The Business Cycle and Industry Comovement

Andreas Hornstein

The U.S. economy, as of the writing of this article, is in its longest postwar expansion. This expansion has prompted various proponents to declare a "new" economy and the death of the business cycle. These pronouncements may well turn out to be premature, as similar announcements have proved in the past. In this case we can already say that the current expansion shares one feature with all previous business cycles, namely that all parts of the economy take part in the expansion, although possibly to different degrees. In particular, although the symbol of the "new" economy appears to be the Internet, a general expansion of all industries in the manufacturing and the service sector accounts for the growth in GDP. Indeed, it is the general up and down movement of all parts of the economy that defines the business cycle in Burns and Mitchell's (1946) early work.

In contrast to this earlier work, modern business cycle research has focused for the most part on the comovement of aggregate variables, like output, employment, consumption, investment, the price level, interest rates, etc. In part, the focus on the aggregate economy has been justified by the observed comovement, which is supposed to indicate the presence of common aggregate disturbances to which all parts of the economy respond in a similar way. The argument for aggregate shocks as the source of business cycles proceeds as follows (Lucas 1977). Suppose the economy is subject to a large number of industry-specific disturbances which are unrelated to each other. Then we would expect that these disturbances change the relative productivities of various inputs such as labor. This change in relative productivities, in turn, should lead to a reallocation of inputs. That is, input use should decline in industries with falling relative productivities and should increase in industries with

Andreas.Hornstein@rich.frb.org. I would like to thank Yash Mehra, Pierre Sarte, and John Weinberg for helpful comments. The views expressed are the author's and not necessarily those of the Federal Reserve Bank of Richmond or the Federal Reserve System.

rising relative productivities. What we actually observe, however, is the opposite outcome; therefore we should conclude that the business cycle is not due to unrelated industry disturbances, but rather to aggregate disturbances that affect all sectors of the economy. One natural candidate for an aggregate disturbance is, of course, monetary policy. Given the current economic expansion, which appears to be driven to some extent by the widespread application of computer technology, aggregate productivity shocks are also a possibility.

In this article, I argue that industry comovement is an important defining characteristic of the business cycle, and that current economic theory has difficulties accounting for this characteristic. I first document the pattern of industry comovement for inputs and outputs. I then discuss a simple extension of the standard aggregate business cycle model to make two points. First, I formalize the argument against unrelated industry disturbances as the cause of business cycles. Second, I point out that even if there are only aggregate disturbances, one should not necessarily expect that all sectors of the economy respond in the same way to these disturbances. Finally, I provide some evidence on the extent to which the economy is subject to aggregate productivity disturbances.

1. COMOVEMENT IN THE U.S. ECONOMY

Industry comovement over the business cycle means that the level of activity in different industries increases and decreases together. There are various ways to measure the activity level of an industry. One method is to ask how many inputs are used or how many goods are produced in an industry. For this article, I use data from Jorgenson, Gollop, and Fraumeni (1987), who provide annual series on inputs and outputs at the two-digit industry level. Their data set covers prices and quantities for industry gross output and use of capital services, labor, materials, and energy for the years 1950-1991.[1] I will show that, for almost all measures of activity, industries move together over the business cycle. This result confirms previous work by Christiano and Fitzgerald (1998), who study the comovement of quarterly two-digit industry employment, and Murphy, Shleifer, and Vishny (1989), who study annual one-digit industry value added and employment.

In addition to short-term business cycle fluctuations, most economies are characterized by substantial structural change over time. This change means that some industries are growing, and their production and use of resources is increasing over time relative to other industries such as services or the financial industries. Likewise, other industries' contribution to the economy is declining,

[1] The data used here are taken from Jorgenson's Web page at http://www.economics.harvard.edu/faculty/jorgenson/data.html. All industries of the data set are included, except agriculture (1) and government enterprises (36).

such as textiles. Since I am not interested in the long-run secular changes of industries, I remove this trend component by using a band pass filter.[2]

I study the comovement of industries using two different measures. For the first measure, I consider the comovement of industry variables with their corresponding aggregate counterparts, for example the comovement of industry employment with aggregate employment. For the second measure, I consider cross-industry comovement directly, for example the pairwise industry employment correlations. I find that in almost all industries employment is positively correlated with aggregate employment and that this relationship is quite tight. Furthermore, the same positive comovement of industry variables with aggregate variables occurs for all other output and input measures, such as gross output, value-added, capital services, employment, and intermediate inputs. For pairwise cross-industry correlations, positive correlations are also much more frequently observed than negative correlations. Finally, the positive comovement pattern does not only apply to the manufacturing sector but also to the service sector and the construction industry. Only the mining sector has several industries which do not move in step with the rest of the economy.

In order to study the comovement of industry series with aggregate series, I construct aggregate quantities as Divisia indices using the price and quantity industry series. A Divisia index is a way to weight the contribution of individual series to the aggregate series. Suppose we have a collection of goods with prices and quantities for different time periods $\{q_{it}, p_{it} : i = 1, \ldots, N$ and $t = 1, \ldots, T\}$; then we define the growth rate of the aggregate quantity index between periods t and $t+1$ as the weighted sum of the growth rates of the individual series

$$\Delta \ln q_t = \sum_{i=1}^{N} \bar{\omega}_{it} \Delta \ln q_{it},$$

where an individual series' weight is its average value share $\bar{\omega}_{it} = 0.5(\omega_{i,t+1} + \omega_{i,t})$ and $\omega_{i,t} = p_{i,t}q_{i,t}/\sum_{j=1,N} p_{j,t}q_{j,t}$. I use this method to construct aggregate input and output series from the industry series and to construct for each industry an intermediate goods index from the materials and energy use series. For each industry, I also construct a value-added quantity index (Sato 1976). Value added of an industry is the total value of payments that goes to primary factors of production: capital and labor. Alternatively, value added represents the industry's value of production after deducting payments for inputs, which have been purchased from other industries in the current accounting period, namely intermediate inputs.

[2] I identify the components of a time series with periodicity less than or equal to eight years with the business cyle. The band pass filter which extracts the business cycle component is approximated by a symmetric moving average with four leads and lags. For a description of band pass filters, see Hornstein (1998) or Christiano and Fitzgerald (1998).

Comovement of Sectoral Variables with Aggregate Variables

The results for the comovement of industry variables with aggregate variables are displayed in Tables 1a and 1b. Table 1a displays whether an industry series increases or decreases when its corresponding aggregate series increases. Most industry series move contemporaneously with their aggregate counterpart, but I want to allow for the possibility that an industry series is leading or lagging the aggregate series. For this purpose, Table 1a displays the correlation which is maximal in absolute value among the contemporaneous, once-lagged and once-led correlations. In Table 1b, I provide a measure of how tight the relation between the industry and the aggregate economy is. For this purpose I regress the industry series on one lagged value, one leading value, and the contemporaneous value of the aggregate series. Table 1b then displays the R^2 of this regression, that is the variation of the industry series explained by variation of the aggregate series through this regression equation. The higher is the R^2, the tighter is the fit between the industry and the aggregate series.

