}_d - \mu\left(1-\alpha_n\right)\hat{z}_n - \left(1-\mu\right)\left(1-\alpha_d\right)\hat{z}_d\right] / \left[\alpha_n\mu + \frac{q_n}{c}\left[\mu\left(1-\alpha_n\right) + \left(1-\mu\right)\left(1-\alpha_d\right)\right]\right]
\end{aligned}$$

and the hat notation denotes percentage change.

The equilibrium response to a productivity change includes the induced response of investment to a change in productivity. Higher productivity increases the economy's ability to produce capital goods. This occurs either directly when productivity in the durable goods sector increases or indirectly when productivity in the nondurable goods sector increases and less resources are needed to produce intermediate inputs for the durable goods sector.

[12] With the indivisible labor specification, demand for labor in the nondurable goods sector is $w/p_n = \left(1-\alpha_n\right) k_n^{\alpha_n} z_n^{1-\alpha_n} h_n^{-\alpha_n}$ and labor supply is $w/p_n = \left[k_n^{\alpha_n}\left(z_n h_n\right)^{1-\alpha_n} - m\right]\left(1-\gamma\right)/\left[\gamma\psi\left(1-\tau_n\right)\right]$.

For standard consumption smoothing reasons investment then increases and employment in both sectors increases.[13]

Since we attribute positive cross-sectoral comovement to an intermediate input mechanism we would like to have direct observations on the use of intermediate inputs. Unfortunately this information is not available. What we can say is that our explanation is not inconsistent with the observation that the relative price of nondurable goods is pro-cyclical, Greenwood et al.(1997). In Table 4 we report the cyclical behavior of two relative prices, the price of nondurable consumption goods and services relative to the price of producer durable equipment, and the price of value-added in the nondurable goods sector relative to that price in the durable goods sector. The relative price of nondurable goods is indeed procyclical, but note that the relative value-added price of nondurable goods is weakly countercyclical.

Murphy et al.(1989) argue that models in which intermediate inputs transmit productivity shocks are inconsistent with the observed pro-cyclicality of the relative price of nondurables. Their argument involves two points. First, a productivity increase in the durable (nondurable) goods sector represents a positive demand (supply) shock in the market for intermediate goods and should result in an increase (reduction) of the relative price of intermediate goods. Second, they suggest that productivity changes in the nondurable goods sector dominate productivity changes in the durable goods sector. Our model of sectoral comovement is entirely based on intermediate inputs, but we have found that productivity changes in the durable goods sector dominate productivity changes in the nondurable goods sector. In Table 4 we also display the model's contemporaneous correlation of the relative price of nondurable goods with GDP.[14] In the model economy the relative price of nondurables is procyclical because productivity in the durable goods sector is more volatile than in the nondurable goods sector. When there are only productivity shocks in the durable

[13] We can use essentially the same argument as introduced above if we use a divisible labor specification for preferences or if the elasticity of substitution between value-added and intermediate goods is not unitary. Experiments indicate that the cross-sectoral correlation between employment declines as the elasticity of substitution increases. In the previous section we have argued that our choice of a unitary elasticity of substitution represents an upper bound, but even for high substitution elasticities the cross-sectoral employment correlation remains positive, for example for $\rho = 0.5$ the contemporaneous correlation is 0.92.

[14] We do not display the correlation of the relative value-added price for the model because with unitary elasticity of substitution between value-added and intermediate inputs, there is a perfect negative correlation between the relative price of nondurables and the relative value-added price.

(nondurable) goods sector, the relative price of nondurables is procyclical (countercyclical).

The positive cross-sectoral correlation of value-added is supported by the strong cross-sectoral correlation of employment. Since value-added also depends on sectoral productivity and capital stocks which are less correlated than employment, the cross-sectoral correlation between value-added is weaker than the one for employment. Some of the positive comovement of sectoral value-added comes from the fact that productivity innovations are positively correlated. For example, if sectoral productivity is uncorrelated, the contemporaneous correlation for sectoral value-added drops from 0.7 to 0.3.

