# "Inventory Investment and Output Volatility"

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**Abstract:** This paper reports the results of a detailed examination of the hypothesis that improved inventory management and production techniques are responsible for the decline in the volatility of U.S. GDP growth. Our innovations are to look at the data at a finer level of disaggregation than previous studies, to exploit cross-sectional heterogeneity to obtain clearer identification of this hypothesis, and to provide a complete accounting of the change in GDP volatility. Changes in inventory behavior can account directly for only up to half of the total reduction in GDP volatility. Cross-section evidence from the manufacturing and trade sector indicates that change in the covariance structure among industries accounts for most of the remaining portion of the reduction in GDP volatility. Sales have become less correlated among industries and inventory investment has become more correlated. These distinctive changes in co-movement of industries suggest that development and management of supply chains may be an indirect channel through which changes in inventory management and production techniques have influenced GDP volatility.

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## 1. Introduction

Two recent thought-provoking papers have documented a decline in the volatility of U.S. real GDP growth. McConnell and Perez-Quiros (1999) argue that the volatility of GDP growth experienced a one-time drop around 1984, with volatility since then being about half what it was before then, as can be seen in Figure 1 (vertical line at 1984:Q1). Blanchard and Simon (1999) also argue that the volatility of GDP growth has declined, but believe that it has been declining steadily since the 1950s. Although the two studies disagree on the nature and timing of the decline in volatility, they agree that the decline in volatility is linked to inventory investment.[1]

Other studies have also investigated the reduction in volatility but do not attribute it to inventory investment. Stock and Watson (2002) attribute most of the reduction to improved monetary policy, and Ahmed, Levin, and Wilson (2002) attribute most of the reduction to "good luck." Ramey and Vine (2001) argue that the apparent strong link between output volatility and inventory behavior is an indirect consequence of lower sales volatility. They demonstrate that a small reduction in sales volatility will induce a large decline in output and inventory volatility if there are non-convexities in the cost function, and provide evidence from U.S. auto plants.

McConnell and Perez-Quiros report that output volatility declined primarily in inventory holding (goods producing) sectors, especially durable goods industries, and conclude (p. 1474), "Clearly, some aspect of inventory investment in the United States has changed in such a way as to have markedly reduced the volatility of U.S. output fluctuations." Kahn, McConnell and Perez-Quiros (2002) further demonstrate that the decline in output and inventory volatility coincides with a decline in the ratio of inventories-to-sales (I/S ratio), which they assume reflects

[1] Warnock and Warnock (2000) offer similar evidence based on employment, and also suggest a possible role for inventory management changes in reducing volatility. Kim and Nelson (1999) also provide evidence of a break in 1984 using a nonlinear business cycle model, but they do not offer explanations for the break.

improved inventory management techniques. They further speculate that improvements in management techniques resulted from the installation of information technology capital.

Blanchard and Simon instead focus on the correlation of inventory investment with sales growth. They report that the correlation was positive (pro-cyclical inventory investment) until the mid-1980s, when it turned significantly negative (counter-cyclical). This change accounts for much of the reduction in output volatility and they conclude, “This fact…. *must* [emphasis added] have come from a change in the inventory management of firms.”

In this paper, we conduct a more detailed investigation of the hypothesis that changes in inventory behavior are responsible for a reduction in output volatility. Although the existing evidence is intriguing, it is only suggestive thus far (as authors in the literature have pointed out). At fairly *aggregate* levels, it appears that volatility and inventory behavior may be correlated, but of course correlation does not imply causation. Even if the hypothesis is true, there is little understanding of exactly how or why it is true. Our innovation is to begin examining the cross-section evidence on inventory behavior and volatility change at the detailed industry level. In this introductory exploration, we take as given a one-time break (reduction) in GDP output volatility in 1984, as argued by McConnell and Perez-Quiros.

Examination of cross-section evidence offers several advantages over aggregate approaches. First, cross-section data offer greater opportunity to obtain clearer identifying restrictions on potential explanations for the reduction in aggregate volatility. For example, industries that exhibit greater improvements in inventory management should experience greater reductions in volatility. Second, detailed industry data can offer a clearer view of the mechanism by which inventory management works to reduce volatility through reference to specific developments in the industry. For example, widespread publicity has been given to just-in-time techniques adopted by the automotive industry. Third, an important innovation in inventory management has been the development of more sophisticated supply chains among firms and industries. Studying detailed industries allows us to examine the role of inventory management in the stage-of-fabrication linkages of supply chains.