Industry employment in the manufacturing sector moves with aggregate employment, as Table 1a demonstrates. The correlation between industry and aggregate employment in the manufacturing sector (industries 7 through 27) are all positive, and almost all of them are contemporaneous and quite high, at least 0.4 or higher. Furthermore, as we can see from Table 1b, the relationship between the industry and the aggregate series are quite tight with R^2s of at least 0.4. The main exceptions are tobacco (8), petroleum and coal (16), and food (7), industries where employment is not closely related to the aggregate economy.[3] Notice that these are industries which are subject to shocks exogenous to the aggregate economy, like weather or world oil markets, and whose contribution to the aggregate economy is limited.

The close relation between industry and aggregate variables also holds for other inputs and outputs. With few exceptions, industry gross output, value added, use of intermediate goods, and capital services are all positively correlated with the corresponding aggregate variables. The exceptions concern tobacco (8), leather (18), apparel (10), lumber and wood (11), petroleum and coal (16), primary metals (20), and transportation equipment (25). To the extent that an industry variable declines when the aggregate increases, the relationship tends to be quite weak, with R^2s less than 0.2. Only the use of capital services in primary metals (20) has a strong negative correlation with a high R^2. These results are consistent with Murphy, Shleifer, and Vishny (1989).

The evidence for industry comovement with aggregate variables is not limited to the manufacturing sector. We also find strong evidence for the service sector and the construction industry. Employment in service sector industries

[3] This evidence confirms Christiano and Fitzgerald's (1998) analysis of employment in the manufacturing sector with monthly data.

Table 1a Maximal Correlation of Industry Series with Aggregate Series

Sector	*q*	*y*	*k*	*l*	*x*	*m*	*e*
2 Metal mining	0.53	0.44	-0.13^{+}	0.44	0.41	0.39	0.57
3 Coal mining	-0.31^{+}	0.51	−0.13	0.30	-0.51^{+}	-0.52^{+}	-0.35^{+}
4 Oil and gas extraction	0.47	0.73	0.30	-0.48^{+}	-0.56^{+}	-0.57^{+}	0.19^{+}
5 Non-metallic mining	0.66	0.72	0.25^{-}	-0.31^{+}	0.28	0.29	0.47
6 Construction	0.74	0.61	0.32	0.70	0.74	0.74	0.67
7 Food	0.45	0.44	0.31	0.29^{+}	0.20^{-}	0.21^{-}	0.26^{-}
8 Tobacco	-0.21^{+}	0.38	-0.24^{+}	0.19	−0.32	−0.33	-0.30^{-}
9 Textile mill products	0.78	0.46^{+}	0.58	0.66	0.82	0.83	0.64
10 Apparel	0.72	0.67	-0.43^{-}	0.52	0.55	0.54	0.57
11 Lumber and wood	0.72	−0.30	0.43	0.77	0.75	0.74	0.68
12 Furniture and fixtures	0.93	0.90	0.70	0.84	0.87	0.87	0.76
13 Paper and allied	0.78	0.75	0.62	0.69	0.62	0.62	0.62
14 Printing	0.70	0.69	0.67	0.50	0.62	0.62	0.54
15 Chemicals	0.92	0.77	0.72	0.77	0.73	0.72	0.50
16 Petroleum and coal	0.53	0.62^{+}	0.50	0.37^{+}	0.50	-0.31^{+}	0.70
17 Rubber and misc. plastics	0.88	0.78	0.31	0.85	0.84	0.85	0.60
18 Leather	-0.30^{-}	−0.39	0.60	0.46	0.63	0.63	0.65
19 Stone, clay, and glass	0.92	0.89	0.75	0.84	0.87	0.87	0.75
20 Primary metal	0.90	0.75	-0.67^{+}	0.65	0.89	0.90	0.69
21 Fabricated metal	0.93	0.88	0.76	0.86	0.89	0.89	0.77
22 Machinery, non-electrical	0.79	0.79	0.75	0.86	0.75	0.75	0.69
23 Electrical machinery	0.86	0.84	0.72	0.88	0.86	0.86	0.73
24 Motor vehicles	0.78	0.77	0.66	0.79	0.77	0.77	0.65
25 Transportation equipment	0.40^{-}	0.49^{-}	0.64^{-}	0.62	0.33^{-}	0.32^{-}	-0.22^{+}
26 Instruments	0.70	0.73	0.76	0.67	0.55	0.55	0.54
27 Misc. manufacturing	0.73	0.65	0.46	0.47	0.65	0.64	0.65
28 Transportation	0.88	0.75	0.61	0.84	0.90	0.91	0.78
29 Communications	0.43	-0.45^{+}	0.33	0.55	0.56	0.56	0.35
30 Electric utilities	0.71	0.66	0.17^{+}	0.58^{-}	0.18	0.15	0.45
31 Gas utilities	-0.29^{+}	-0.57^{+}	0.38	0.66	0.41^{+}	-0.24^{-}	0.55
32 Trade	0.79	0.82	0.82	0.81	0.62	0.62	0.57
33 FIRE	0.41^{+}	0.22^{+}	0.75	0.24^{-}	0.49^{+}	0.47^{+}	0.37^{+}
34 Services	0.69	0.71	0.72	0.74	0.47	0.46	0.58

Note: The industry series are gross output q, value-added y, capital k, employment l, intermediate input aggregate x, materials m, and energy e. A correlation is the maximal correlation in absolute value of the contemporaneous, one-period lagged, and one-period leaded correlation between the industry variable z_i and the corresponding aggregate variable $\bar{z}$, $corr[z_{i,t}, \bar{z}_{t+s}]$ with $s = 1, 0, -1$. A plus (minus) superscript denotes that the industry variable is leading (lagging) the aggregate variable, that is $s = 1$ ($s = -1$). No superscript indicates that the contemporaneous correlation is maximal.

(28-34) and construction (6) tends to show a strong positive correlation with aggregate employment above 0.5, and the relationship tends to be quite tight, with R^2 above 0.5. Finance, insurance, and real estate (FIRE) (33) is the only industry where employment is not tightly correlated with aggregate employment.

