Declines in the Volatility of the US Economy;

A Detailed Look

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This paper uses GDP-by-state and industry data, and looks at the decline in volatility of the U.S. economy that occurred in about 1984. It finds that this decline primarily results from declines in covariances between industries, or between states, rather than declines in variances of the individual industries or states. Similarly, it finds that changing shares of more- and less-volatile industries account for little of the overall decline in volatility. It suggests that some of the general explanations suggested by some analysts—such as better inventory management or improved labor markets—are best suited for specific industries or industry groups, rather than the overall economy. General explanations that would tend to work in many industries—such as better business planning due to lower price volatility or improved information technology—might account for much of the decline in overall volatility. Nevertheless, many industries experienced increased volatility. The paper also takes a brief look at the earlier, very large decline in volatility that occurred after the era of the great depression and World War II, and suggests that institutional factors have historically been important in determining volatility.

Declines in Volatility of the US Economy; A Detailed look

By Bruce T. Grimm and Brian K. Sliker

STARTING in about 1984, the volatility of annual economic growth has declined noticeably—a phenomenon that some economists refer to as the "great moderation." One of the first papers that analyzed this (McConnell, Moser, and Perez Quiros 1999), attributed much of this smoothing of growth to inventory investment and consumer spending. Subsequent work by Fixler and Grimm (2005) also found that the volatility of revisions to the estimates of gross domestic product (GDP) declined after 1984, but not as much as the declines in the volatility of GDP itself. Kevin Stiroh (2006) analyzed several studies of the smoothing and took a new approach that yielded results that were not fully consistent with many of the hypotheses advanced in them. Stiroh examined the decline in overall volatility by disaggregating it into individual industries and found that much of the decline resulted from decreased covariances between industries—that is, less of a tendency for industries' output to move together—rather than from volatility declines in the individual industries.

This analysis, which is largely based on the Bureau of Economic Analysis (BEA) GDP-by-state statistics, takes a look at specific states, regions, industries, and industry groups and examines how they affect the volatility of overall economic growth. It disaggregates GDP growth by states and economic regions as well as by 63 industries and 13 industry groups. Like Stiroh, this study finds that declines in covariances—either between states or regions, or industries or industry groups—are the predominant factors in the decline in the volatility for the whole economy. The covariances measure the effects of the interactions between industries or states on the aggregate economy.

The principal findings are as follows:

- Declines in the volatility of states, regions, industries, or industry groups do not account for much of the decline in the volatility of GDP growth. In fact, when disaggregating by regions and industry groups, less than one-eighth of the decline in the variance of GDP growth is due to declines in variances of the regions and industry groups. When disaggregating by states and individual industries, less than one-fiftieth of the decline is due to declines in their variances.

A number of BEA staff members have contributed to this analysis. They include Andrew Bernat, George Downey, Dennis Fixler, Carrie Litkowski, Robert Yuskavage, and James Zavrel. Robert J. Gordon provided very useful comments, as did other members of BEA's advisory committee.

- Some analysts have suggested that an increased share of less-volatile services industries, and a decreased share of more-volatile manufacturing industries are important factors in the decline in aggregate volatility. However, increases in the shares of services industries have been roughly offset by declines in the shares of even less volatile government industries. Thus, changes in shares, on net, have not been important components in the overall decline in volatility.

- Explanations of the decline in volatility suggested by some analysts—such as better inventory management, improved labor markets, and better technologies—seem best suited for some specific industries or industry groups rather than for the aggregate economy.

- The declines in volatility are far from universal. Somewhat less than half of industries, and nearly one-third of states experienced increases in volatility. In nearly one-fourth of economic regions and industry groups, there were increases in the variance of GDP-by-state growth. These increases are not consistent with the general explanations that have been advanced for smoothing of the economy.

- The results of this study indicate considerable differences when disaggregating by geographical area and industry. The explanations that have been proposed by other analysts appear to work for, at most, subsets of industries. For example, Ramey and Vine (2005) studied in detail the causes of the decline in volatility in the auto industry that mirrored the overall decline. For some states and industries, there may also be "bad luck" institutional explanations that resulted in increased volatility. Thus, the explanations that focus on individual industries or industry groups provide only a modest portion of the causes of the aggregate decline in volatility. Further, the increased volatility in many states and industries partially offsets the declines in other states and industries.

- As discussed in Appendix 4, "Variance and Covariance Effects; an Example," it is unlikely that explanations that focus on individual industries or groups of industries will provide the major causes of the decline in overall volatility. Because the shares of industries or industry groups are squared in calculating the effects of changes in their variances on aggregate variance, these effects are inherently small. For example, the share of GDP from all manufacturing in the period 1978-97 is roughly 15 percent, and the decimal weight of its variance in the variance of all GDP is less than about 2 ¼ percent.

- The geographical and industrial analyses in this paper generally confirm Stiroh's finding that the general explanations previously advanced do not explain volatility in a majority of industries, and apply only to some industries and geographic areas. Like Stiroh's work, the "good luck" hypothesis of reduced economic shocks, which was advanced by Stock and Watson (2002), is consistent with many of the findings in this analysis[1]. The decline in volatility of inflation that occurred beginning in 1983 is an example of these reduced shocks.

The remainder of this paper looks at the following: variances and covariances of components and their effects on overall volatility; declines in the volatility of the growth of GDP and of GDP by state; volatility state by state; some possible explanations; and finally some conclusions. Three of the appendixes at the end of this study take a closer look at various statistical issues related to the study. Two additional appendixes describe how variance and covariance effects of components impact aggregates, and describe the regional and industrial data set used by the study.

The Effects of Variances and Covariances

This study relies on GDP-by-state statistics from BEA. GDP by state is simply the amount of GDP generated by a state. National, or total, GDP by state is simply the sum of the GDPs by state for all states plus the District of Columbia.

The equation below states that the level of aggregate real national GDP by state, Y_t, is the sum of the levels of individual states' GDPs, y_{it}, plus a residual, u_{it}, that stems from the effects of chaining together the states' estimates.[2]

$$Y_t = \sum_{i=1}^{51} y_{it} + u_{it}$$

Similarly, for a given industry or industry group, national GDP by state is the sum of all states' GDPs that is generated by that industry or industry group.

The growth rate of national real GDP by state, X_t, may be stated as a weighted sum of the growth rates of the individual states' GDPs, x_{it}, and an error term, e_t.[3]

$$X_t = \sum_{i=1}^{51} w_i x_{it} + e_t$$

Note that the x measures are the growth rates of the corresponding y measures.
Using weights that are equal to the averages of state ratios to the national total in real terms (constrained to sum to 1.000) over the 20-year period 1978–97, the average annual national growth rate of real GDP by state is 3.0 percent. The difference between the sums of the levels with and without the residuals is 0.073 percent per year, or a bit less than one-fortieth of the average growth rate. The effects of the error terms introduced by the weights appear to be modest. For more information, see appendix 1. The variance of the growth rates of total GDP by state may be decomposed into variance effects for indi-

[1] Gordon (2005) found evidence of the role of reduced price shocks in the decline in volatility.
[2] There is no residual if all the state price indexes used to obtain real estimates from current-dollar estimates are the same.
[3] The error term is introduced by the use of fixed weights over time.

vidual states—or regions—and “covariance effects” including a residual, as given by the following equation.

$$Var(X) = \sum_{i=1}^{51} w_i^2 \operatorname{var}(x_i) + 2\sum_{i=1}^{50} \sum_{j=i+1}^{51} w_i w_j \operatorname{cov}(x_i, x_j) + f(u,e)$$

Where $\operatorname{var}(x_i)$ is the variance of GDP by state for state i,
$\operatorname{cov}(x_i,x_j)$ is the covariance of GDP by state for states i and j
f(u,e) is the unknown function of residuals u and e

There can be more than 1,200 covariances when a state-by-state disaggregation is used, so it is convenient to deal with the weighted sum of the variance effects in one group (the first term in the above equation) and the covariance terms in a second group (the second term). The last term, *f(u,e)*, is the unknown net effects of the chain-effect residuals and any weight-term errors. The f(u,e) errors function is lumped in with the covariance effects, however limited experimentation suggests that these effects are relatively small. As a result of the *f(u,e)* term, the variance effects term is only approximate, and the sum of the other terms is only approximately the covariance effects. The approximations, however, mean that the quantitative results should only be viewed in qualitative terms even though the effects of the f(u,e) term are likely to be quite small compared to the covariance effects. Despite this, the results are sufficiently strong that conclusions can be drawn.