Our results support the hypothesis that changes in inventory behavior helped reduce the volatility of output. Industry-level data reveal a strong cross-section correlation between reductions in output volatility and reductions in average inventory-to-sales ratios, which presumably reflect improved management techniques. However, the direct influence of changes in inventory behavior accounts for only slightly less than half of the total reduction in GDP volatility. The remainder must be explained either by factors unrelated to inventory behavior or by indirect effects of changes in inventory behavior.

A novel finding is that much of the remaining portion of the reduction in GDP volatility is attributable to lower covariance of output and sales – both between the inventory-holding sector and other sectors, and among industries within the inventory-holding sector itself – and to reduced covariance between sales and inventory investment. In particular, although most industries experienced lower sales volatility, most of the reduction in aggregate sales volatility is attributable to reduced covariance among industries' sales. We hypothesize that this covariance reduction may be evidence of indirect effects of changes in inventory behavior that have occurred through the development and management of sophisticated supply chains in the economy.

The paper contains three main sections. Section 2 describes our decomposition of the variance of GDP volatility among major sectors. It shows that improvements in inventory management may be an important contributor to lower GDP volatility and that change in the covariance structure is another important factor. Section 3 examines industry-level behavior within the inventory-holding sector, noting the heterogeneity in reductions of industry volatility and the connection to industry size. It also reports an analogous decomposition of output volatility for the combined manufacturing and trade sector. Section 4 presents some simple cross-sectional evidence on inventory management and production volatility at the industry level. Conclusions follow in Section 5.

## 2. Aggregate Decomposition

Initial observations about inventory behavior and output volatility have been based on national income and product account (NIPA) data at high levels of aggregation. Output is real GDP growth, and inventories are total private business stocks. The total private business sector includes diverse industries such as farming, construction, manufacturing, and trade (wholesale and retail), as well as an "other" category. Inventories generally are not held by many other service-producing sectors, such as finance, insurance, and real estate (FIRE), transportation, services, and government.[2] Thus, the economy comprises two main sectors: one that holds inventories and one that does not.

This two-sector decomposition of the economy raises the first obvious question. Did output volatility change in both the inventory-holding sector and the sector without inventories? If output volatility declined in the sector without inventories as much as it did in the inventory-holding sector, one should question whether inventory management could be responsible for the decline in aggregate GDP volatility.

### *2.1 Methodological Approach*

To answer this question, we examine the output growth behavior of three main sectors of GDP and calculate how much of the change in volatility of real GDP growth is attributable to each sector.[3] The goods sector (G) is assumed to be the inventory-holding sector. The structures sector (ST) mainly produces to order and holds few, if any, inventory stocks.[4] The third sector, services (SV), does not hold inventories. In the NIPA, output (real GDP) of the goods sector is the sum of the levels of final sales of goods and total private sector inventory investment:

$$Y_t = S_t + \Delta I_t \ .$$

Because NIPA output is a value added concept, inventory investment includes all types of stocks (finished goods, work-in-process, and materials and supplies). Output (real GDP) in services and structures equals final sales of those sectors.

We must use growth rates of the data because they are expressed in chain-weighted 1996 dollars. The chain-weighting procedure of constructing real data has advantages with regard to growth rate calculations and price measurement, but it introduces severe difficulties with aggregating and manipulating data in levels. As a result, we focus on contributions to aggregate real growth, i.e., real growth rates weighted by shares of nominal data.[5] Only growth contributions of GDP components can be aggregated exactly to equal GDP growth. Raw growth rates can be aggregated approximately, but the error typically is too large to permit exact

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[2] Firms in these sectors may actually hold inventories, but inventory data are not collected for these sectors. Households also probably hold some inventories of goods, but these are not counted either.
[3] Kahn, McConnell, and Perez-Quiros (2002) use the same disaggregation scheme and compute some, but not all, of the variance decomposition components that we report.
[4] Data on construction inventories are available only since 1997 as a result of the recent change in industrial classification scheme to NAICS from SIC.
[5] For more details about the proper procedures for working with chain-weighted data, see Landefeld and Parker (1997) and Whelan (2000). In particular, note that there is essentially no "clean" way to measure or control for changes in real shares across industries.

decompositions. Throughout the paper, lowercase characters denote growth rates (e.g., $y_t$) and an overhead tilde denotes growth contributions ($\tilde{y}_t$).