Table 1b R^2 from Regression of Industry Series on Aggregate Series

Sector	*q*	*y*	*k*	*l*	*x*	*m*	*e*
2 Metal mining	0.50	0.33	0.04	0.23	0.26	0.24	0.38
3 Coal mining	0.20	0.28	0.05	0.18	0.25	0.27	0.15
4 Oil and gas extraction	0.34	0.61	0.15	0.35	0.34	0.37	0.05
5 Non-metallic mining	0.60	0.68	0.12	0.14	0.16	0.14	0.31
6 Construction	0.78	0.60	0.09	0.58	0.81	0.80	0.65
7 Food	0.25	0.41	0.06	0.16	0.08	0.09	0.09
8 Tobacco	0.12	0.22	0.08	0.07	0.20	0.19	0.13
9 Textile mill products	0.85	0.21	0.35	0.57	0.89	0.89	0.48
10 Apparel	0.65	0.50	0.31	0.43	0.48	0.46	0.40
11 Lumber and wood	0.79	0.12	0.19	0.70	0.84	0.83	0.63
12 Furniture and fixtures	0.90	0.83	0.60	0.80	0.84	0.83	0.61
13 Paper and allied	0.69	0.61	0.51	0.57	0.51	0.50	0.39
14 Printing	0.61	0.55	0.41	0.25	0.55	0.56	0.33
15 Chemicals	0.85	0.65	0.49	0.74	0.62	0.62	0.29
16 Petroleum and coal	0.35	0.40	0.20	0.12	0.36	0.21	0.60
17 Rubber and misc. plastics	0.81	0.64	0.33	0.83	0.78	0.78	0.50
18 Leather	0.19	0.21	0.43	0.53	0.57	0.58	0.49
19 Stone, clay, and glass	0.86	0.80	0.61	0.74	0.84	0.84	0.65
20 Primary metal	0.92	0.64	0.50	0.44	0.89	0.90	0.54
21 Fabricated metal	0.93	0.81	0.53	0.76	0.87	0.88	0.61
22 Machinery, non-electrical	0.88	0.82	0.63	0.82	0.83	0.83	0.63
23 Electrical machinery	0.82	0.83	0.52	0.81	0.77	0.76	0.65
24 Motor vehicles	0.74	0.73	0.50	0.80	0.71	0.71	0.54
25 Transportation equipment	0.34	0.37	0.42	0.54	0.31	0.30	0.24
26 Instruments	0.67	0.70	0.57	0.60	0.45	0.45	0.43
27 Misc. manufacturing	0.60	0.47	0.32	0.33	0.51	0.49	0.51
28 Transportation	0.82	0.62	0.37	0.75	0.84	0.85	0.62
29 Communications	0.34	0.25	0.20	0.59	0.35	0.35	0.26
30 Electric utilities	0.56	0.47	0.06	0.54	0.06	0.03	0.20
31 Gas utilities	0.17	0.36	0.18	0.60	0.24	0.13	0.33
32 Trade	0.76	0.79	0.72	0.65	0.51	0.50	0.32
33 FIRE	0.25	0.07	0.56	0.16	0.35	0.35	0.24
34 Services	0.52	0.60	0.53	0.60	0.29	0.29	0.38

Variables other than employment also increase and decrease with their aggregate counterparts. Only for communications (29) and gas utilities (31) do we observe some negative comovement, but the relationship is not very strong, as the low R^2s indicate. Mining is the only sector which does not always increase and decrease with the rest of the economy. In particular, coal mining (3) and oil and gas extraction (4) are not synchronized with the aggregate economy.

Construction, manufacturing, and services contribute about 95 percent to private sector value added and employ almost all labor in that sector. Thus, for the majority of the U.S. economy's industries, gross output, value added, the use of capital services, employment, and intermediate inputs tend to increase and decrease with their aggregate counterparts.

Comovement of Variables Across Sectors

Not only do individual industries move with the aggregate economy, but there is also strong evidence that industries move together individually.[4] Tables 2a through 2d and Figures 1 through 4 display some of the evidence on the pairwise comovement between industries. Even for a small number of industries, there exists a large number of possibilities to pair any two of these industries. I represent this information in two ways. In Tables 2a through 2d, I show the quartile and average values for the pairwise maximal correlations. In Figures 1 through 4, I show the histograms for the maximal and contemporaneous pairwise correlations.

Consider the manufacturing sector. As seen in Figure 1 and Table 2a, the pairwise correlations for industry inputs and outputs are predominantly positive and quite high. Gross output, employment, and energy use display a consistent and strong positive correlation across industries. The average correlation coefficient is about 0.5, and more than three-fourths of all industries are positively correlated with each other. Capital services are less strongly correlated, and there is a relatively high number of negative correlations for value added and material use, especially for maximal correlations. The average correlation coefficient for these variables remains positive, about 0.3.

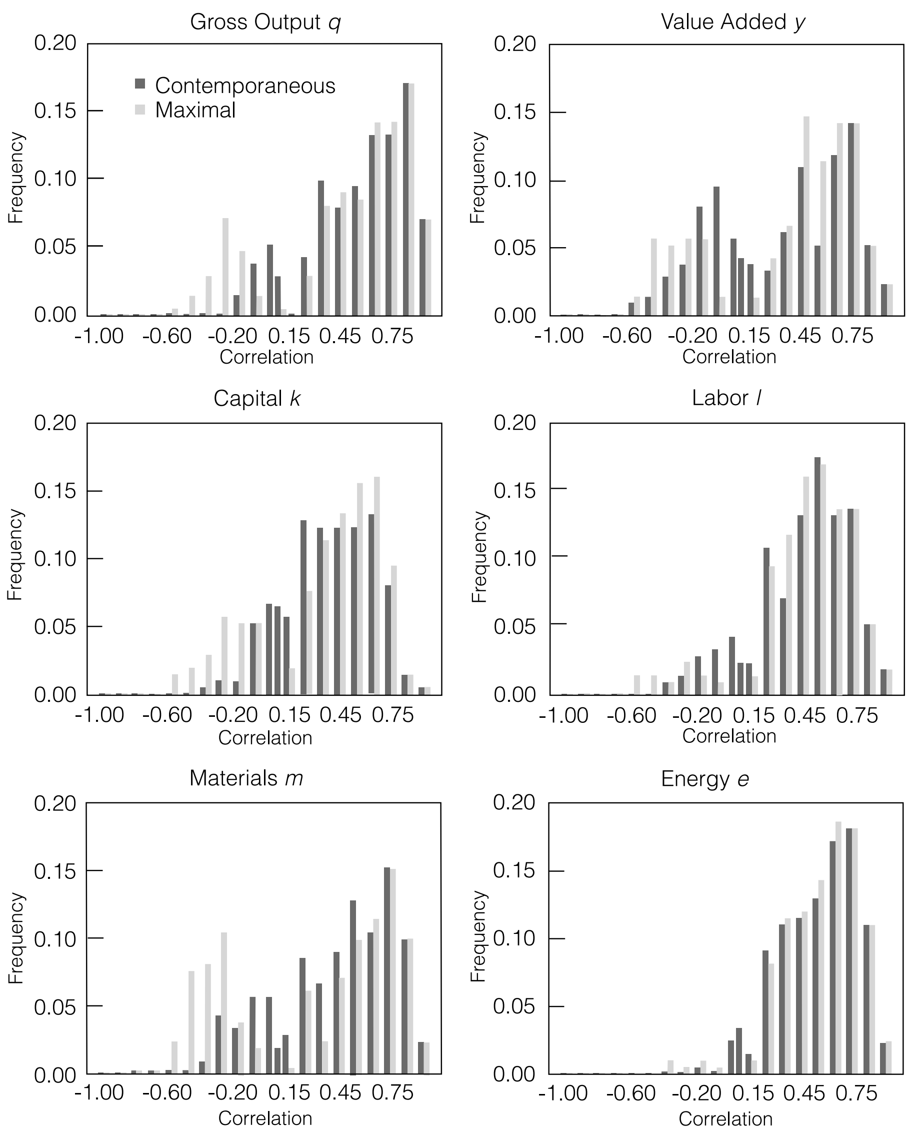
As noted previously, the manufacturing sector industries that produce durable goods tend to be more closely related than those that produce nondurable goods (Christiano and Fitzgerald 1998).[5] Figures 2 and 3 and Tables 2b and 2c confirm this observation. For more than three-fourths of all industries in the durable goods manufacturing sector, we find that all output and input measures are positively correlated across industries, the average correlation coefficient being about 0.5. In the nondurable goods manufacturing sector, employment, energy, and gross output display consistent positive correlations across industries, while value added, capital use, and especially material use show a number of negative correlations. The negative correlations are mainly due to one industry, tobacco (8), which as already noted above is not that tightly related to the aggregate economy.