In the model household and business investment are stronger correlated than in the U.S. economy, but like the U.S. economy household investment is leading the business cycle. Following a productivity increase in either sector, capital becomes more productive and in order to increase the production of capital goods investment in the durable goods sector increases, whereas investment in the nondurable goods sector is postponed for one period. The positive wealth effect of a productivity increase raises household consumption of capital services, and household sector investment increases contemporaneously with the productivity shock. Since investment in the nondurable goods sector represents the bulk of business investment, household investment leads business investment. Recent extensions of the growth model which have addressed household investment, in particular residential housing, have not been successful in explaining this feature of the business cycle, for example Greenwood and Hercowitz (1991) and Fisher (1994). We view it as some success that our work which has not been focused on residential investment nevertheless has household investment leading business investment.

4.2. Relative Volatilities and Comovement with GDP

In the U.S. economy the durable goods sector is more volatile than the nondurable goods sector, and almost all variables are closely correlated with GDP. The model economy replicates and exaggerates the qualitative pattern of relative volatilities, and it also displays very high correlations of almost all variables with GDP. The behavior of intermediate inputs in the model is also consistent with general observations relating to intermediate inputs in the U.S. economy. Table 5 reports volatilities, that is standard deviations of percentage deviations from trend, and contemporaneous correlations with GDP.

In the U.S. economy aggregate employment is about as volatile as aggregate GDP, and aggregate labor productivity is about half as volatile as aggregate GDP. In the model economy both, aggregate employment and labor productivity, are about half as volatile as GDP. This is a feature our model has in common with many other one-sector real business cycle models.[15] The model economy is less volatile than the U.S. economy, GDP in the model is about four fifth as volatile as in the U.S. economy. Again, this is comparable to other one-sector real business cycle models where productivity changes are the only source of fluctuations.[16]

The behavior of the aggregate economy represents a weighted average of the behavior of the durable goods sector and the nondurable goods sector. In the U.S. economy the durable goods sector is more than twice as volatile than the nondurable goods sector. The model economy does capture these differences in relative volatilities for value-added and employment, but it also exaggerates them. For example, value-added (employment) in the durable goods sector is more than five (ten) times as volatile as value-added (employment) in the nondurable goods sector.

The most volatile component of final demand in the U.S. economy is investment in the durable goods sector. This component is about twice as volatile as investment in the nondurable goods sector and one and a half times as volatile as household investment. Total investment in the business sector, however, is less volatile than household investment, since investment in the durable goods sector contributes only one sixth to total investment in the business sector. In the model economy investment in the durable goods sector is also the most volatile component of final demand. Compared with the U.S. economy, investment in the business sector is excessively volatile, and the household purchases of nondurable and durable goods are too smooth. Essentially there are not enough frictions which prevent big changes of the investment volume in the business sector.[17]

[15] Even though we follow Hansen (1985) and introduce a labor indivisibility into the model, employment is not very volatile relative to GDP.

[16] Experiments show that aggregate GDP in the model economy with productivity fluctuations in the durable (nondurable) goods sector only is about 50 (60) percent as volatile as GNP in the baseline model.

[17] An admittedly ad-hoc procedure to improve the performance of the model with respect to the behaviour of investment is to introduce convex adjustment costs to investment. Experiments show that small adjustment costs reduce the volatility of investment in the nondurable and durable goods sector considerably. These adjustment costs also induce a positive contemporaneous comovement of investment in the durable

The model's business cycle is as persistent as the U.S. business cycle, the first order autocorrelation for GDP in the model and in the data is about the same. All variables move with GDP and the highest correlation coefficient is usually the contemporaneous one. Similar to other one-sector growth models with productivity changes as the only source of fluctuations, labor productivity and GDP are more strongly correlated in the model than in the data. This is especially true for the durable goods sector. The sectoral components of business investment are less correlated with GDP than total business investment. This indicates the negative contemporaneous cross-sectoral correlation of investment discussed above.

In the model intermediate inputs are almost perfectly correlated with GDP and somewhat less volatile than value-added in the durable goods sector. As mentioned above we do not have direct observations on the use of intermediate goods in the durable goods sector for the U.S. economy. An analysis of Jorgenson et al.(1987)'s data, however, shows that for most industries the use of intermediate inputs is strongly correlated with gross output, Hornstein (1996).