Declines in Volatility: GDP, GDI and GDP by State

Until 1997, total real GDP by state is more closely aligned with real GDI rather than with real GDP as computed by the national income and product accounts (charts 1 and 2). Although movements in GDP and GDI differ moderately, GDP and GDI are equally valid measures of aggregate economic activity (Fixler and Nalewaik 2006). All three measures of U.S. economic activity had higher volatility in 1978–84 than they did in 1985–97. In 1978–84, real GDP had the highest volatility of the three aggregates. In 1985–97, it had the lowest volatility and therefore the largest decline in volatility.

This analysis focuses on GDP by state, which has the smallest decline in volatility. Nevertheless, the sizes of volatility for the three methods and the declines after 1984 are sufficiently similar that qualitative results based on any of the measures should hold for the other two as well.

Regions and industry groups

One way to slice the data is to disaggregate overall economic activity—total GDP by state—into 13 industry groups or 8 economic regions. The results of each disaggregation are similar (table 1).

The first line shows the national-level variances and change in variance in growth of aggregate GDP by state from 1978–84 to 1985–97. The next line shows, for industry groups, the weighted sums of the industry groups' variances and the change between periods. Slightly more than one-eighth of the decline in national variance is due to a decline in the weighted sum of the industry groups' variances. As shown in the third line, the remainder accounts for the rest of the overall decline and is mainly a result of declines in the covariances among the industry groups.[4]

The final pair of lines in table 1 show the same information, but decomposed by economic region. The results are quantitatively similar to those of the decomposition by industry groups. One-sixth of the national decline in variance is due to a decline in the weighted sum of variances of the regions. The residual, five-sixths of the total, is primarily due to declines in covariances between the regions.

Thus, a preponderance of the overall decline in the variance in annual real economic activity is due to the declines in the covariances of industry groups' or regions' economic activities. For example, covariance effects account for 33.6 percentage points of the decline of 36.2 percentage points in the variance of the durable manufacturing industry group. The variances decline for 10 of 13 industry groups and for 6 of 8 regions. For roughly one-fourth of both industry groups and regions, volatility actually increased in the 1985–97 period.

States and individual industries

Another way to look at the data is to disaggregate total GDP by state by individual industries and by states. As shown in chart 3, the states with increased variances clustered in three areas; the northeast states, the south-central states, and Alaska and Hawaii. The results of this more detailed disaggregation are shown in table 2. The effects of the weighted sums of the 63 industries' GDP-by-state contributions are smaller—relative to the national variance—than those for industry groups. The decline in individual industries' contributions only explains a 0.1 percentage point decline in the national GDP-by-state decline of 5.4 percentage points. The residual effects—again predominantly covariance-related effects—are more than 50 times the size of the variance effects.

[4] This finding reinforces that of Stiroh (2006), who found that 80 to 85 percent of the overall smoothing in GDP is due to declines in covariances between industries. All fixed-weighting schemes miss changes in aggregate variance due to shifts among components with different variances. In order to evaluate the effects of shifts, the second and third lines of table 1 were recalculated using 1978–84 weights for the early period variance effects and 1985–97 weights for those of the later period. The change in the weighted sum of industry groups' variances declined 0.1 percentage point less than shown in table 1. This suggests that, at the industry group level of disaggregation, the effects of changing weights are rather small.

The final two lines of the table show the same information for states. The quantitative results are same as those for industries. The covariance-related effects are again more than 50 times the size of the variance effects.[5]

Thus, regardless whether the disaggregation is by industries or by states, the variance effects are very small relative to the covariance effects, and account for very little of the smoothing of national GDP by state.

State-by-State Volatility Industry groups disaggregated by state

Table 3 shows the changes in industry groups' variances, as disaggregated by states. The variances of GDP-by-state measures decline for 10 of 13 industry groups.[6] In 7 of the 10, the covariance effects contribute more than nine-tenths of the declines in the industry groups' variances, and in 2 industry groups, declines in the covariance effects more than offset increases in the variance effects. Only for construction did a decline in variance effects more than offset a modest increase in covariance effects. For the two industry groups (communications and "electric, gas, and sanitary services") that had increases in variances, both the variance effects and the covariance effects contribute to the increases; the covariance effects contribute most of the increases in communications and electric, gas, and sanitary services. Thus, as is true for regions, the covariance effects contribute the large majority of the overall patterns. The industry groups that experience increased volatility account for roughly one-sixth of total national GDP by state, so industry groups with declines in volatility represent the large bulk of the economy.

Individual industries disaggregated by state

Table 4 shows the changes in individual industries' variances as disaggregated by states.[7] Column 1 shows the variances across states for the 63 industries in 1978–84, and column 2 shows the changes in variances from 1978–84 to 1985–97.[8] The changes are far from uniform; in 27 industries, accounting for 38 percent of total current-dollar GDP by state in 1997, there are increases in variances. These increases are widespread, and occur in all eight industry groups that contain more than one industry. There is a statistically significant relationship between the size of industries' variances in the earlier period and the size of the decline—the larger the earlier period variance, the larger the

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[5] The difference in magnitude of the decline in national GDP by state using the sum of each GDP-by-state estimates rather than the published chained estimates may be roughly gauged by the fact that the decline in variance using the additive numbers is 0.06 percentage point larger than that using the published, chained numbers.

[6] Most industry groups have production in most states. For example, 47 states have production in the mining industry group.

[7] Changes in variances of GDP by state with an industry disaggregation are not evaluated because for just over half of the industries (32), some states had to be combined because of very low or no GDP from the industry. This makes it impossible for the results to be fully comparable with those reported for a state disaggregation in this analysis.

[8] One industry-state combination is removed from the analysis: Alaska is removed from the pipeline transportation industry. The opening of the Trans Alaska Pipeline during 1977 led to a more than 1,850 percent increase in 1978 for pipeline GDP for Alaska. This was a one-time event that had nothing to do with volatility in general, but was large enough in its effects to distort the measures for all pipelines.

decline—but there is little cross-industry relationship between the earlier period variances and the later period variances (see appendix 2).

Thirty-two industries have weighted sums of state variances (variance effects) that are positive (column 3). Twenty-seven industries have both declines in variance and negative weighted sums of the variances. These industries account for just 36 percent of current-dollar national GDP by state in 1997. Thus, the decline in variance in national GDP by state occurs as declines in some industries more than offset increases in others, and within industries, increases in the variances of some states' industry GDP by state are more than offset by declines in others.

The residuals, which reflect the covariance effects for individual industries, are shown in column 4. These account for most of the overall changes in variance for industries. Without regard to sign, the covariance effects are larger than the variance effects in 60 of 63 industries.[9] Also without regard to sign, the average share of the change accounted for by covariance effects is 95 percent; on a weighted basis—using 1978–97 average weights—the share is 84 percent. This figure is similar to Stiroh's (2006, p. 3) finding that about 80 percent of the decline in output variance can be traced to smaller covariances between industries, but our analysis is for covariances between states and within industries. As with the variance effects, the covariance effects are far from uniform; they increased in 29 of the 63 industries.