Finally, consider the cross-industry correlation pattern for the private business sector, excluding mining, summarized in Figure 4 and Table 2d. As we can

[4] It is useful to study the comovement of individual industries for the following reason. An aggregate series is the sum of sectoral series. Therefore, even if the sectoral series are independent of each other, we would observe that each individual series is positively correlated with the aggregate series since it is perfectly correlated with its own contribution to the aggregate series.

[5] Another difference between the nondurable goods and the durable goods sector is that output and input use tends to be more volatile for industries in the latter sector.

Figure 1 Frequency Distribution of Cross-Industry Correlations for All Manufacturing Industries



see, cross-industry correlations for employment, capital services, energy use, and gross output are consistently positive, whereas the pattern is somewhat weaker for value added and materials use. Again, the negative correlations we observe can be attributed to a small number of industries. For gross output,

Table 2a Manufacturing Sector: Maximal Cross-Correlations

	q	*y*	*k*	*l*	*x*	*m*	*e*
Minimum	−0.64	−0.58	−0.59	−0.60	−0.62	−0.63	−0.40
1st Quartile	0.30	−0.15	0.15	0.28	−0.26	−0.30	0.35
Median	0.56	0.44	0.40	0.47	0.48	0.43	0.55
3rd Quartile	0.74	0.61	0.56	0.61	0.66	0.66	0.68
Maximum	0.94	0.90	0.87	0.91	0.91	0.91	0.90
Average	0.44	0.30	0.30	0.41	0.29	0.25	0.51

Note: For notation see Table 1a.

Table 2b Manufacturing Sector: Nondurable Goods, Maximal Cross-Correlations

	q	*y*	*k*	*l*	*x*	*m*	*e*
Minimum	−0.29	−0.58	−0.44	−0.58	−0.60	−0.62	0.09
1st Quartile	0.25	−0.25	−0.15	0.22	−0.35	−0.40	0.32
Median	0.47	0.29	0.25	0.33	−0.11	−0.21	0.42
3rd Quartile	0.66	0.49	0.40	0.49	0.60	0.59	0.60
Maximum	0.89	0.90	0.67	0.91	0.84	0.84	0.88
Average	0.40	0.19	0.16	0.32	0.10	0.05	0.46

Note: For notation see Table 1a.

Table 2c Manufacturing Sector: Durable Goods, Maximal Cross-Correlations

	q	*y*	*k*	*l*	*x*	*m*	*e*
Minimum	−0.53	−0.42	−0.56	−0.45	−0.57	−0.56	−0.40
1st Quartile	0.55	0.40	0.42	0.49	0.42	0.41	0.52
Median	0.67	0.59	0.54	0.61	0.60	0.60	0.62
3rd Quartile	0.78	0.71	0.62	0.70	0.72	0.72	0.74
Maximum	0.91	0.89	0.87	0.88	0.88	0.88	0.90
Average	0.53	0.45	0.48	0.57	0.43	0.43	0.58

Note: For notation see Table 1a.

most of the negative correlations are accounted for by tobacco (8) and gas utilities (31). For value added, most of the negative correlations are accounted for by leather (18), lumber and wood (11), and gas utilities (31).

Figure 2 Frequency Distribution of Cross-Industry Correlations, Nondurable Goods Only

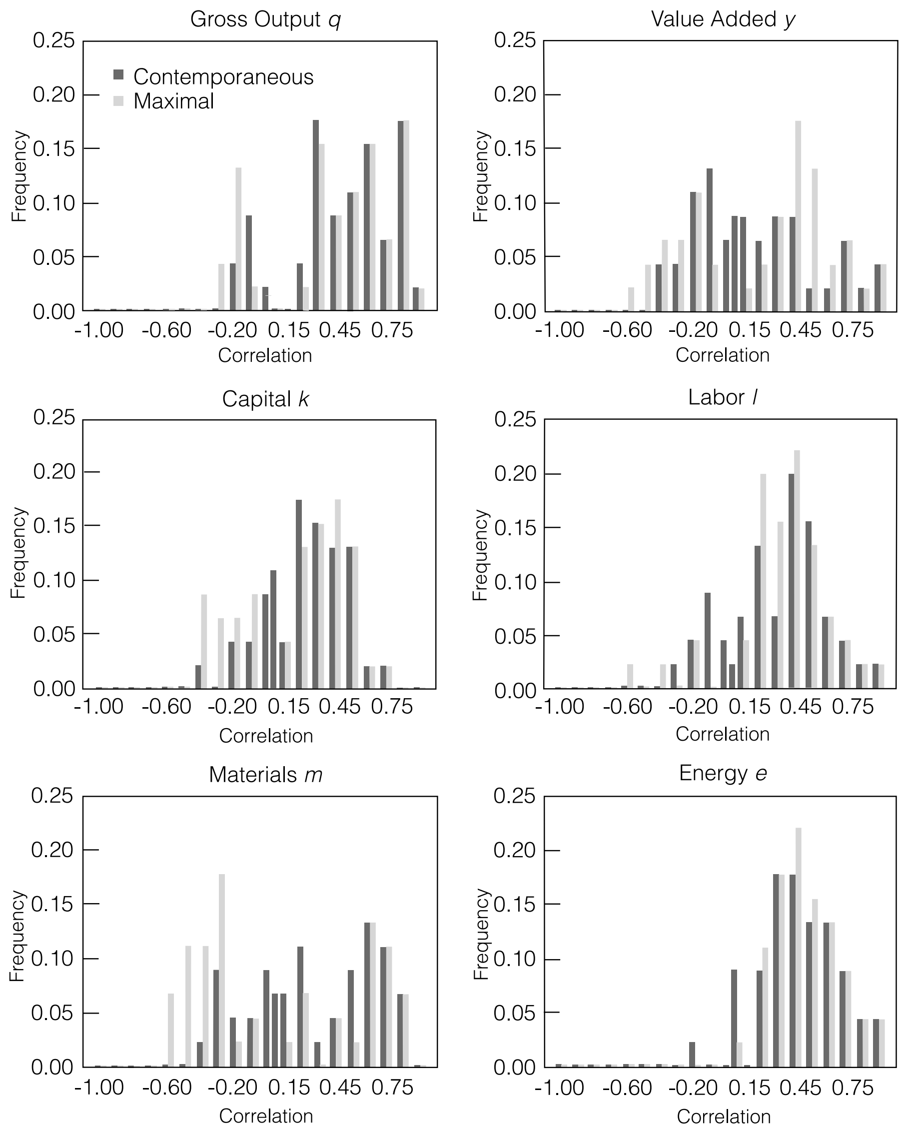


Figure 3 Frequency Distribution of Cross-Industry Correlations, Durable Goods Only