5. Conclusion

In this paper we have shown that a two-sector stochastic growth model is consistent with positive comovement of employment and output in the durable and nondurable goods producing sector. A crucial element for this result is that nondurable goods serve as intermediate inputs in the production of durable goods. We also observe that measures of total factor productivity show higher productivity fluctuations in the durable goods sector than in the nondurable goods sector. Because of these differential productivity volatilities, the model economy replicates the observed procyclicality of the price of nondurable goods relative to durable goods.

Several unresolved issues remain. For one, we do not explain why productivity shocks in the durable goods sector are so big relative to the shocks in the nondurable goods sector. The study of more disaggregated data could point out the relative contributions of partic-

and non-durable goods producing sectors.

ular industries to productivity fluctuations in the durable and nondurable goods producing sectors. It is unlikely, however, that a multi-sector growth model with a detailed input-output structure can account for these sectoral shocks through the amplification of small independent industry shocks, Dupor (1996). On the expenditure side, we have shown that our model replicates the observation that household investment leads business investment over the business cycle. It remains to be seen how robust this feature is, especially since our model does not account very well for the cyclical behavior of business investment.

Finally, we note that the issue of cross-sectoral comovement of employment and output in a closed economy corresponds to the issue of cross-country comovement of employment and output in open economies. For open economies we observe that the cross-country correlations between output and employment tend to be positive, yet most existing multi-country growth models predict negative correlations, Baxter (1995). Our results for the closed economy suggest that an explicit consideration of trade in intermediate goods will help improve the performance of multi-country growth models, e.g. Costello and Praschnik (1993).

Appendix

The data are taken from the Citibase data set, unless otherwise stated. We use annual data from 1954 to 1992. We use the series on population of the U.S. including armed forces overseas to express all variables in per capita terms. The durable goods sector consists of the construction and the manufacturing durables industries. The nondurable goods sector consists of agriculture, mining, nondurable manufacturing, transportation and utilities, wholesale and retail, finance, insurance and services. We derive output, employment, and capital stock series for each industry and then aggregate (sum) to the two sectors. Aggregate output, employment, and capital is the sum of the sectoral components.

Industry output is value-added or gross product originating (GPO) in constant dollars from BEA. In 1991 BEA revised industry GPO data substantially, and it is now publishing constant 1987 dollar industry GPO data starting 1977, DeLeeuw et al.(1991). To obtain industry output series for the period 1954-1992, we have linked the constant 1982 dollar pre-revision industry GPO series from 1954 to 1976 with the current revised series in 1977. Industry employment is the number of full-time equivalent employees.

Capital stocks are constructed from industry investment data from the BEA, assuming constant geometric depreciation, see Greenwood et al.(1996). Industry business investment covers investment in nonresidential structures plus producers' durable equipment. The annual depreciation rates are 12.4% for equipment and 5.6% for nonresidential structures. For structures we use constant 1987 dollar investment data. For equipment we use current dollar investment data and deflate the series with Gordon (1990)'s equipment price index. The total industry capital stock is the sum of equipment and structures.

To calculate labor's share in value-added we use industry series on compensation of employees, proprietors income, and net indirect taxes (business transfer payments, indirect business taxes, and subsidies) by industry from 1977 to 1992. We calculate labor's share in value-added net of indirect taxes and we also assume that the labor income share in proprietors income is the same as the overall labor income share, Cooley and Prescott (1995).

Consumption covers personal consumption expenditures for nondurable goods and services minus personal consumption expenditures for housing. Household investment covers personal consumption expenditures for durable goods plus investment in residential structures.

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Table 1: Input-output table for the durable and nondurable goods producing sector[a]

Industries / Commodities	Nondurable goods	Durable goods	Final demand	Total output
Nondurable goods	1,683,692 (40.5%)	351,414 (26%) [37.9%]	2,126,037	4,161,143
Durable goods	184,698 (4.4%) [7.5%]	425,023 (31.4%)	743,293	1,353,014
Value-added	2,292,753	576,577	2,869,330	5,514,157

[a] The input-output table has been constructed from the 1982 Benchmark U.S. Input-Output Use Table, Survey of Current Business (1991), Table 2, pp.42–49. Values are millions of dollars at producers' prices. The durable goods sector consists of sectors 11 and 12, 20–23, and 35–64. The nondurable goods sector consists of all other sectors from 1 to 77. We have excluded sectors 78–85, which inludes among others government agencies and enterprises. Percentages in parentheses denote the input's share in payments to all inputs in the sector where the input is used. Square brackets denote the same input share when output is measured net of internal use of goods.