Figure 2 plots real GDP growth contributions for the goods, services, and structures sectors plus the contribution of inventory investment since 1947. It is immediately apparent that the variance of goods output is lower in the period after the early 1980s (vertical lines at 1984:Q1), and that the variance of inventory investment is lower during this period as well.[6] The variance of structures output also appears to have dropped since the early 1980s. After declining early in the sample, the variance of services output has been fairly steady since around 1960, so the service sector does not exhibit the same kind of one-time drop in output volatility around 1984. Also, note that since the variances of goods output and inventory investment are much larger than the variances of structures and services output, declines in the variances of goods output and inventory investment have more scope for accounting for the decline in overall GDP volatility.

Table 1 provides a variance decomposition of quarterly GDP growth contributions for each of the three major sectors. We calculate the unconditional variances of output over the two periods identified by McConnell and Perez-Quiros (1999) – an early period, prior to 1984:Q1, and a late period, 1984:Q1 through 2001:Q4. The early period begins in 1959 to coincide with the sample period of the industry-level data available for the manufacturing and trade sectors used in the subsequent sections of the paper.

Looking down a particular column of Table 1 we find the components of the variance decomposition of real GDP growth,

[6] The variance of the growth contribution of final sales in the goods sector, not shown in Figure 2, is also lower after the early 1980s, as is apparent from Table 1 below.

$$\begin{aligned}&\mathrm{Var}(y) = \mathrm{Var}(\tilde{y}_G) + \mathrm{Var}(\tilde{y}_{SV}) + \mathrm{Var}(\tilde{y}_{ST}) \\ &+2\left[\mathrm{Cov}(\tilde{y}_G, \tilde{y}_{SV}) + \mathrm{Cov}(\tilde{y}_G, \tilde{y}_{ST}) + \mathrm{Cov}(\tilde{y}_{SV}, \tilde{y}_{ST})\right]\end{aligned},$$

where "Var" and "Cov" stand for time series variance and covariance, respectively. The variance of goods output is decomposed further as follows:

$$\mathrm{Var}(\tilde{y}_G) = \mathrm{Var}(\tilde{s}_G) + \mathrm{Var}(\Delta\tilde{i}_G) + 2\mathrm{Cov}(\tilde{s}_G, \Delta\tilde{i}_G) \ .$$

Some of the information in the table is similar to that reported in Kahn, McConnell, and Perez-Quiros (2002). However, by including information they did not report or emphasize, the table offers a more complete understanding of the total change in GDP volatility. The first two columns report the variance or covariance in the early and late periods, and the third column reports their ratio (late/early). Ratios less than one indicate a decline in volatility. The last two columns report the percent shares of the changes in total GDP variance, $\Delta\mathrm{Var}(y)$, accounted for by changes in each component of the decomposition, and the percent shares of the changes in the goods sector output variance, respectively. For example, the goods variance term 63.8, is $100 \times [\Delta\mathrm{Var}(y_G) / \Delta\mathrm{Var}(y)]$, and likewise for all other terms.

***2.2 Decomposition Results***

The results in Table 1 reveal that the 64 percent of the reduction in output volatility did indeed occur in the goods sector, and that much of this reduction involved changes in inventory investment behavior. However, the table also reveals clearly that the change in overall GDP volatility cannot be attributed simply to the goods sector or to inventory investment alone. Instead, the volatility reduction is more widespread and complex.[7]

Output volatility declined significantly in the goods and structures sectors but not in the services sector. Output variance fell by a factor of four (output standard deviation fell by a factor of two) in both the goods and structures sectors, as measured by the variance ratios. Because the structures sector does not hold officially measured inventories, a simple inventory management story cannot explain the volatility reduction in structures. However, because the construction sector does hold some stocks, and because the structures sector uses goods supplied by wholesalers, retailers, and manufacturers, the structures sector is closely linked to the goods sector. Smoother production of structures should affect inventory and production behavior in the goods sector, and more reliable production or inventory management in industries that produce construction goods should influence the structures sector production behavior. For example, fewer shortages of construction materials (in the goods sector) should reduce the variance of structure sector output.

In contrast to these sectors, output variance in services was about the same in both periods (variance ratio about 1). This lack of a discernable reduction in services output volatility raises doubts about explanations of reduced GDP volatility that depend on a reduction in aggregate shocks, or "good luck." Aggregate shocks seemingly would affect all sectors of the economy, unless there were some complicated feedback mechanism at work that offsets the aggregate effects on services. However, the stability of services output growth leaves room for explanations that rely on differential effects among sectors, where services are affected less than other sectors.

Because output volatility declined only in the goods and structures sectors, which either hold inventories or may be linked to inventory behavior, it is natural to suspect that changes in inventory management may be connected to the volatility decline.[8] So, the answer to our earlier

[7] Kim, Nelson, and Piger (2001) also found the reductions in volatility to be widespread and point out that the volatility of aggregate final sales declined similarly to the volatility of GDP.
[8] Kahn, McConnell, and Perez-Quiros (2002) also make this point.

question of whether output volatility changed by the same amount in the inventory-holding and non-inventory holding sectors is “no.”