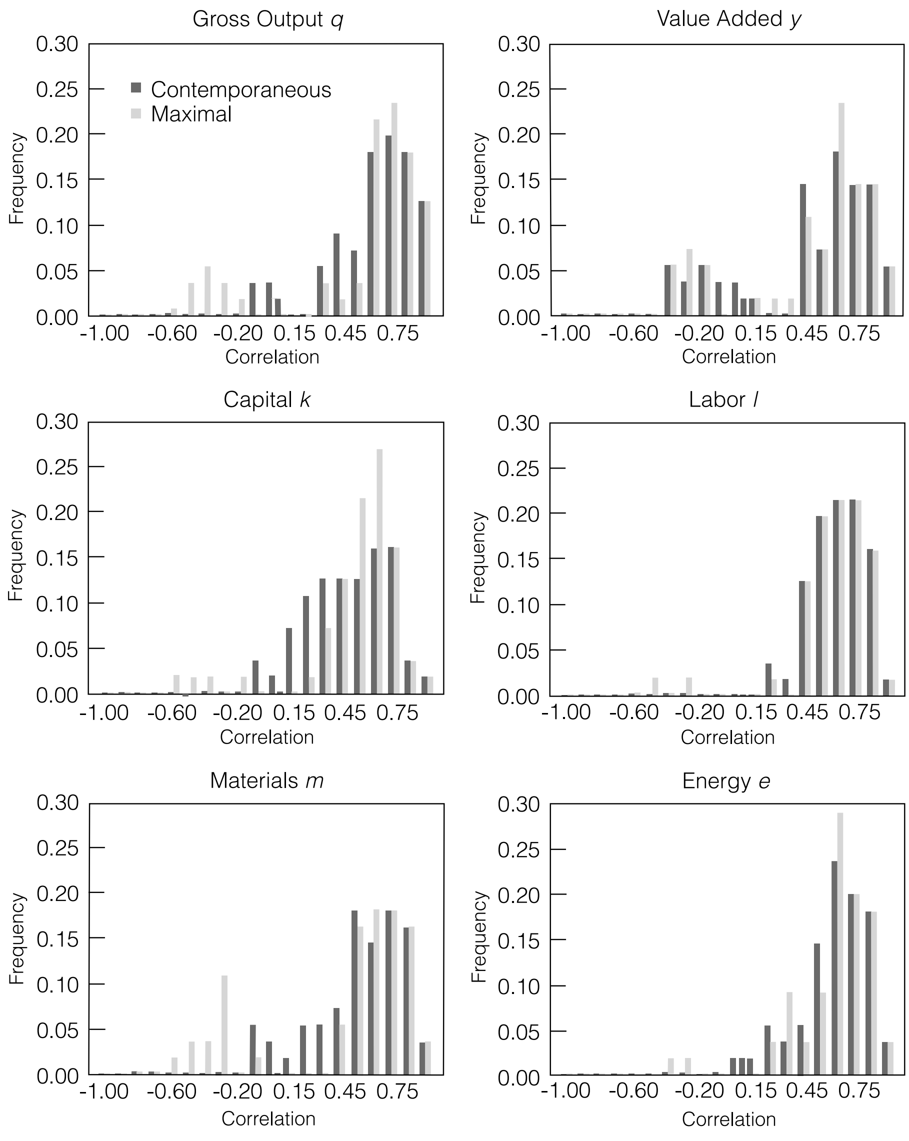


Figure 4 Frequency Distribution of Cross-Industry Correlations for All Industries, Except Mining

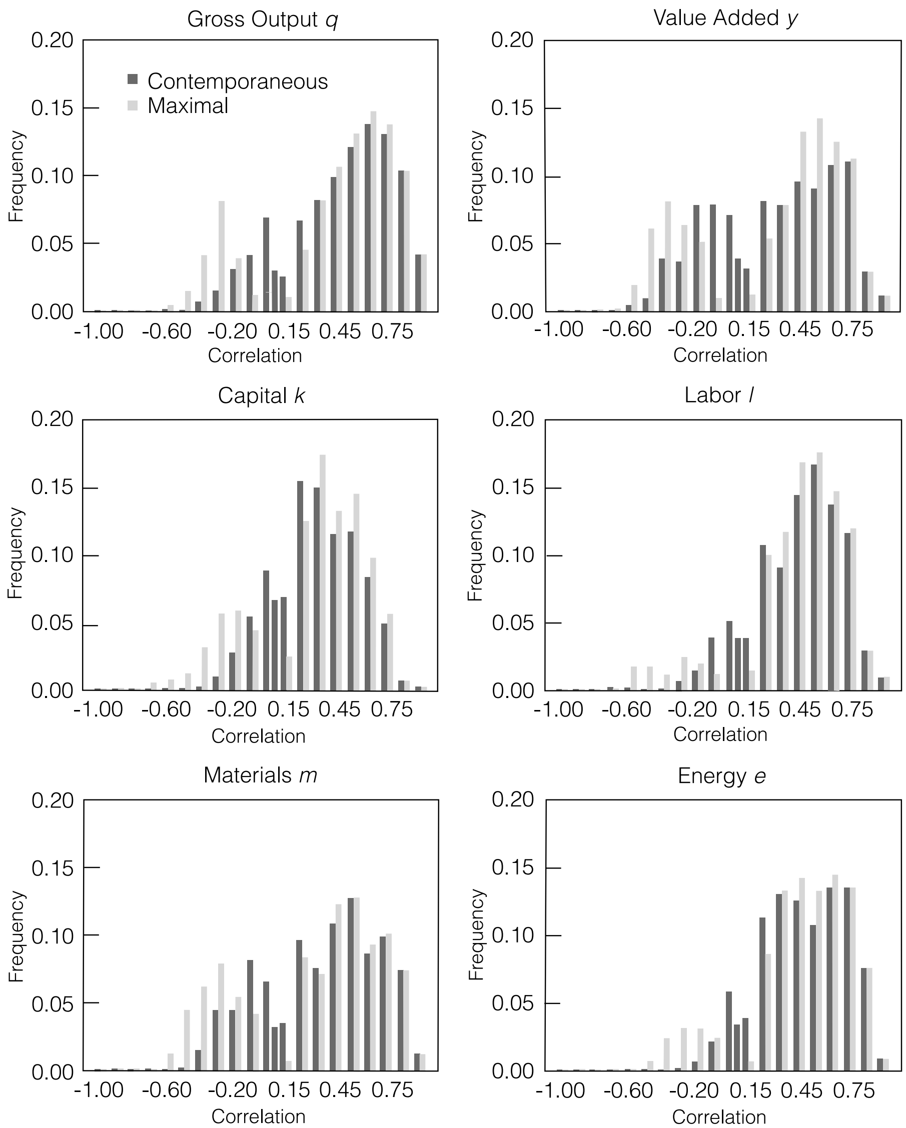


Table 2d All Industries Except Mining: Maximal Cross-Correlations

	q	*y*	*k*	*l*	*x*	*m*	*e*
Minimum	−0.64	−0.72	−0.72	−0.64	-0.62	-0.63	-0.49
1st Quartile	0.25	−0.21	0.14	0.27	0.13	−0.15	0.28
Median	0.51	0.39	0.32	0.44	0.41	0.38	0.45
3rd Quartile	0.67	0.57	0.49	0.59	0.59	0.58	0.62
Maximum	0.94	0.90	0.87	0.91	0.91	0.91	0.90
Average	0.39	0.24	0.25	0.38	0.30	0.26	0.40

Note: For notation see Table 1a.