Table 2: Calibration

Steady state values		
Value added share of nondurable goods sector,	y_n/y	0.88
Employment share of nondurable goods sector,	h_n/h	0.88
Investment-GDP ratio,	$(i_n + i_d + i_h)/y$	0.22
Investment shares		
Nondurable goods sector,	i_n/y	0.09
Durable goods sector,	i_d/y	0.01
Household,	i_h/y	0.12
Capital-GDP ratios		
Nondurable goods capital,	k_n/y	0.78
Durable goods capital,	k_d/y	0.10
Household capital,	k_h/y	0.97
Income share of intermediate inputs,	$p_n m/q_d$	0.45
Relative price of nondurables,	p_n	1.00
After-tax rate of return on capital,	r	0.05
Parameter values		
Preferences		
Time preference,	β	0.97
Elasticity of substitution between consumption of durable services and nondurable goods,	$1/(1-\eta)$	1.00
Share of nondurable consumption,	ξ	0.84
Depreciation rate of household capital,	δ_h	0.10
Disutility of work effort,	ϕ	0.11
Technology		
Depreciation of capital in nondurable goods sector,	δ_n	0.09
Depreciation of capital in durable goods sector,	δ_d	0.11
Capital income share in nondurable goods sector,	α_n	0.30
Capital income share in durable goods sector,	α_d	0.30
Scale coefficient,	ζ	2.01
Intermediate input share,	μ	0.45
Elasticity of substitution between intermediate goods and value-added index,	$1/(1-\rho)$	1.00
Growth rate of labor-augmenting technical change,	γ	0.02
Taxes		
Labor income tax,	τ_h	0.30
Capital income tax,	τ_k	0.80

Table 3: Cross-sectoral comovement[a].

	U.S. economy			Model economy		
	s=-1	s=0	s=1	s=-1	s=0	s=1
Value-added	0.35	0.72	0.42	0.45	0.68	0.43
$y_{n,t}$ and $y_{d,t+s}$				(0.17)	(0.12)	(0.15)
Employment	0.61	0.90	0.44	0.69	1.00	0.69
$h_{n,t}$ and $h_{d,t+s}$				(0.08)	(0.00)	(0.08)
Labor productivity	-0.21	0.29	0.60	0.37	0.60	0.32
$y_{n,t}/h_{n,t}$ and $y_{d,t+s}/h_{d,t+s}$				(0.20)	(0.13)	(0.15)
Business investment	0.18	0.68	0.51	0.67	-0.32	-0.20
$i_{n,t}$ and $i_{d,t+s}$				(0.05)	(0.12)	(0.14)
Household investment	0.51	0.20	-0.38	0.93	0.75	0.30
$i_{b,t}$ and $i_{h,t+s}$				(0.02)	(0.07)	(0.16)

[a] The variables are defined in the appendix. The log of a variable is detrended using the Hodrick-Prescott (1981) filter with the smoothing parameter set at 400. For the model economy we provide for each variable the average value of its standard deviation and contemporaneous correlation with aggregate GDP from 100 samples with the respective sample standard deviation in parentheses.

Table 4: Contemporaneous correlations of relative prices with GDP[a]

U.S. economy[b]		Model economy	z_n shocks only	z_d shocks only
p_n	p_n^y/p_d^y	p_n	p_n	p_n
0.48	-0.15	0.51	-0.98	0.92
		(0.18)	(0.00)	(0.02)