The variance decomposition for the goods sector in Table 1 supports a role for inventory management changes in the reduction of GDP volatility. The variance of goods inventory investment declined by 60 percent, from the early period to the late period, and the covariance between inventory investment and sales declined, becoming much more negative in the latter period, as was observed first by Blanchard and Simon (1999). However, the variance of final goods sales also declined by more than half.

Interestingly, the covariance among the three aggregate sectors also declined considerably from the early period to the late period. Qualitatively, the most notable change was that services became uncoupled from the rest of the economy. Services sector output, which had been positively correlated with output in the goods and structures sectors during the early period, became uncorrelated with the other sectors in the later period. The change was particularly marked for the covariance between goods and services, which actually declined so much that it turned slightly negative in the later period. The covariance between goods output and structures output also became much smaller.

The last two columns of Table 1, which show how much each component contributed to the reduction in GDP volatility, reinforces the points observed earlier. Reductions in the variances of output in the three primary sectors account for 73 percent of the decline in GDP volatility, and declines in the covariance among the three sectors’ output accounts for the remaining 27 percent. Among variance terms, note that the service sector – which accounts for more than 50 percent of nominal GDP – accounted for essentially none of the reduction in variance. Reduction in the variance of output in the structures sector – which accounts for nearly 10 percent of nominal GDP – accounted for more than 9 percent of the decline in GDP volatility, i.e., proportional to its size. Thus, the reduction in variance of the goods sector – which accounts for a little more than one-third of nominal GDP – accounted for a disproportionately large 64 percent share of the reduction in GDP volatility.

Within the goods sector, changes in inventory behavior are responsible for most of the change in goods output volatility. Reductions in the variance of inventory investment and reductions in the covariance between inventory investment and sales of goods together account for 69 percent of the reduction in goods output variance and hence 44 percent of the reduction in GDP variance. However, the reduction in the variance of goods sales is substantial, accounting for the remaining 31 percent of the decline in goods output variance and thus nearly one-fifth of the decline in GDP volatility.[9] This fact appears to support the argument of Ramey and Vine (2001) at the aggregate level. However, we show later that the vast majority of this change in aggregate sales volatility is attributable to reduced covariance of sales among industries.

### *2.3 Some Implications of the Decomposition Results*

The direct effects of changes in inventory behavior – i.e., reductions in the variance of goods inventory investment and in the covariance of goods sales and inventory investment – can account for about half of the decline in GDP volatility. The remaining half of the decline in GDP volatility occurred through reductions in the variance of the sales of the goods sector (19.6 percent) and of the structures sector (9.4 percent) and through reductions in covariance. These reductions may be explained by non-inventory related factors but it is also possible that changes in inventory behavior may have indirect effects that help account for this remaining half of the reduction in GDP volatility. Changes in inventory management techniques should theoretically affect the sales behavior of supplier firms. So some of the reduction of the variance of sales of the goods sector could be an indirect influence on the supply chain of the adoption of new inventory and production management techniques. The reduction in the covariance of goods and structures is estimated to account for 19 percent of the reduction in GDP volatility. This too may partially reflect the adoption of inventory and production control methods by goods suppliers who supply construction materials to the structures sector.

If a key factor behind changes in inventory behavior involves changing supply chain relationships between firms and industries, then inventory management changes in one firm or industry should affect the sales behavior of an upstream firm or industry. Furthermore, inventory innovations occurring through supply chain management likely would change the covariance between firms and industries. The importance of changes in covariance is reinforced when we look further inside the goods sector, which we turn to next.

## 3. Inventory Sector Decomposition

To investigate the cross-section evidence on the link between inventory behavior and output volatility, we examine the inventory and production behavior of industries within the goods, or inventory-holding, sector. This section reports the results of three basic calculations. First, we look at the industry-level distributions of changes in volatility to see whether volatility declined uniformly across industries or not. Second, we check to see whether changes in output volatility across industries were related to the size of industries. Finally, we decompose the variance of the goods sector to gain a better understanding of the potential role of industry-level covariance reductions.

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[9] Kahn, McConnell, and Perez-Quiros (2002) emphasize that the reduction in sales volatility is much smaller in

*3.1 Data and Methodological Issues*

In this part of the investigation, we used quarterly data from the Bureau of Economic Analysis for the manufacturing and trade (M&T) sector during the period 1967 through 2002:Q1. For this analysis, we divided the sector into 2-digit SIC manufacturing industries and 3-digit SIC retail and merchant wholesale trade industries. NIPA data are not available at this level of industry detail and frequency.