In sum, by disaggregating individual industries by states, it is hard to discern the source of the decline in variance of national GDP by state. For individual industries, the covariance effects greatly outweigh the variance effects, and are larger in absolute size in all but three industries. The variance and covariance effects generally reinforce each other; they have opposite signs in just 15 industries. The diversity at this level of disaggregation suggests that the general explanations advanced by other researchers—except perhaps for the "good luck" hypothesis—do not fit well with the estimates of volatility for all industries or industry groups or for all states or regions.

Possible Causes of the Decline in Volatility

As noted by Ramey and Vine (2005), Stock and Watson (2002), and Stiroh (2006), there are several proposed explanations for the decline in overall variance. Stiroh obtained industry results that did not generally fit well with most of the explanations. The results described in this paper are similar. In particular, the finding of lack of uniformity in the directions of changes in volatility across industries and industry groups, or states and regions, is difficult to reconcile with the general explanations, such as improved inventory management or better economic and fiscal policies. Also, the use in this paper of 20-year average weights in calculating variance effects all but eliminates declines in variance effects due to a shift toward smoother sectors of the economy, such as services industries. As discussed in appendix 4, at finer levels of disaggregation, shifts in weights are very unlikely to be able to provide much of the explanation of the decline

[9] For real estate, the covariance effects are slightly larger than the variance effects.

in volatility. For example, the share of the economy by relatively less volatile services industries' GDP by state—cited by some analysts—rose 0.016 percentage point from 1978-84 to 1985-97. This increase, however, was offset by a 0.023 percentage point decline in the share of government industries, which are even less volatile.

The various explanations do fit well with some individual industries or industry groups. For example, a review of farm GDP found that very high volatility in the 1978–84 period reflects some years with widespread poor farming weather combined with very volatile prices for some farm products. The pattern is not repeated in the 1985–97 period In contrast, the agricultural services, forestry, and fishing industry— which seems likely to be closely related to the farm industry in the medium to long term—is less volatile, but its volatility increases in the later period. Thus, the hypothesis of good luck in the form of smaller exogenous shocks in the 1985–97 period seems to fit well with the farm industry's experience.

Other industries seem poorly suited to any of the proposed explanations. For example, of the three government industries—which have relatively low volatility throughout the 20-year sample period—two have small declines in volatility in the 1985–97 period, and the third has a small increase. There is little reason to expect that governments would be much affected by the various explanations. Another example is provided by depository institutions, which have had major structural changes, evolving from an era dominated by smaller state companies to an era dominated by regional or national companies. Reflecting this transformation, the industry's volatility—which is relatively low in 1978–84—increases sharply in the 1985–97 period. This increase appears to be the result of changes in the structure of the industry and does not seem to fit well with the proposed explanations.

The overarching feature of the decline in variance of national GDP by state is that the various parts of the economy move less like one another than they did before 1985. This phenomenon was found for most industry groups and economic regions. It is also true for the 37 industries that experienced declines in variances; in 35 of these industries, the covariance effects are larger than the variance effects and typically are much larger. As suggested above, no one cause is able to explain the declines in variances in the industries that experienced declines. For example, the improved inventory management explanation suggested by McConnell and Perez Quiros (2000) seems better suited to manufacturing industries than for services industries. The increases in variances of some industries within industry groups are not fully consistent with, for example, the "better policy" explanation that has been advanced by some analysts. Stiroh's (2006) finding that improved labor market dynamics underlies much of the overall decline in volatility suggests a channel through which better planning was implemented.

In general, the large numbers of industries—and to a lesser extent states—that have experienced increased volatility strongly suggest that no one explanation will fit all the patterns of volatility. There are several, however, worthy of more discussion.

Some analysts have suggested that faster-growing industries might have higher volatility. A review of the industry-level data, however, found no indication of this. For example, the correlation of growth rates and variances across industries is just 0.10 in the 1978-84 period, and -.013 in the 1985-97 period. There are some explanations—such as Stiroh's (2006) improved labor management explanations—that cut across regions and industries that might help account for the observed decline in GDP volatility.

Technology. One explanation of decreased volatility is the adoption of improved technology. The improved inventory management explanation fits into this category, but there are no data at the detailed levels used in this study to evaluate this. A similar explanation is that increasing adoption of new information technology allowed better, more efficient management of businesses and control of employment, production, and inventories. The increases in information technology investment are quite striking; real investment in information processing equipment and software rose from $9.5 billion in 1972 to $218.9 billion in 1997.

Imports. A second explanation deals with imports. The average ratio of real U.S. imports to real GDP is 0.062 in the 1978–84 period and 0.084 in the 1985–97 period. Increased imports can lower volatility in at least two ways. First, changes in imports can be used to help absorb demand shocks to domestic industries. Second, imports can reduce the covariances between states. For example, an auto assembly plant in state A initially uses parts and subassemblies manufactured in state B. If the assembly plant switches to parts and subassemblies imported from abroad, then the motor vehicle manufacturing industries in states A and B become less alike because imports are affected by fluctuations in state A, but the motor vehicle production in state B no longer retains the links to state A's production.

Inflation. A third possible explanation concerns the end of high inflation rates by 1983.[10] High rates of inflation previously made business planning more difficult and, more importantly, resulted in high volatility in relative prices that exacerbated the planning difficulties.[11] The effects of this relative price volatility may well be even more important than the effects of higher volatility in overall prices. Gordon (2005) has emphasized the importance of more volatile prices in transmitting supply shocks in the era of higher volatility. Lower price volatility makes it easier to do efficient business planning and therefore may lead to lower volatility in the outputs of industries. The decline in inflation volatility explanation appears to encompass the better economic policy explanation suggested by some economists; more effective anti-inflation monetary policies, in particular, can lead to lower and less volatile inflation.

[10] Neff (1949) found that the economies of six large cities moved less alike in 1921-29 than they did in the rest of the 1919-45 period. He attributed this to the effects of relative price stability because "... it is through shifting prices that much of the linkage between areas takes place" (117).

[11] See, for example Debelle and Lamont (1997).

Chart 4 shows 6-year variances for real GDP and for the GDP price index. (The estimates for 1955 are the variances for 1950-55, and so on.) Until about 1970, there is little apparent relationship between the two measures' variances. For the period 1970-1990, the two variances move closely together, both in terms of major movements, and also in terms of local peaks and troughs. After about 1990, there again is little detailed correspondence, but both variance series remain low in comparison with earlier years.

Some observers have suggested that, instead of a decline starting about 1984, the higher variances in the 1970s and early 1980s are the exceptions to a longer run declining trend. Blanchard and Simon (2001) argued that there has been a ". . . large underlying decline in output volatility (and a) steady decline over several decades. . .(that) was interrupted in the 1970s and early 1980s, and returned to trend in the late 1980s and the 1990s." Appendix 3 looks at the longer run pattern of volatility of real GDP.