2. COMOVEMENT IN TWO SIMPLE DYNAMIC GENERAL EQUILIBRIUM MODELS

In this section, I discuss why the observed comovement of inputs and outputs across industries is difficult to reconcile with the basic business cycle model. First, I describe a simple model where labor is the only input to production, and where permanent changes in productivity do not affect employment. For a two-sector version of this economy, I then formalize the argument that changes in relative productivities cause sectoral employment to move in opposite directions. Finally, I discuss a two-sector interpretation of the neoclassical growth model. In this model, employment in the consumption and investment goods sectors move in opposite directions following an aggregate shock that affects production equally in the two sectors.

A Simple Model of Production and Employment

Consider the following simple economy. There are two goods, consumption c and labor n. Labor is used to produce the consumption good

$$c = zn^{\alpha},$$

with $0 < \alpha \leq 1$, and z is labor productivity. Output is produced under conditions of constant returns to scale if $\alpha = 1$. A representative agent has a fixed labor endowment of 1 which can be supplied as labor or used as leisure l, $n + l = 1$. Preferences over consumption and leisure are

$$u(c, l) = \frac{[cl^{\gamma}]^{1-\sigma} - 1}{1 - \sigma}, \tag{1}$$

with $\sigma, \gamma \geq 0$. The competitive equilibrium of this economy is Pareto-optimal. For this setup, Pareto-optimality means that the equilibrium allocation of consumption and labor maximizes the utility of the representative agent subject to being feasible. An allocation is optimal, if at the margin, the utility loss from using one more unit of labor in production is equal to the utility gain derived from the additional consumption produced by that unit of labor:

$$\frac{\partial u}{\partial c} \cdot \frac{\partial c}{\partial n} = \frac{\partial u}{\partial l} \tag{2}$$

We can use this condition to solve for the optimal labor supply:[6]

$$n = \frac{\alpha}{\alpha + \gamma}.$$

Notice that optimal employment is independent of productivity z. An increase of productivity raises the marginal product of labor and thereby the real wage. Because a higher real wage makes leisure relatively more expensive, the agent consumes less leisure and supplies more labor. This result is called the substitution effect of the real wage increase. A rise in real wages also increases the income of the agent, thereby increasing the demand for leisure and reducing the labor supply. This result is called the income effect of the real wage increase. For the class of preferences defined by (1), the income and substitution effect cancel each other and employment does not depend on the productivity level (King, Plosser, and Rebelo 1987). This property of preferences is desirable if we want to match the long-run behavior of employment in industrialized countries. Relative to the increase in labor productivity over the last hundred years, per capita employment has scarcely moved.

Changes in Relative Productivities

Now consider a two-sector version of the economy described above. To keep things simple, I will treat the two sectors symmetrically. Essentially, the two sectors will only differ with respect to their relative labor productivities. In this economy, aggregate employment also does not depend on labor productivity. Furthermore, employment in the two sectors will always move in opposite directions if relative labor productivity changes. Thus there is negative comovement of employment if productivity changes in the two sectors are not perfectly correlated.

Production of each consumption good is

$$c_i = z_i n_i^{\alpha},$$

with $0 < \alpha \leq 1$. The agent's preferences for the two consumption goods and the labor supply for the two sectors are defined in two stages. First, there is a utility index for aggregate consumption:

$$c = (c_1^{\rho} + c_2^{\rho})^{1/\rho},$$

[6] Using the definition of the production and utility function and substituting for marginal utilities and marginal product of labor yields $\left[c^{-\sigma}(1-n)^{\gamma(1-\sigma)}\right] \cdot \left[\alpha \frac{c}{n}\right] = \gamma c^{1-\sigma}(1-n)^{\gamma(1-\sigma)-1}$, which can be solved for n.

with $\rho \leq 1$. If $\rho = 1$, then the two goods are perfect substitutes. If $\rho = 0$, then the elasticity of substitution is unitary, and the agent spends constant and equal shares of income on the two goods. There is also a disutility index for labor supply in the two sectors:

$$n = (n_1^{\psi} + n_2^{\psi})^{1/\psi},$$

with $\psi \geq 1$. Labor supplied to the two sectors is a perfect substitute when $\psi = 1$. The agent's utility is again a function of the consumption and leisure $l = 1 - n$ as defined in (1). For each consumption good, an optimal allocation equates the marginal utility gain from consuming one more unit of the good with the marginal utility loss from producing this good,

$$\frac{\partial u}{\partial c_i} \cdot \frac{\partial c_i}{\partial n_i} = \frac{\partial u}{\partial l} \cdot \frac{\partial n}{\partial n_i}.$$

This optimality condition, after some algebraic manipulation, simplifies to

$$\alpha \left(\frac{c_i}{c}\right)^{\rho} = \gamma \left(\frac{n}{1-n}\right) \left(\frac{n_i}{n}\right)^{\psi} \text{ for } i = 1, 2.$$

The ratio of the two optimality conditions yields an expression for the relative employment as a function of relative productivities:

$$\frac{n_1}{n_2} = \left(\frac{z_1}{z_2}\right)^{\rho/(\psi - \alpha\rho)}.$$

If the two goods are substitutable in consumption, $\rho > 0$, then employment in sector one increases relative to employment in sector two if the relative productivity of sector one increases. On the other hand, if the two goods are complementary in consumption, $\rho < 0$, then employment is shifted from the relatively more productive sector to the less productive sector, because the agent tries to maintain the same consumption ratio. With some additional algebraic manipulations, we can show that aggregate employment is again independent of productivity, that is, the percentage increase of employment in one sector is always balanced by the same percentage reduction of employment in the other sector. This result, of course, implies that employment in the two sectors always moves in opposite directions if relative productivities change.