Three important differences arise between the NIPA and the M&T data. First, the M&T sector represents only a subset of the NIPA goods sector, which includes other sectors such as mining and agriculture. Second, the M&T sales data do not exclude input materials costs, and thus M&T output is gross production rather than value added. This means that there is double counting of sales (especially within manufacturing) when one firm's or industry's sales are another's inputs. If production is Cobb-Douglas with constant returns in all factors with separable input materials, the variance of gross production is

$$\mathrm{Var}(y) = \mathrm{Var}[(1-\alpha)v] + \mathrm{Var}(\alpha m) - 2\mathrm{Cov}[(1-\alpha)v, \alpha m] \ ,$$

where $v$ denotes value added, $m$ denotes input materials usage, and $\alpha$ denotes materials' share. Thus, the variance of gross production can be larger or smaller than the variance of value added, depending on the magnitudes of the variance of materials usage and its covariance with value added (which presumably is positive).[10] We recognize the importance of using value added, as emphasized by Humphreys, Maccini, and Schuh (2001), but the use of gross production is common in inventory studies, and high-frequency data on value added for detailed industries are unavailable. In calculating production, we used total inventory stocks, as in the NIPA.

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durable goods industries where I/S ratios have declined more. Nevertheless, the fact remains that a substantial fraction of total GDP volatility reduction is coming through reductions in sales volatility.

[10] We thank Susanto Basu for reminding us of this point.

A third empirical difference between the NIPA and the M&T data is that M&T output data are not published, but rather must be constructed from sales and inventory investment data. Furthermore, growth contributions are not published for the chain-weighted M&T data. Consequently, we derive industry (subscript *j*) output growth rates from sales growth rates and inventory investment growth rates using lagged nominal weights:

$$y_{jt} = \theta^{s}_{j,t-1} s_{jt} + \theta^{i}_{j,t-1} \Delta i_{jt} \ ,$$

where $s_{jt} = (\Delta S_{jt} / S_{j,t-1})$ is the growth rate of real sales, $\Delta i_{jt} = (\Delta^2 I_{jt} / \Delta I_{j,t-1})$ is the growth rate of real inventory investment, and $\theta^{s}_{j,t-1} = (\hat{S}_{j,t-1} / \hat{Y}_{j,t-1})$ and $\theta^{i}_{j,t-1} = (\Delta \hat{I}_{j,t-1} / \hat{Y}_{j,t-1})$ are lagged *nominal* (denoted by ^) output shares that sum to 1. Nominal output shares must be used because real shares cannot be constructed with chain-weighted real data in levels (see Whelan 2000 for details).

To obtain an approximately correct variance decomposition, we must also construct aggregate M&T output growth using an approximation to the chain aggregate rather than using the actual growth rate of the chain aggregate. We use the Tornqvist formula recommended by Whelan (2000, equation 2, page 10),

$$y_t = \sum_{j=1}^{J} \theta^{y}_{jt} y_{jt} \ ,$$

where $\theta^{y}_{jt} = (1/2) \sum_{\tau=0}^{1} (\hat{Y}_{j,t-\tau} / \hat{Y}_{t-\tau})$ are industry nominal output shares. Henceforth, we use the weighted growth rates as described above but suppress the weights in all notation. Note that the derived industry output growth rates and the Tornqvist aggregate growth rate both involve approximation error.[11]

To gauge the magnitude and nature of the difference between the reported NIPA goods sector output growth rate and the M&T gross output growth rate (with output calculated by the Tornqvist formula), see Figure 3. The two most obvious and important conclusions to draw from the figure are that the output growth rate measures are positively correlated (about 0.7) and that both exhibit a notable reduction in variance beginning around 1984. Overall, M&T gross production is less variable than NIPA value added output, most likely because the M&T sector excludes relatively high-variance sectors (e.g., agriculture) but possibly for reasons related to materials usage, as explained above. However, the relative variance of output in the late and early periods is virtually the same between the two measures (see Table 2).

***3.2 Industry-Level Volatility Change***

The first question we ask is whether all industries in the goods sector experienced similar reductions in output and inventory investment volatility. For each M&T industry, we calculated volatility ratios for $y_{jt}$, $s_{jt}$, and $\Delta i_{jt}$. Figure 4 plots the unweighted frequency distributions of these ratios; the right-hand tail includes all ratios greater than 3. Although the growth of inventory investment, $\Delta i_{jt}$, is the relevant component of the growth of output, $y_{jt}$, it is much more volatile than the other growth rates and somewhat unfamiliar. Consequently, we also show the distribution of volatility ratios for scaled absolute inventory investment, $\left|\Delta I_{jt}\right| / S_{j,t-1}$, a measure used commonly in the recent literature.