More detailed analyses are needed to tell the full story, but it is likely to be made up of industry and regional details that are beyond the scope of this analysis. An example of this is provided by the motor vehicle industry, which had a decline in volatility of about 75 percent to the later period. The largest component of this industry is automobile manufacturing. Anecdotal evidence suggests that the clustering of suppliers near final assembly plants led to improved efficiency and, presumably, smoothness. Import penetration was increasingly important during the sample period. Also, foreign manufacturers began assembling many models domestically and built new plants for this. This was accompanied by a large-scale shift in motor vehicle manufacturing from the Great Lakes states to the Southeastern states. Presumably, more detailed analyses using additional sources of information would yield additional insights into the decline in volatility in the motor vehicle manufacturing industry.[12]

New Issues

This analysis has attempted to examine changes in the variance of aggregate economic activity using detailed industrial and geographic disaggregations. It raises a new question: what about the 27 industries and 15 states that have increases in variance? All of the industries have increases due to covariance effects, and all but 4 also have increases due to variance effects. For these industries, the increases range from 0.4 percentage point for stone, clay, and glass products manufacturing to 454.0 percentage points for nondepository institutions. In 25 industries, the covariance effects are larger than the variance effects. Thus, for these industries the reverse of the patterns of the industries with declines in variance appears to be true; the primary effects within the industries are those of movements by the states becoming more like one another.
A possibility is that most or all of the explanations advanced by various analysts are correct in some instances, but that institutional conditions in the various industries

[12] Ramey and Vine (2005) emphasize the importance of declines in the volatility of durables-goods manufacturing industries, particularly motor vehicle manufacturing, to the overall decline in volatility. The small portion of the economy accounted for by motor vehicles, however, means that this is not a sufficient explanation for the overall decline in volatility.

resulted in deviations from the overall trends. Even the industries with increases in variance may be affected by the general explanations, but institutional conditions or other causes more than offset these.

It seems likely that reasons for the changes in variances of individual industries will be revealed only by further examination of the proposed causes, as well as detailed reviews of the individual industries. If such studies are undertaken, they ought to include the industries with both increases and declines in variance. Only such analyses could clearly distinguish institutional reasons from the good luck explanation.

Conclusions

The decline in volatility in real economic activity that began in about 1984 is widespread but far from universal. The detailed results of this analysis do not fully support the general explanations suggested by some analysts, such as better economic policies, although they do not preclude the explanations from having had roles in the decline in volatility. Some explanations, such as better inventory management, improved labor markets, and better technologies, seem best suited for some specific industries or industry groups. The explanations examined in this analysis likewise do not seem to fit well with all industries, although they work reasonably well in the aggregate. However, the good luck hypothesis seems likely to hold in many cases. The states with increased volatility are apparently clustered geographically, which suggests that additional factors may be at work. In the longer run, institutional factors seem to have been very important. It may well be that declines in volatility may be best analyzed at a very detailed level, paying special attention to industry-specific (or state-specific) detailed causes.

Appendix 1: Weightings and Variance and Covariance Effects

For simplicity, fixed weights are used in this analysis rather than time varying weights. Because estimates of movements in GDP-by-state components are based on percent changes, it is necessary to weight together the lower level component variances to calculate their effects on variances of higher level aggregates. The methodology used in this analysis requires that the weights for the individual states or industries, or regions or industry groups, sum to one.

However, the published real (chained-dollar) measures are not additive and do not sum to the chained estimates. Also, the sums of the components of higher level real aggregates may not equal the chained totals. A discussion of the advantages and costs of chained indexes may be found in Landefeld, Moulton, and Vojtech (2003). [13]

13 BEA switched to chain indexes in 1996. The previous, fixed-weight methodology produced additive real estimates, but did not preserve real growth rate patterns with changes in base periods. The current estimates are based on Fisher chains, in which Laspeyres and Paasche quantity indexes are geometrically averaged to compute the chains. Using chain methodology, the weights are different for each year in the sample. See Landefeld, Moulton, and Vojtech (2003, p. 10) for a more complete discussion.

For this analysis, real dollar-based weights were used. This necessitated creating alternative estimates of higher level aggregates by summing the lower level components and using these sums to calculate weights. These sums often are slightly different than the published chained-dollar aggregates. For example, the 1978–97 average national real GDP by state for petroleum and coal products manufacturing is $25.877 billion, but the corresponding average summed-total GDP by state estimate is $25.827 billion, slightly less than 0.2 percent smaller.

Because the bulk of this analysis concerns the sources of volatility of real GDP by state and its components, weights based on the ratios of components to more aggregate GDP-by-state measures were chosen for the empirical work. For example, the ratios of states' fabricated metal products industry real GDP by state to the total of all states' fabricated metal products industry real GDP by state are used to weight the variances of the individual states. The weights are calculated for each year in 1978–97, and the 20 sets of weights are averaged to obtain average weights for the full sample period.

There is no clear-cut, "right" way to calculate weights over a two-decade time span that does not have an impact on the relative importance of the variance and covariance effects. Stiroh (2006) used two-period averages of observed weights. However, any scheme with variable weights should properly treat them as stochastic, along with the growth rates. This would greatly complicate the variance decomposition.

For this study, the 20-year average was chosen as a compromise; it was used in all estimates in this study.

Appendix 2: Earlier Period Variances, Declines in Variances, and Later Period Variances

Table 5 shows the results of ordinary least squares cross-section regressions. (The numbers in parentheses below the coefficient terms are absolute values of t-test statistics for the coefficients.) The two lines show the results of regressions that try to explain the declines in variances by the sizes of the earlier period variances. The first line shows the results of a regression that includes all 63 industries; the variances are calculated for the periods 1978–84 and 1985–97. The second line shows results for a regression that excludes the 10 industries with the largest changes in variances; it is shown to evaluate the possibility that outliers are distorting the estimated relationships.

The results are similar, suggesting that outliers do not distort the results. There is a strongly statistically significant negative relationship between the size of the earlier period industry variance and the size of their changes. The values of the coefficients of the variance in both equations are not significantly different from one another (with t-test statistics against one another of less than 1.0).

Appendix 3: Long-term Trends in the Volatility of the Economy

Blanchard and Simon (2001) looked at the volatility of U.S. economic activity using a moving 20-quarter calculation of the variance of real GDP. They found a pattern beginning in the 1970s similar to the pattern reported in this analysis. Their sample began in the early 1950s, and they found a trend decline from the mid-1950s to the late 1990s that was interrupted by increased variances in the 1970s and early 1980s. The apparent importance of price volatility noted in this study could be part of such an interruption.

Because quarterly estimates of real GDP are only available beginning with the first quarter of 1947 and because they used 20-quarter calculations of variance, Blanchard and Simon were not able to push their variance calculations back before 1952. Annual estimates of real GDP, however, are published by BEA beginning with 1929. This means that 6-year variances can be calculated beginning with 1935. These are shown for the period 1935–2005 in chart 5. The variances until the early 1950s are extremely high in comparison with those thereafter. The variance of real GDP declined by more than nine-tenths from 1930-54 to 1955-69, increased by half to 1970-84, then declined by four-fifths to 1985-2006 (the so called great moderation).

Time Period	Variance of Real GDP (percent)
1930-1954	69.7
1955-1969	5.4
1970-1984	7.5
1985-2006	1.5

It is not surprising that there are very high variances in the years before the 1950s. The observations though about 1940 cover the period dominated by the economic dislocations associated with the Great Depression. Those in the 1940s are greatly influenced by the changes that occurred as the economy first shifted to an all-out effort to support World War II and then returned to a peacetime status. By the mid-1950s, the economy was generally in a “normal” mode, albeit with somewhat higher defense spending than before 1940.

Viewed in the longer term framework, the relatively low GDP variances in the 1960s may be viewed alternatively as a temporary departure from a long period of higher variance that occurred in a decade that had just one recession near its beginning. Indeed, the variance of prices—used in this analysis as a proxy for the pattern of cross-sectional price volatility—was low, which helps explain the period of lower variances in the 1960s. The other two proxy measures suggest high variances. Import penetration was low until a pickup that began in the late 1960s. Similarly, information technology had little influence; the information processing equipment and software industry’s share of GDP was 0.2 percent or less until it began to increase sharply in the mid 1970s.

Thus, institutional circumstances appear to dominate the pattern of real GDP variance until the mid-1950s.