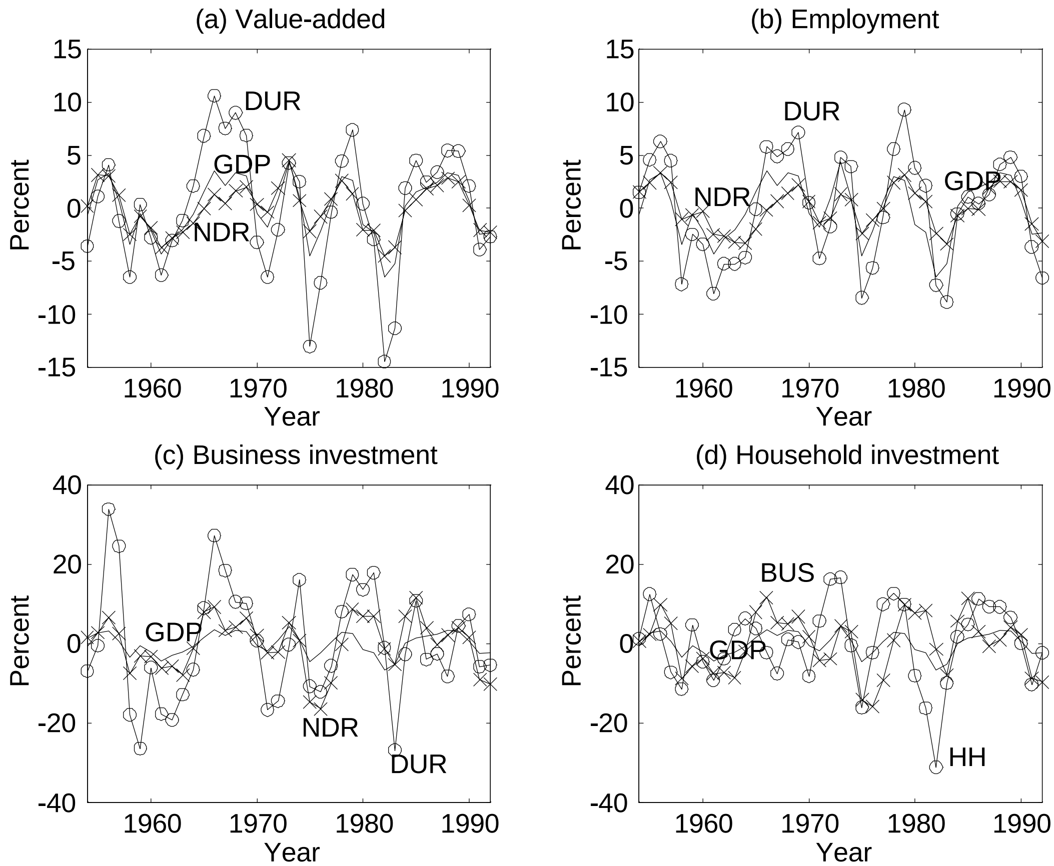
[a] See Table 3, note a.
[b] For the U.S. economy p_n denotes the price of nondurable consumption goods and services relative to the price of producer durable equipment from Gordon (1990), and p_n^y/p_d^y denotes the ratio of value-added deflators for the nondurable goods and durable goods sector.

Table 5: Relative volatilities and comovement with GDP[a]

	U.S. economy		Model economy			
	Standard Deviation	Correlation with GDP[b]	Standard Deviation		Correlation with GDP[b]	
Aggregate production						
GDP	2.75	0.58	2.27	(0.40)	0.62	(0.12)
y						
Employment	2.62	0.83	1.10	(0.22)	0.86	(0.06)
h	[0.95]		[0.49]			
Labor productivity	1.59	0.37	1.44	(0.27)	0.92	(0.03)
y/h	[0.58]		[0.63]			
Durable goods production						
Value-added	5.84	0.91	7.99	(1.50)	0.87	(0.06)
y_d	[2.13]		[3.54]			
Employment	5.01	0.87	5.12	(1.08)	0.85	(0.06)
h_d	[1.82]		[2.26]			
Labor productivity	3.33	0.28	3.12	(0.54)	0.83	(0.08)
y_d/h_d	[1.21]		[1.39]			
Intermediate input			5.84	(1.19)	0.95	(0.02)
m			[2.57]			
Nondurable goods production						
Value-added	2.17	0.94	1.72	(0.32)	0.95	(0.02)
y_n	[0.79]		[0.76]			
Employment	1.97	0.74	0.57	(0.11)	0.86	(0.06)
h_n	[0.72]		[0.25]			
Labor productivity	1.40	0.42	1.40	(0.28)	0.82	(0.07)
y_n/h_n	[0.51]		[0.62]			
Expenditure components						
Investment, total	6.73	0.89	6.96	(1.34)	0.91	(0.04)
i	[2.45]		[3.08]			
Investment, business	7.15	0.66	8.49	(1.71)	0.82	(0.06)
i_b	[2.60]		[3.75]			
Investment, durables	14.41	0.56	34.76	(5.98)	0.46	(0.08)
i_d	[2.24]		[15.58]			
Investment, nondurables	6.64	0.64	10.23	(1.64)	0.56	(0.13)
i_n	[2.42]		[4.55]			
Investment, households	9.81	0.74	6.58	(1.04)	0.87	(0.04)
i_h	[3.57]		[2.93]			
Consumption	1.75	0.85	1.40	(0.28)	0.82	(0.07)
c	[2.45]		[0.62]			