[11] Thus, the aggregate M&T output growth rate is not exactly the same as the output growth rate that would be calculated from an output measure obtained by adding the reported level of sales to the reported change in inventory investment.

Nearly all industries in M&T experienced dramatic reductions in output volatility, as can be seen from the upper left panel of Figure 4. The vast majority of industries experienced output variance reductions of more than one-half, and many experienced reductions of more than one-fourth. Most industries also experienced sizable reductions in sales volatility (upper right panel), but the median reduction in volatility was clearly smaller for sales than for production. Interestingly, a small but nontrivial portion of industries actually saw their sales variance increase by as much as 50 percent. The substantial difference between volatility reductions in production and volatility reductions in sales implies that inventory investment volatility changes must have been quite heterogeneous.

Indeed, not all industries experienced reductions in the volatility of inventory investment growth (lower left panel). In fact, about half of all industries experienced reductions in the variance of the rate of growth of inventory investment, $\Delta i_{jt}$, but the other half saw increases in the variance – some industries' late period variance was more than three times larger than the early period variance. Scaled absolute inventory investment, $|\Delta I_t| / S_{t-1}$, did become less volatile for most industries (lower right panel). But the growth of inventory investment, $\Delta i_{jt}$, exhibited more heterogeneous changes in volatility, actually becoming more volatile – ratios greater than 1 – for a substantial fraction of industries.

Although virtually all industries experienced reductions in output volatility, the extensive heterogeneity in the volatility of sales and inventory investment growth should provide sufficient scope for cross-section identification of the effects of inventory behavior on output volatility. First, however, we examine the importance of heterogeneity in industry size and the covariance among industries in the determination of aggregate output volatility.

### *3.3 Industry Size and Volatility Change*

Hypothetically, the reduction in output variance in the goods sector could have resulted from compositional shifts among industries within the sector. Industries with relatively low variance in the early period may have increased in size relative to industries with relatively high variance, leading to a reduction in aggregate volatility but without much change in industry volatility. The results portrayed in Figure 4, which show virtually all industries declining in volatility, seem to rule out compositional shifts as the primary explanation. More detailed examination of the data also has not revealed evidence of a significant secondary effect of compositional change.

However, one systematic compositional effect does stand out, as illustrated by Figure 5. Larger industries, measured in terms of nominal output shares, tended to experience larger relative declines in their production volatility. This tendency, indicated by the regression line in the figure, is significant but fairly modest, at least in linear terms.[12] An increase of 1 percentage point in aggregate share is associated with a decrease of 0.04 in the volatility ratio.

***3.4 Inventory Sector Decomposition***

In the decomposition of GDP variance done in Section 2, we found that reductions in goods output volatility accounted for nearly two-thirds of the change in GDP volatility. Here we report the results of an analogous decomposition of M&T aggregate output variance. This M&T variance decomposition provides a complete accounting of the changes in aggregate variances of $y_t$, $s_t$, and $\Delta i_t$ in terms of the changes in industry variances of $y_{jt}$, $s_{jt}$, and $\Delta i_{jt}$, as well as all covariance terms among industries and variables.

Table 2 reports the decomposition of change in the variance of M&T output growth. The first three rows pertain to the components of the cross-section output variance decomposition,

$$\text{Var}(y) = \sum_{j=1}^{J} \text{Var}(y_j) + 2\sum_{j \neq k} \text{Cov}(y_j, y_k) \ .$$

The remaining rows pertain to the cross-section decomposition of the sales and inventory investment components of output growth,

$$\text{Var}(y) = \sum_{j=1}^{J} \left[ \text{Var}(s_j) + \text{Var}(\Delta i_j) \right] + 2\sum_{j \neq k} \left[ \text{Cov}(s_j, s_k) + 2\text{Cov}(s_j, \Delta i_k) + \text{Cov}(\Delta i_j, \Delta i_k) \right] \ .$$

The table includes the variance and covariance terms in the early and late periods (first two columns), their ratio (third column), and the share of aggregate (M&T) output variance change (fourth column). The last column reports the shares of industry variance and covariance terms within each aggregate variable type.[13]