Appendix 4: Variance and Covariance Effects; an Example

In this example, the weighted sum of three variables—X, Y, and Z—forms an aggregate, A:

$$A = w_x X + w_y Y + w_z Z \tag{1}$$

As in the rest of this study, the weights are constrained to be fixed, nonnegative and sum to 1:

$$w_x + w_y + w_z = 1 \tag{2}$$

The average of the aggregate over T periods is:

$$\bar{A} = (\sum_{t=1}^{T} A_t)/T \tag{3}$$

and similarly for its components X, Y, and Z. And the counterpart of equation (1) for the averages may be written:

$$\bar{A} = w_x \bar{X} + w_y \bar{Y} + w_z \bar{Z} \tag{4}$$

The deviation of observation t from the average is:

$$A_t - \bar{A} = w_x (X_t - \bar{X}) + w_y (Y_t - \bar{Y}) + w_z (Z_t - \bar{Z}) \tag{5}$$

and the squared deviation is:

$$\begin{aligned}(A_t - \bar{A})^2 = {} & w_x^2 (X_t - \bar{X})^2 + w_y^2 (Y_t - \bar{Y})^2 + w_z^2 (Z_t - \bar{Z})^2 \\ & + 2w_xw_y(X_t - \bar{X})(Y_t - \bar{Y}) + 2w_xw_z(X_t - \bar{X})(Z_t - \bar{Z}) + 2w_xw_z(X_t - \bar{X})(Z_t - \bar{Z})\end{aligned} \tag{6}$$

The average of the squared deviations over *T* periods is:

$$\begin{aligned}\sum_{t=1}^{T}[(A_t - \bar{A})^2]/T = {} & w_x^2 \sum_{t=1}^{T}[(X_t - \bar{X})^2]/T + w_y^2 \sum_{t=1}^{T}[(Y_t - \bar{Y})^2]/T + w_z^2 \sum_{t=1}^{T}[(Z_t - \bar{Z})^2]/T \\ & + 2w_xw_y \sum_{t=1}^{T}[(X_t - \bar{X})(Y_t - \bar{Y})]/T + 2w_xw_z \sum_{t=1}^{T}[(X_t - \bar{X})(Z_t - \bar{Z})]/T + 2w_yw_z \sum_{t=1}^{T}[(Y_t - \bar{Y})(Z_t - \bar{Z})]/T\end{aligned} \tag{7}$$

This is also the formula for the variance of A, expressed as the weighted sum of the variances of X, Y, and Z plus the weighted sums of the covariances of X, Y, and Z:

$$\mathrm{Var}(A) = w_x^2\,\mathrm{Var}(X) + w_y^2\,\mathrm{Var}(Y) + w_z^2\,\mathrm{Var}(Z) \qquad (8)$$
$$+ 2\,w_x\,w_y\,\mathrm{Covar}(X,Y) + 2\,w_x\,w_z\,\mathrm{Covar}(X,Z) + 2\,w_y\,w_z\,\mathrm{Covar}(Y,Z)$$

The weights for the variances are the squares of the weights from equation 2, and the weights for the covariances are the corresponding products of the weights.

Growth accountants use equations like (1) or (5) to attribute aggregate movements to the movements of components or to weight-shifts among members. Although it might seem natural also to attribute changes in aggregate variance to changes in components' variances, equation (8) with its doubled-up covariance terms, and squared own-weights for components, indicates that such an unambiguous attribution is not generally available. Even if all of the covariance terms were zero, the squared weights would not by themselves sum to 1. By contrast, squaring both sides of equation (2) indicates that the square of the sum of weights still equals 1:

$$w_x^2 + w_y^2 + w_z^2 + 2\,w_x\,w_y + 2\,w_x\,w_z + 2\,w_y\,w_z = 1.$$

This study calculates the change in Var(A) from one subperiod of years (i.e., in subperiod I, t = 1,2,3,…S) to the next (i.e., in subperiod II, t = S+1, S+2, S+3,…T), holding weights fixed across both subperiods. That is, subtract the second period's variance from the first period's:

$$\mathrm{Var}(A)_{\mathrm{I}} - \mathrm{Var}(A)_{\mathrm{II}} = \qquad (9)$$
$$\mathbf{\{}w_x^2[\mathrm{Var}(X)_{\mathrm{I}} - \mathrm{Var}(X)_{\mathrm{II}}] + w_y^2[\mathrm{Var}(Y)_{\mathrm{I}} - \mathrm{Var}(Y)_{\mathrm{II}}] + w_z^2[\mathrm{Var}(Z)_{\mathrm{I}} - \mathrm{Var}(Z)_{\mathrm{II}}]\mathbf{\}} +$$
$$\mathbf{\{}2\,w_x\,w_y\,[\mathrm{Covar}(X,Y)_{\mathrm{I}} - \mathrm{Covar}(X,Y)_{\mathrm{II}}] + 2\,w_x\,w_z\,[\mathrm{Covar}(X,Z)_{\mathrm{I}} - \mathrm{Covar}(X,Z)_{\mathrm{II}}]$$
$$+ 2\,w_y\,w_z\,[\mathrm{Covar}(Y,Z)_{\mathrm{I}} - \mathrm{Covar}(Y,Z)_{\mathrm{II}}]\mathbf{\}}$$

On the right-hand side of (9), the first expression (in braces) comprises the "variance effects," while the rest makes up the "covariance effects." Variances are by construction nonnegative, but differences between them can take either sign. Covariances can be either positive or negative, so there is no reason to expect that either variance or covariance effects will dominate. However, as the number of sectors increases, from the simple 3 of this example to larger *n*—such as 51 states or 63 industries—the likelihood of greater importance for the covariance effects increases. For example, as the number of variance-difference terms increases from 3 to n, the number of covariance-difference terms increases from 6 to $n(n–1)$.

To illustrate, assume that the weights are all equal (i.e., $w_i = 1/n$), and all individual variance and covariance differences in (9) are the same and equal to v. Then the "variance effects" are equal to nv, while the "covariance effects" sum to $n(n–1)$v. The ratio of the covariance-effects sum to the variance-effects sum is $n–1$, which is essentially the same as the number of disaggregated components. Thus, in this study, the high ratios of covariance effects to variance effects across 13 industry groups or 8 regions reported in Table 1, or across 63 industries or 51 states reported in Table 2, are not surprising. It follows that explanations for the aggregate variance decline in terms of declines in component variances are likely to be incomplete.

Appendix 5: Regional and Industrial Data

Real GDP-by-state statistics with industry detail are available on BEA's Web site <www.bea.gov>. Data for 1977 to 1997 is available on an Standard Industrial Classification (SIC) basis. Data for 1997 to 2007 is available on a North American Industry Classification System (NAICS) basis. BEA strongly cautions against linking the SIC and NAICS estimates. There are several reasons for this. The two series are based on different source data and methodologies. One result is that NAICS-based GDP-by-state estimates are generally consistent with BEA's GDP measure from the national income and product accounts and SIC-based GDP-by-state estimates are more consistent with gross domestic income (GDI). The differences may affect the levels and growth rates of GDP-by-state estimates, making it unwise to construct a single time series.

This analysis relied on the SIC estimates, which are based on annual percent changes, resulting in a time series from 1978 to 1997. BEA does not at present consider available price estimates to be adequate to estimate real industry GDP-by-state statistics for years prior to 1977.

The change in the GDP volatility in or near 1984 that has been identified by several researchers is used in this analysis as a break point. The study evaluates two periods, 1978–84 and 1985–97. Seven observations are available for the higher-volatility 1978–84 period, and 13 for the lower-volatility 1985–97 period. These small sample sizes argue against doing elaborate statistical analyses, so significance tests of the declines in variances are not computed.