Changes in Aggregate Productivity

I now reinterpret the standard neoclassical growth model as a two sector economy with a consumption goods sector and an investment goods sector. In contrast to the findings of the previous section, this example demonstrates that even without any change in relative sectoral productivities in the two sectors, employment in one sector can move opposite to that in the other simply because the two sectors respond differently to the same shock.[7]

Consider the representative agent described before but now assume that the agent is infinitely lived and has the utility function (1) for every period. The agent discounts future utility at rate $0 < \beta < 1$ and the utility from the consumption-labor sequence $\{c_t, n_t\}$ is given by

$$\sum_{t=0}^{\infty} \beta^t u(c_t, 1 - n_t).$$

There is now one consumption good and an investment good. The investment good x_t is used to augment the capital stock k_t according to

$$k_{t+1} = (1 - \delta)k_t + x_t$$

and $0 < \delta < 1$ is the capital depreciation rate. In the standard neoclassical growth model, capital and labor are used to produce a homogenous output good that can be used for investment or consumption. For the present interpretation of the model, I instead assume that the investment and consumption good are produced in two distinct sectors with the technologies

$$c_t = z_t k_{ct}^{1-\alpha} n_{ct}^{\alpha} \text{ and } x_t = z_t k_{xt}^{1-\alpha} n_{xt}^{\alpha},$$

where $0 < \alpha < 1$. Notice that relative productivity in the two sectors does not change. There are only aggregate productivity changes. The total amount of capital and labor used has to satisfy

$$k_t = k_{ct} + k_{xt} \; and \; n_t = n_{ct} + n_{xt}.$$

Again the competitive equilibrium is Pareto-optimal. Furthermore, the equilibrium allocations of this economy are the same as in the standard growth model.

How does this economy respond to a productivity increase? In general, we cannot derive analytical solutions for the behavior of equilibrium allocations for this economy, rather we have to derive numerical solutions. (See for example King, Plosser, and Rebelo [1987] or Benhabib, Rogerson, and Wright [1991]). It is straightforward, however, to interpret the economy's equilibrium response to the productivity increase. In this economy, output, consumption, investment, and employment all increase. Consumption increases because the representative agent prefers more consumption to less, and higher productivity enables the economy to produce more goods for consumption with the same amount of resources. Investment increases because the household accumulates capital

[7] This observation appears in Benhabib, Rogerson, and Wright (1991). See also Christiano and Fitzgerald (1998).

in order to smooth consumption over time. Employment increases because the higher productivity increases the real wage and labor supply.[8]

What are the implications of the model for sectoral comovement? The model clearly captures the sectoral comovement of output. But I will now show that even though both consumption and investment increase, employment in the two sectors move in opposite directions. Consider the intratemporal optimality condition for the allocation of labor to the production of consumption goods, which is essentially the same as (2) above. At the margin, the utility gain from the production of one additional consumption good has to be balanced by the utility loss from the additional labor supply,

$$\frac{\partial u_t}{\partial c_t} \cdot \frac{\partial c_t}{\partial n_{ct}} = \frac{\partial u_t}{\partial l_t}. \tag{3}$$

Using the definitions of the utility and production functions, we can simplify this expression[9] to

$$\frac{\alpha}{n_{ct}} = \frac{\gamma}{1 - n_{ct} - n_{xt}}.$$

This equation clearly shows that following the productivity increase, employment in the consumption goods sector falls since total employment increases. Furthermore, employment in the investment goods sector has to increase because total employment increases and employment in the consumption goods sector declines. Thus, employment in the two sectors moves in opposite directions.[10] To understand this behavior of sectoral employment, note that higher employment in the consumption goods sector implies two things. It implies a decline of the marginal product of labor in the production of consumption goods. Likewise, it implies a decline of the marginal utility of consumption since consumption increases. For the optimality condition (3) to be satisfied, the marginal utility of leisure has to decline, that is, the consumption of leisure has to increase. But leisure can only increase if employment in the investment goods sector declines, since employment in the consumption goods sector is assumed to increase.

---

[8] In this model, as in the previous static models, a change in productivity has both substitution and wealth effects. The higher productivity increases the marginal product of labor, which induces the agent to substitute from leisure to work time. It also increases wealth, which induces the agent to consume more leisure. In the long run, the two effects cancel each other, but during a transitional period, the substitution effect dominates.

[9] The expression is $\left[c_t^{-\sigma} (1 - n_t)^{\gamma(1-\sigma)}\right] \left[\alpha \frac{c_t}{n_{ct}}\right] = \gamma c_t^{1-\sigma} (1 - n_t)^{\gamma(1-\sigma)-1}$

[10] Christiano and Fitzgerald (1998) discuss the comovement problem for a somewhat more general specification of the growth model.

3. TOTAL FACTOR PRODUCTIVITY COMOVEMENT

As shown in the last section, simple multisector extensions of the neoclassical growth model have difficulties accounting for industry comovement in the presence of aggregate or sector-specific disturbances. The question remains whether the economy is mainly driven by aggregate or sector-specific disturbances.

In the introduction, I alluded to monetary policy shocks as a possible aggregate shock. Here I look at whether we should think of productivity disturbances as aggregate or sector-specific shocks. For this purpose, I study the comovement of measures of total factor productivity (TFP) across industries. I find that TFP in different industries move together over the business cycle, but that comovement appears to be weaker than for outputs or inputs. This finding seems to indicate that industry changes in productivity are not dominated by aggregate productivity changes.

Consider an industry where output is produced using capital, labor, materials, and energy as inputs to a constant returns-to-scale technology

$$q_t = z_t f(k_t, n_t, m_t, e_t), \tag{4}$$

and z represents industry TFP. Changes in output can be attributed to corresponding changes in inputs and TFP, and a first order approximation of the change in output is

$$dq_t = z_t[f_{k,t}dk_t + f_{n,t}dn_t + f_{m,t}dm_t + f_{e,t}de_t] + f_t\, dz_t,$$

where $f_{k,t} = \partial f(k_t, n_t, m_t, e_t)/\partial k_t$ and similarly for the other inputs. Dividing the equation by output yields an expression for output growth as a weighted sum of input growth rates and the TFP growth rate:

$$\frac{dq_t}{q_t} = \frac{f_{k,t}k_t}{f_t}\frac{dk_t}{k_t} + \frac{f_{n,t}n_t}{f_t}\frac{dn_t}{n_t} + \frac{f_{m,t}m_t}{f_t}\frac{dm_t}{m_t} + \frac{f_{e,t}e_t}{f_t}\frac{de_t}{e_t} + \frac{dz_t}{z_t},$$

where each input's weight is equal to the elasticity of output with respect to that input. For given weights, we can use this expression to solve for the TFP growth rate.

Solow's (1957) important insight was that, in a competitive economy, input elasticities can be measured through observations on factor income shares. Suppose that the industry is competitive in input and output markets and that everybody has access to the technology represented by (4). Consider a firm which maximizes profits, sells the output good at a price p_t, and hires, or purchases the services of, inputs capital, labor, materials, and energy at prices w_{kt}, w_{nt}, w_{mt}, and w_{et}. In order to maximize profits, a firm will hire labor until the marginal revenue from the last unit of labor hired equals its price, that is,

$$p_t f_{n,t} = w_{nt}.$$

Multiplying each side of the equation with $n_t/p_t q_t$ shows that the elasticity of output with respect to labor is equal to the share in total revenues that goes to labor:

$$\frac{f_{nt} n_t}{f_t} = \frac{w_{nt} n_t}{p_t q_t} = \omega_{nt}.$$

The same applies to all other inputs. We can therefore measure productivity growth using observations on output growth, input growth, and revenue shares of inputs. This measure of TFP growth is the Solow residual:

$$\frac{dz_t}{z_t} = \frac{dq_t}{q_t} - \left[\omega_{kt}\frac{dk_t}{k_t} + \omega_{nt}\frac{dn_t}{n_t} + \omega_{mt}\frac{dm_t}{m_t} + \omega_{et}\frac{de_t}{e_t}\right]. \quad (5)$$

The Solow residual provides an accurate measure of disembodied technical change as long as we are willing to assume that all markets are competitive.