In general, volatility in the M&T sector declined similarly to the volatility decline of the overall NIPA goods sector, as can be seen by comparing the first three columns of Table 2 with the same columns in Table 1. The output volatility ratio is nearly identical: 0.24 in M&T versus 0.26 in the NIPA goods sector. However, the volatility of M&T sales and inventory investment declined more than in the goods sector, falling about 80 percent compared with 60 percent or less. In contrast, the covariance between sales and inventory investment did not decline as much in M&T as it did in the NIPA goods sector.[14]

The shares of aggregate M&T volatility change accounted for by the aggregate components of output are also broadly similar to those in the goods sector, as can be seen by comparing the last two columns of Tables 1 and 2. Reductions in the volatility of sales and

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[12] The data points in Figures 5 through 8 are industries' SIC number. A glance at Figure 5 suggests the true relationship may be nonlinear, but we have not explored this possibility.

[13] Note that the approximation errors from using nominal weights and the Tornqvist formula prevent the variance decomposition from adding up exactly. The cumulative approximation error typically is not more than 3 percentage points for any particular category.

inventory investment accounted for 42 percent and 51 percent, respectively, of the decline in M&T output volatility, compared with 31 percent and 49 percent, respectively, for the goods sector. The relatively larger contribution of M&T sales volatility change is offset by a relatively smaller contribution of the sales-inventory investment covariance change (7 percent versus 20 percent).

Thus far, the aggregate M&T results generally affirm the conclusions drawn from the NIPA goods sector, suggesting that the difference between gross production and value added may not be important for understanding the change in output volatility. The reduction in volatility of inventory investment accounts for about half of the decline in output volatility. The reduction in the volatility of sales is also quite important, and a reduction in the covariance between sales and inventory-investment is nontrivial. Together, the direct effects of changes in inventory behavior account for more than half of the decline in M&T output volatility.

However, the industry-level decomposition of M&T output volatility brings to light an important and intriguing role for changes in the covariance structure among industries in explaining the reduction of GDP volatility. In particular, note that the cumulative covariance among industry output growth rates accounts for 28 percent of the reduction in M&T output volatility. Because the reduction in goods sector output volatility accounted for about 64 percent of the decline in GDP volatility, this result suggests that this reduction in covariance among industry output growth accounts for nearly one-fifth (about 18 percent) of the decline in GDP volatility. Put differently, a significant portion of the explanation for lower GDP volatility lies in an uncoupling of the well-known cyclical co-movement of output of industries in the economy.

[14] Note that the first three columns of Table 2 are based on published chain weighted data on M&T sales and inventory investment with M&T production simply the sum these. The last two columns of Table 2 use M&T production growth rate series calculated by the Tornqvist formula discussed in section 3.1.

The importance and richness of the change in covariance structure is even more apparent when we look at the decomposition of M&T output into its sales and inventory investment components. As we saw earlier in Figure 4, the majority of industries experienced significant declines in the volatility of their sales growth. Despite this, the decomposition in Table 2 indicates that for aggregate M&T sales, the vast bulk of the reduction in sales volatility (87.6 percent) occurred through reductions in covariance among industry sales rather than through reductions in the variance of each industry's sales. This result indicates that although individual industries may have experienced significant reductions in sales volatility, this reduced volatility alone does not account for much of the aggregate change in GDP volatility.

In stark contrast, for M&T inventory investment growth, the reduction in aggregate inventory investment volatility was more than accounted for (126 percent) by reductions in the variances at the industry level. In fact, the total covariance between industries' inventory investment growth actually increased – that is, became either more positive or less negative. This increase in covariance increased aggregate M&T output volatility, and thus contributed negatively (-23 percent) to the actual decline in M&T output volatility.

Changes in inventory behavior explain about half of the reduction in output volatility directly through reductions in inventory investment volatility. It is likely that improved inventory management techniques are responsible for this change. However, Table 2 suggests that changes in the covariance structure among industries that hold inventories play a roughly equal role in explaining reduced output volatility. We suspect that changes in the industry covariance structure point toward a more sophisticated indirect channel through which inventory behavior has influenced output volatility.

Specifically, the reduced co-movement of industry sales and increased co-movement of inventory investment among industries seem to suggest that changes in so-called supply chain relationships among M&T industries may have altered the covariance structure. Development and management of supply chains has played a pivotal role in the implementation of inventory management techniques such as just-in-time production. Supply chains have also been affected by the evolution of information technology, which has increased real time sharing of information on final demand between supplier and customer, increased outsourcing by manufacturing firms, and encouraged the adoption of flexible manufacturing techniques.