A problem arises when the contribution to GDP by state by specific industries is not substantial in at least some years. In this analysis, when the industry-level GDP by state values are not at least $10 million in at least one year, the industry contribution to GDP in a given state is added to contribution of the same industry in an adjacent state. For example, the contributions to GDP by the motor vehicle industry in Maryland and the District of Columbia are combined, as are the GDP contributions of the motor vehicle industries in Maine, Vermont, and New Hampshire. Some thinly populated Western states with small motor vehicle industry activity are also combined.

If the values are all below $10 million, the industry contributions to GDP are set to zero for that state. This generally preserves the national total real GDP by state for industries. In the most prominent case, the GDP by state for pipelines (other than natural gas) are not separately identified (or set to zero) in 14 states. This convention produces very small impacts on the estimates of results presented below for states and is not needed for regions. Some sort of aggregation is necessary because it is impossible to calculate variances for state industry GDP if one or more observations are less than $0.5 million.

Chart 1.--Real GSP and Real GDP; percent change

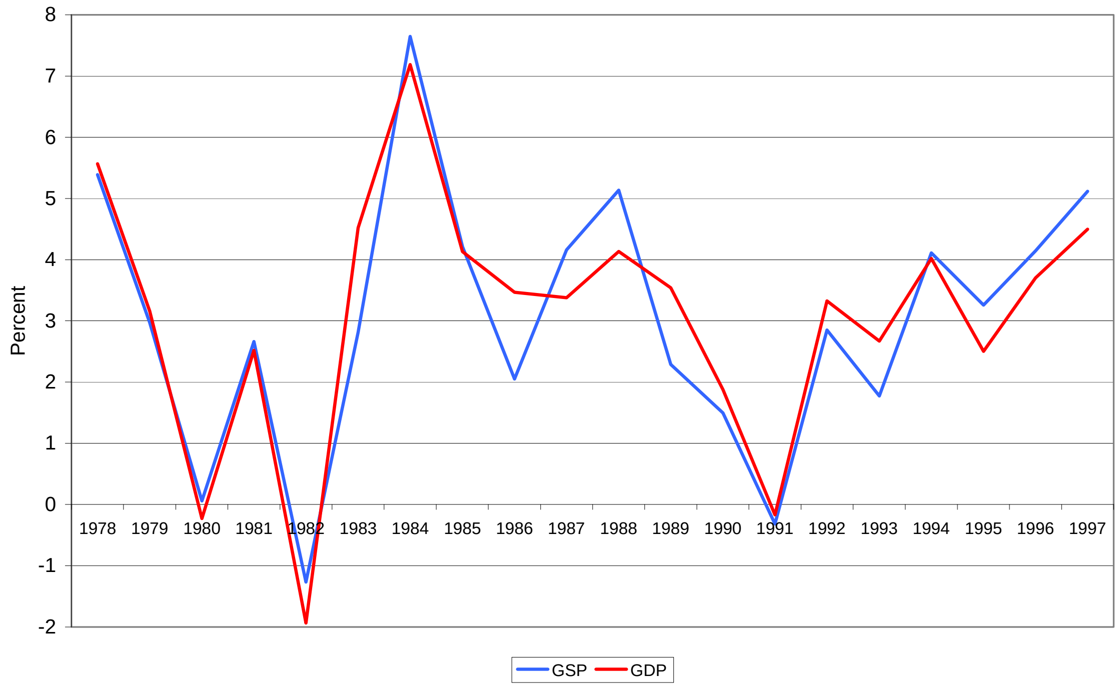

Chart 2.--Real GSP and Real GDI; percent change

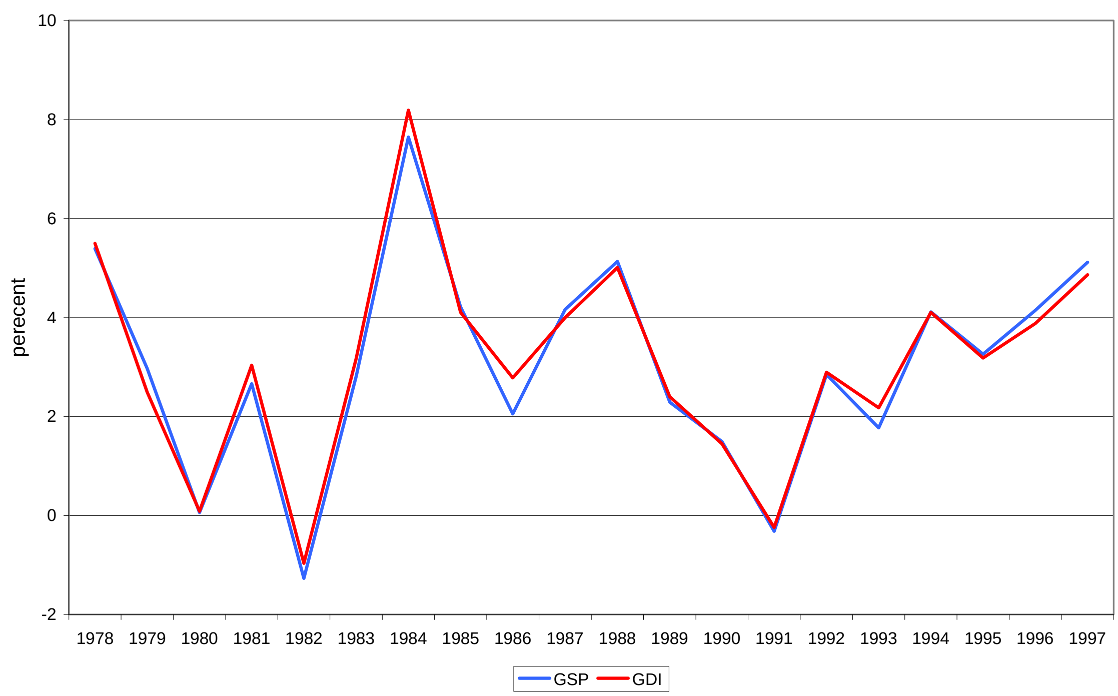

Chart 3

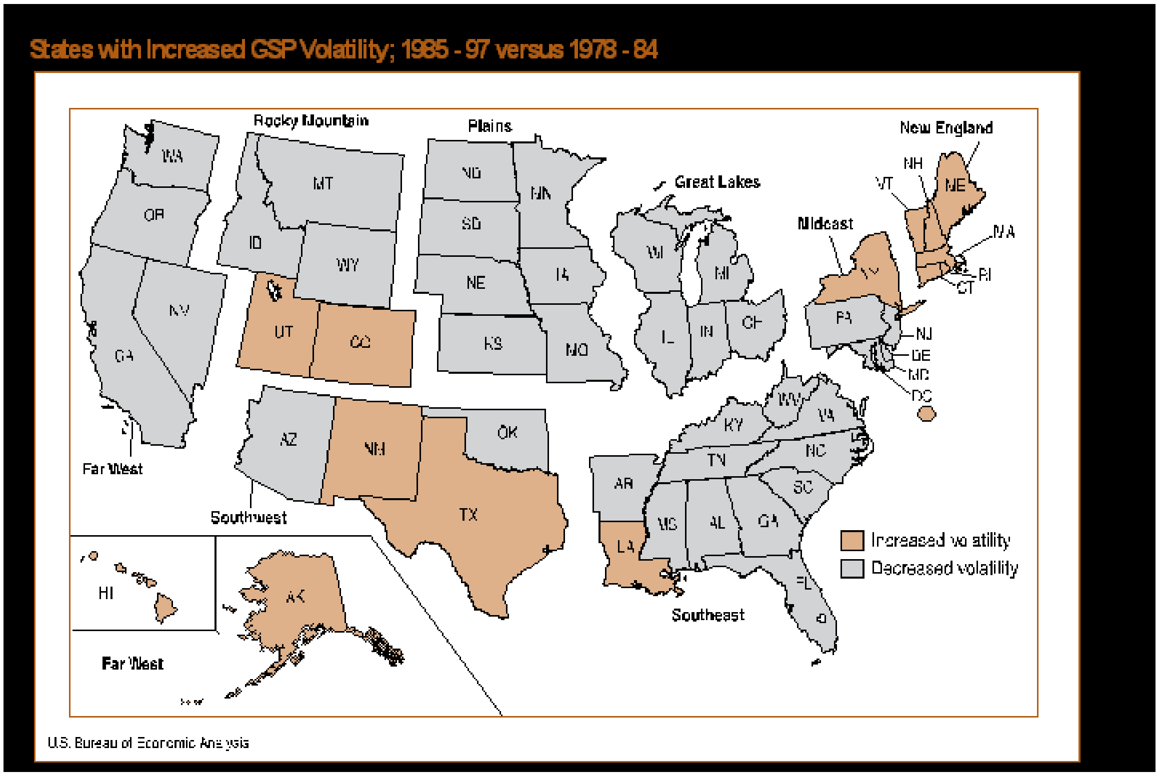
States with Increased GSP Volatility; 1985 - 97 versus 1978 - 84
Rocky Mountain
Plains
New England
Great Lakes
Mideast
Far West
Southwest
Southeast
Far West
WA
OR
CA
NV
ID
MT
WY
UT
CO
AZ
NM
TX
OK
ND
SD
NE
KS
MN
IA
MO
AR
LA
WI
MI
IL
IN
OH
KY
TN
MS
AL
GA
FL
SC
NC
VA
WV
PA
NY
VT
NH
ME
MA
RI
CT
NJ
DE
MD
DC
HI
AK
Increased volatility
Decreased volatility
U.S. Bureau of Economic Analysis

Chart 4. 6-Year Variances

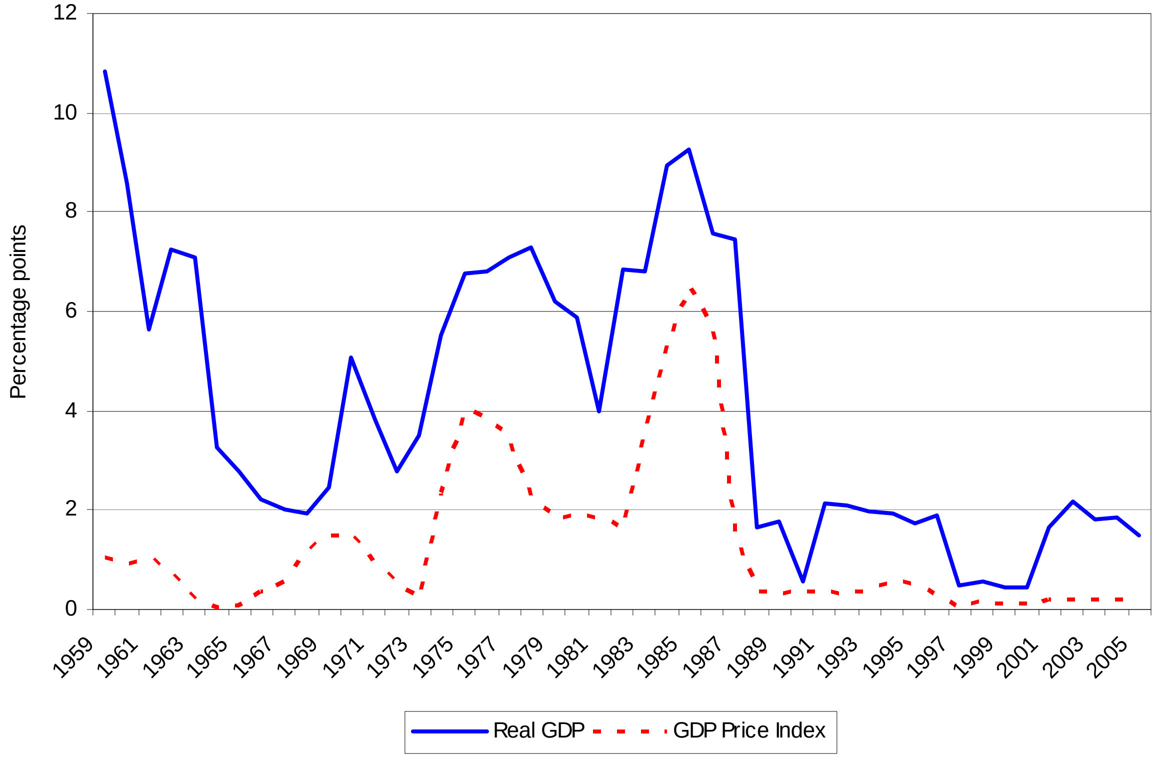

Chart 5. 6-Year Variance of Real GDP

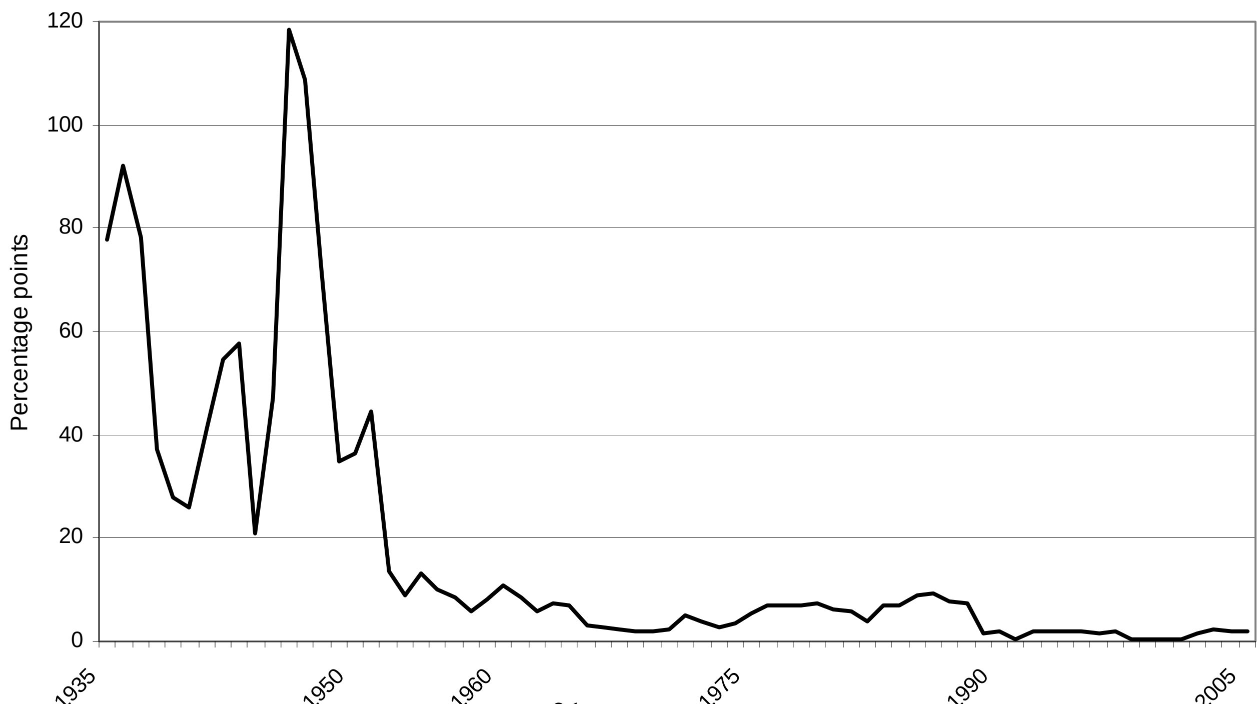

Table 1.— Industry Groups' and Regions'Effects on the Variance of Real National GDP by State
[Percentage points]