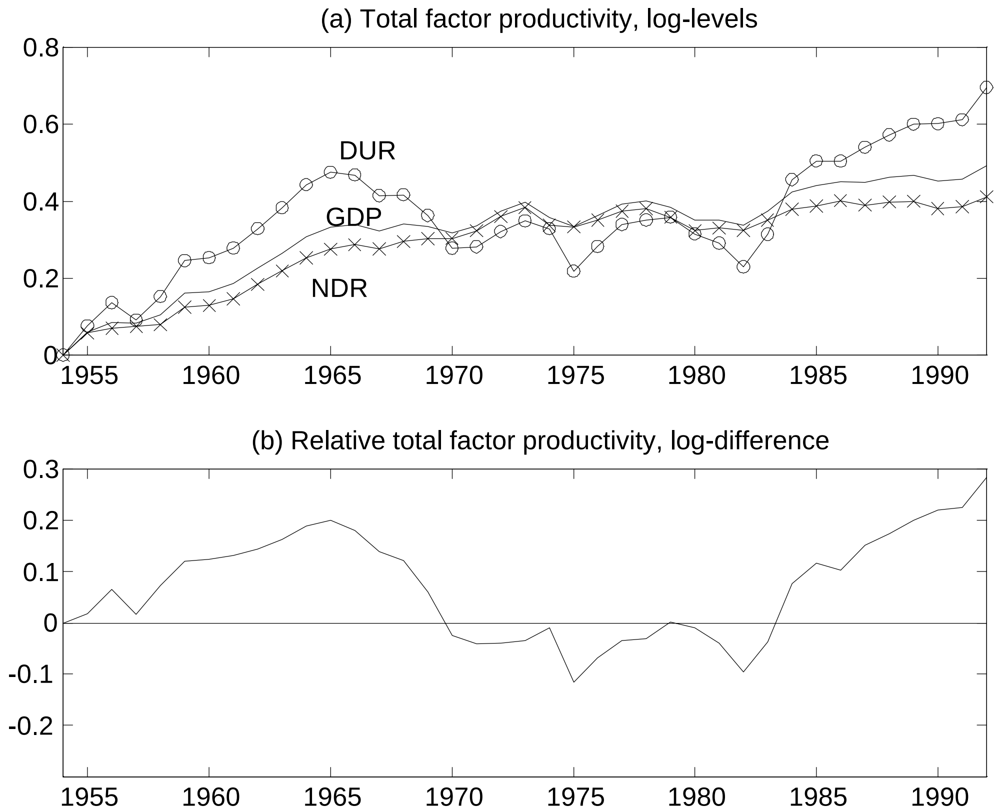
[a] See Table 3, note a. The entries in square brackets are the average values of a variable's standard deviation relative to the standard deviation of aggregate GDP.
[b] The correlation of GDP with GDP denotes the correlation of GDP with lagged GDP.

Figure 1. The sectoral business cycle, U.S. 1954-92.



Note: GDP is aggregate gross domestic product in all graphs. DUR ($\circ$) denotes the durable goods sector, NDR ($\times$) denotes the nondurable goods sector, BUS ($\times$) denotes investment in the durable and nondurable goods sector, and HH ($\circ$) denotes household investment.

Figure 2. Sectoral total factor productivity, U.S. 1954-92.



Note: GDP denotes the aggregate economy, DUR ($\circ$) denotes the durable goods sector, and NDR ($\times$) denotes the nondurable goods sector.

Figure 3. The labor market in the nondurable goods sector .