Table 3 characterizes the business cycle comovement of industry TFP for the Jorgenson, Gollop, Fraumeni data set used in Section 2.[11] For the TFP calculations, I consider two production/output concepts: TFP of all inputs with respect to gross output and TFP of primary inputs capital and labor with respect to value added. The qualitative features of TFP comovement are similar to those of input and output comovement. First, there is some evidence that TFP in the different industries increases and decreases together. Second, industries in the manufacturing sector appear to move closer together than do industries in the rest of the economy, and within the manufacturing sector we see more comovement in the durable-goods-producing sector than in the nondurable-goods-producing sector. These observations apply to both gross output based and value-added-based measures of TFP. However, there appears to be less comovement of industry TFP than of industry output and labor input, as seen from the lower average and median correlation coefficients for TFP measures. From this I conclude that there is no strong evidence for an aggregate TFP shock.[12]

[11] I have calculated TFP growth rates for all industries using equation (5). After nomalizing TFP at one in the initial year, TFP levels are calculated as the cumulative sum of the growth rates. The business cycle component is then obtained by detrending industry TFP with the bandpass filter discussed in footnote 2.

[12] In recent work, for example Basu and Fernald (1999), it has been questioned whether Solow residuals accurately measure TFP movements. The issue is whether the assumption of perfect competition and constant returns to scale is appropriate and whether there is substantial unmeasured input variation. It is unlikely that these objections substantially affect the results on comovement of industry TFP. First, in the absence of perfect competition in the product markets or constant returns to scale, one would have to adjust the scale of the measured TFP movements, which would affect the volatility of measured TFP but it is unlikely to affect the industry co-movement pattern. Second, most of the empirical work which tries to account for unmeasured input variation, uses some measured input as a proxy. Since we observe positive comovement for measured industry inputs, this correction removes a component from TFP measures that is positively correlated across industries, and corrected TFP measures are likely to display even less comovement.

Table 3 Maximal Industry Cross-Correlations for Total Factor Productivity

	Gross Output Based				Value-Added Based			
	Mft	NDR Mft	DUR Mft	All	Mft	NDR Mft	DUR Mft	All
Minimum	−0.70	−0.61	−0.70	−0.70	−0.68	−0.62	−0.68	−0.68
1st Quartile	−0.25	−0.30	−0.31	−0.27	−0.26	−0.30	−0.31	−0.27
Median	0.32	0.18	0.39	0.26	0.30	0.15	0.38	0.27
3rd Quartile	0.47	0.51	0.49	0.43	0.47	0.52	0.49	0.43
Maximum	0.88	0.88	0.68	0.88	0.89	0.89	0.69	0.89
Average	0.17	0.13	0.20	0.13	0.16	0.12	0.19	0.12

4. CONCLUSION

I have documented that, over the business cycle, activity in almost all industries of the economy simultaneously increases and decreases. This comovement can be observed for a wide variety of activity measures, such as gross output, value added, employment, the use of capital services, or intermediate inputs. Based on this finding one might conjecture that aggregate disturbances to which all sectors of the economy respond in the same way account for the business cycle. Indeed, one might even suggest that this evidence points to a particular disturbance, namely monetary policy, as a major source of the business cycle. Monetary policy shocks arguably affect all sectors of the economy, while evidence of other aggregate shocks, namely aggregate productivity disturbances, is quite weak. However, as shown here, it is by no means clear that all industries of an economy will respond in the same way to an aggregate shock. Explaining the comovement of industries then appears to be an important task for any theory of the business cycle. Initial attempts to study this problem use natural extensions of the growth model such as the inclusion of the input-output structure of the economy (Hornstein and Praschnik 1997 or Horvath 1998) and limited sectoral mobility of labor (Boldrin, Christiano, and Fisher 1999). Other explanations consider the effect of various frictions in standard multisector growth models, for example credit market imperfections as in Murphy, Shleifer, and Vishny (1989). There has been some progress, but the problem clearly has not been addressed successfully.

REFERENCES

Basu, Susanto, and John G. Fernald, 1999. "Why is Productivity Procyclical? Why Do We Care?" International Finance Discussion Paper 638. Board of Governors of the Federal Reserve System, 1999.

Benhabib, Jess, Richard Rogerson, and Randall Wright. "Homework in Macroeconomics: Household Production and Aggregate Fluctuations," *Journal of Political Economy,* vol. 99, (December 1991), pp. 1166–87.

Boldrin, Michele, Lawrence J. Christiano, and Jonas D.M. Fisher. "Habit Persistence, Asset Returns and the Business Cycle," draft, Northwestern University, 1999.

Burns, Arthur and Wesley C. Mitchell. *Measuring Business Cycles, Studies in Business Cycles No. 2.* New York: NBER, 1946.

Christiano, Lawrence J. and Terry J. Fitzgerald. "The Business Cycle: It's Still a Puzzle," Federal Reserve Bank of Chicago *Economic Perspectives,* vol. 22 (Fourth Quarter 1998), pp. 56–83.

Hornstein, Andreas. "Inventory Investment and the Business Cycle," Federal Reserve Bank of Richmond *Economic Quarterly,* vol. 84 (Spring 1998), pp. 49–71.

Hornstein, Andreas and Jack Praschnik. "Intermediate Inputs and Sectoral Comovement in the Business Cycle," *Journal of Monetary Economics,* vol. 40 (December 1997), pp. 573–95.

Horvath, Michael. "Sectoral Shocks and Aggregate Fluctuations," *Journal of Monetary Economics,* vol. 45 (February 2000), pp. 69–106.

Jorgenson, Dale W., Frank M. Gollop, and Barbara Fraumeni. *Productivity and U.S. Economic Growth,* Harvard University Press: Cambridge, Mass., 1987.

King, Robert G., Charles I. Plosser, and Sergio T. Rebelo. "Production, Growth, and Business Cycles: I. The Basic Neoclassical Model," *Journal of Monetary Economics,* vol. 21 (March/May 1988), pp. 195–232.

Lucas, Robert E. "Understanding Business Cycles," in Karl Brunner and Allan H. Meltzer, eds., *Stabilization of the Domestic and International Economy, Carnegie-Rochester Conference Series on Public Policy,* vol. 5, Amsterdam: North-Holland, (1977).

Murphy, Kevin K., Andrei Shleifer, and Robert W. Vishny. "Building Blocks of Market Clearing Business Cycle Models," in Olivier J. Blanchard and Stanley Fisher, eds., *Macroeconomics Annual 1989.* Cambridge, Mass.: MIT Press, (1989), pp. 247–87.

Sato, Kazuo. "The Meaning and Measurement of the Real Value Added Index," *Review of Economics and Statistics*, vol. 58 (November 1976), pp. 434–42.

Solow, Robert. "Technical Change and the Aggregate Production Function," *Review of Economics and Statistics*, vol. 39 (1957), pp. 312–20.