	Variance		
	1978-84	1985-1997	Change
National GDP by State variance	7.7	2.3	-5.4
Effects of industry groups' variances and covariances			
Weighted sums of groups' variances	1.3	0.6	-0.7
Residual, including covariances	6.5	1.8	-4.7
Effects of regions' variances and covariances			
Weighted sums of regions' variances	1.4	0.6	-0.8
Residual, including covariances	6.3	1.8	-4.5

Table 2.— Industries' and States' Effects on the Variance of Real National GDP by State
[Percentage points]

	Variance		
	1978-84	1985-1997	Change
National GSP variance	7.7	2.3	-5.4
Effects of industries' variances and covariances			
Weighted sums of industries' variances	1.0	0.9	-0.1
Residual, including covariances	6.7	1.5	-5.2
Effects of states' variances and covariances			
Weighted sums of states' variances	0.4	0.3	-0.1
Residual, including covariances	7.3	2.1	-5.2

Table 3.—Changes in Variance of Industry Groups' GDPs Disaggregated by States; 1978-84 to 1985-97
[Percentage points]

Industry Group	1978-84 variance	Change in variance	Weighted sum of variance effects	Covariance effects, other
Agriculture, forestry, and fishing	364.1	-274.5	-12.9	-261.6
Mining	67.9	-45.3	-2.9	-42.4
Construction	84.9	-68.5	-69.0	0.5
Durable manufacturing	58.0	-36.2	-2.6	-33.6
Nondurable manufacturing	17.9	-9.4	-0.3	-9.2
Transportation	31.3	-14.2	-0.4	-13.7
Communications	21.1	41.3	1.6	39.7
Electric, gas, and sanitary services	14.7	20.3	0.5	19.8
Wholesale trade	14.4	-4.0	-0.2	-3.8
Retail trade	19.7	-8.1	-0.2	-7.8
Finance, insurance, and real estate	2.7	-1.0	0.2	-1.2
Services	4.9	-1.9	0.0	-1.9
Government	0.7	0.1	0.1	0.0
Addenda:				
Manufacturing	30.6	-17.0	-0.9	-16.1
Transportation and public utilities	4.8	46.1	1.7	44.4

Table 4.—Changes in Variance of Industries' GDPs; 1978-84 to 1985-97
[Percentage points]

Industry	1978-84 Variance	Change in variance	Weighted. sum of variance effects	Covariance effects, other
Farms	542.6	-376.7	-15.2	-361.4
Ag. services, forestry, and fishing	14.2	21.1	2.5	18.6
Metal mining	202.5	-167.6	3.3	-170.9
Coal mining	80.8	-51.9	-6.2	-45,7
Oil and gas extraction	97.7	7.0	0.4	6.6
Nonmetalic minerals, except fuels	232.4	-190.6	-7.7	-182.9
Construction[a]	84.9	-68.5	-69.0	0.5
Lumber and wood products	77.6	-35.1	-3.1	-32.0
Furniture and fixtures	64.8	-42.0	-0.8	-41.2
Stone, clay, and gas products	124.7	0.4	0.1	0.3
Primary metal industries	200.9	-176.3	-7.5	-168.8
Fabricated metal products	48.5	-19.2	-2.6	-16.6
Industrial machinery and equipment	69.0	4.2	2.3	1.9
Electronic and other … equipment	56.6	18.8	9.5	9.3
Motor vehicles and equipment	471.4	-346.2	-459.3	113.1
Other transportation equipment	131.0	-81.2	0.7	-81.8
Instruments and related products	21.2	197.2	54.7	142.5
Miscellaneous manufacturing	169.2	-142.6	-8.3	-134.3
Food and kindred products	23.2	25.7	1.6	24.0
Tobacco products	131.7	135.5	-9.7	145.2
Textile mill products	24.8	-9.0	-1.4	-7.5
Apparel and other textile products	33.6	-28.2	-1.1	-27.1
Paper and allied products	22.3	5.5	2.1	3.4
Printing and publishing	12.4	-2.5	0.3	-2.8
Chemicals and allied products	39.6	-16.3	3.7	-20.0
Petroleum and coal products	1558.3	-1147.6	-76.0	-1071.6
Rubber and misc. plastics products	43.3	-28.3	-1.3	-27.0
Leather and Leather products	24.9	30.3	15.0	15.3
Railroad transportation	76.6	-39.7	0.2	-39.2
Local and interurban passenger trans.	31.3	7.3	0.9	6.4
Trucking and warehousing	52.0	-44.9	-1.8	-43.1
Water transportation	20.3	8.6	-0.7	9.3
Transportation by air	55.6	-15.2	-0.1	-15.2
Pipelines, except natural gas	216.5	-143.4	-53310.8	53167.5
Excluding Alaska	317.2	-196.7	-4.6	-192.1
Transportation services	15.2	-1.2	0.0	-1.2
Communications[a]	21.1	41.3	1.6	39.7
Electric, gas, and sanitary services[a]	14.7	20.3	0.5	19.8
Wholesale trade[a]	14.4	-4.0	-0.2	-3.8
Retail trade[a]	19.7	-8.1	-0.2	-7.8
Depository institutions	3.7	30.8	7.8	23.0
Nondepository institutions	14.8	454.0	-1413.9	1867.9
Security and commodity brokers	23.7	237.0	64.3	172.7
Insurance carriers	87.8	-40.8	3.0	-43.8
Insurance agents, brokers & services	28.9	27.7	1.5	26.1
Real estate	3.1	-0.4	-0.2	-0.2

Table 4 continued.—Changes in Variance of Industries' GDPs; 1978-84 to 1985-97
[Percentage points]

Industry	1978-84 Variance	Change in variance	Weighted. sum of variance effects	Covariance effects, other
Holding and other investment offices	10.7	327.4	-228.0	555.3
Hotels and other lodging places	18.2	-9.6	-1.4	-8.2
Personal services	13.8	1.4	0.2	1.3
Business services	17.1	18.3	1.4	16.9
Auto repair, services, and parking	28.4	-7.3	-0.5	-6.9
Miscellaneous repair services	82.8	-42.2	-3.9	-38.2
Motion pictures	105.6	-42.0	-17.3	-24.7
Amusement and recreation services	2.1	20.3	3.0	17.3
Health services	2.5	2.1	0.2	1.9
Legal services	14.8	1.5	0.5	1.0
Educational services	5.7	-2.2	-0.2	-2.0
Social services	24.6	-21.1	-1.7	-19.4
Membership organizations	1.1	2.5	0.0	2.5
Other services	19.0	78.9	4.1	74.8
Private households	65.5	-49.8	-3.8	-46.0
Federal civilian (government)	5.2	-1.3	0.1	-1.3
Federal military (government)	2.5	1.1	0.5	0.6
State and local (government)	0.9	-0.3	0.1	-0.3

a. Also designated to be a (one industry) industry group in this study.

Table 5.—Equations Explaining Variances and Changes in Variances for National GDP by State

Dependent variable	Explanatory variable	Constant term	Explanatory variable coefficient	R-bar-square
1a. Delta variance	1978-84 variance	45.675 ***(3.91)	-0.782 ***(15.35)	0.791
1b. Delta variance	1978-84 variance	21.211 ***(4.10)	-0.734 ***(9.70)	0.641
2. 1985-97 variance	1978-84 variance	49.555 ***(3.77)	0.154 (1.39)	0.015

*** $p \leq .001$

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