## 4. Industry Changes in Inventory Management and Output Volatility

To fully understand the role of supply chains in inventory management and production techniques, it is necessary to examine the behavior of sales and inventory investment at the detailed industry level. For example, it is critical to know whether the covariance changes occurred between industries that have known input-output relationships. It also is important to know whether the reductions in inventory investment volatility in a particular industry were connected to that industry's covariance changes. Answers to these and related questions will come only from a more extensive and detailed examination of the industry evidence.

In this final section, we take one step toward the complete disaggregated analysis needed by looking at the connection between output volatility and inventory management at the industry level. Following Kahn, McConnell, and Perez-Quiros (2002), we interpret reductions in I/S ratios as evidence of improved inventory management. To quantify the magnitude of inventory management changes, we calculate the average I/S ratio of each industry in the early and late periods and take their ratio (late average I/S to early average I/S). Thus, a reduction in the average I/S ratio (ratio less than 1) is assumed to indicate improved inventory management. To better isolate the impact of inventory management change, we disaggregate inventories into their three stages of fabrication: raw materials and supplies, work-in-process, and finished goods.

The cross-section data provide evidence of a significant positive relationship between improved inventory management and the volatility of output and inventory investment, as shown in Figures 6 through 8. The literature argues that firms implementing inventory control techniques should experience reduced variance of output and inventory investment. If the I/S ratio change measure is an accurate proxy for the degree to which inventory control techniques or supply chain changes have reduced an industry's stocks, then the figures support this hypothesis. The regression lines indicate that volatility of output and inventory investment (both the growth rate and scaled absolute investment) tends to decline as the average I/S ratio declines. In other words, industries that improved their inventory management techniques more (i.e., reduced their I/S ratios more) experienced greater reductions in volatility.

An important feature of the result shown in Figures 6 is that the relationship between inventory management and output volatility is by far the strongest for raw materials inventories and weakest for finished goods inventories. This result suggests that theories purporting to explain the role of inventory management in output volatility should emphasize input inventories – raw materials and work-in-process stocks – and their effects on production behavior. Because only the usage of input inventories factors directly into production, the impact of improved management of input inventories on production volatility may be more complex. Attention to supply chains via stage-of-fabrication linkages between firms and industries engaged in input-output relationships may be warranted as well.

The evidence from these simple cross-sections is suggestive but incomplete. Much more analysis along these lines is required to provide more convincing and complete evidence. We plan to extend this approach in future research.

## 5. Conclusions

Developments in the inventory-holding goods sector of the economy probably help explain a significant portion of the reduction in GDP volatility after 1984. This explanation, however, will have to be broader than just the implementation of inventory management techniques to account for all of the change in GDP volatility. The variance of sales in the goods sector, the covariance between sales and inventory investment, and the covariance structure among industries' output and sales also have changed significantly and reduced GDP volatility.

Factors unrelated to inventory behavior might be able to explain some of these other developments, but the altered covariance structure seems particularly challenging for the kinds of theories put forward thus far. For example, it is unclear how improved monetary policy would have reduced the co-movement among industries' sales and increased the co-movement among industries' inventory investment. Looking at changes in the supply chain structure of the goods sector seems a more promising avenue of exploration.

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## Table 1
## Decomposition of Volatility Change in Aggregate Output Growth

| | Volatility | | Volatility Ratio (Late/ Early) | Share of GDP Volatility Change (percent) | |
|---|---|---|---|---|---|
| | Early (1959-83) | Late (1984-2002) | | Total | Sector |
| | | | | | |
| Real GDP | 20.0 | 5.17 | .26 | 100.2 | |
| | | | | | |
| Variance Terms | | | | 73.3 | |
| Goods | 12.70 | 3.25 | .26 | 63.8 | 100 |
| Final Sales | 5.48 | 2.58 | .47 | 19.6 | 30.7 |
| Inventory Investment | 7.65 | 3.03 | .40 | 31.2 | 48.9 |
| Covariance (S,ΔI) | -.22 | -1.18 | | 13.0 | 20.4 |
| Services | .52 | .50 | .97 | 0.1 | |
| Structures | 1.79 | .40 | .22 | 9.4 | |
| | | | | | |
| Covariance Terms | | | | 26.9 | |
| Goods, Services | .43 | -.04 | | 6.4 | |
| Goods, Structures | 1.89 | .51 | .27 | 18.7 | |
| Services, Structures | .18 | .05 | .25 | 1.8 | |

Note: Shares of growth contributions do not add to 100 because of rounding.

Source: Haver Analytics, Inc., NIPA data.

**Table 2**
**Cross-Section Decomposition of Volatility Change in Output Growth of the Manufacturing and Trade Sector**

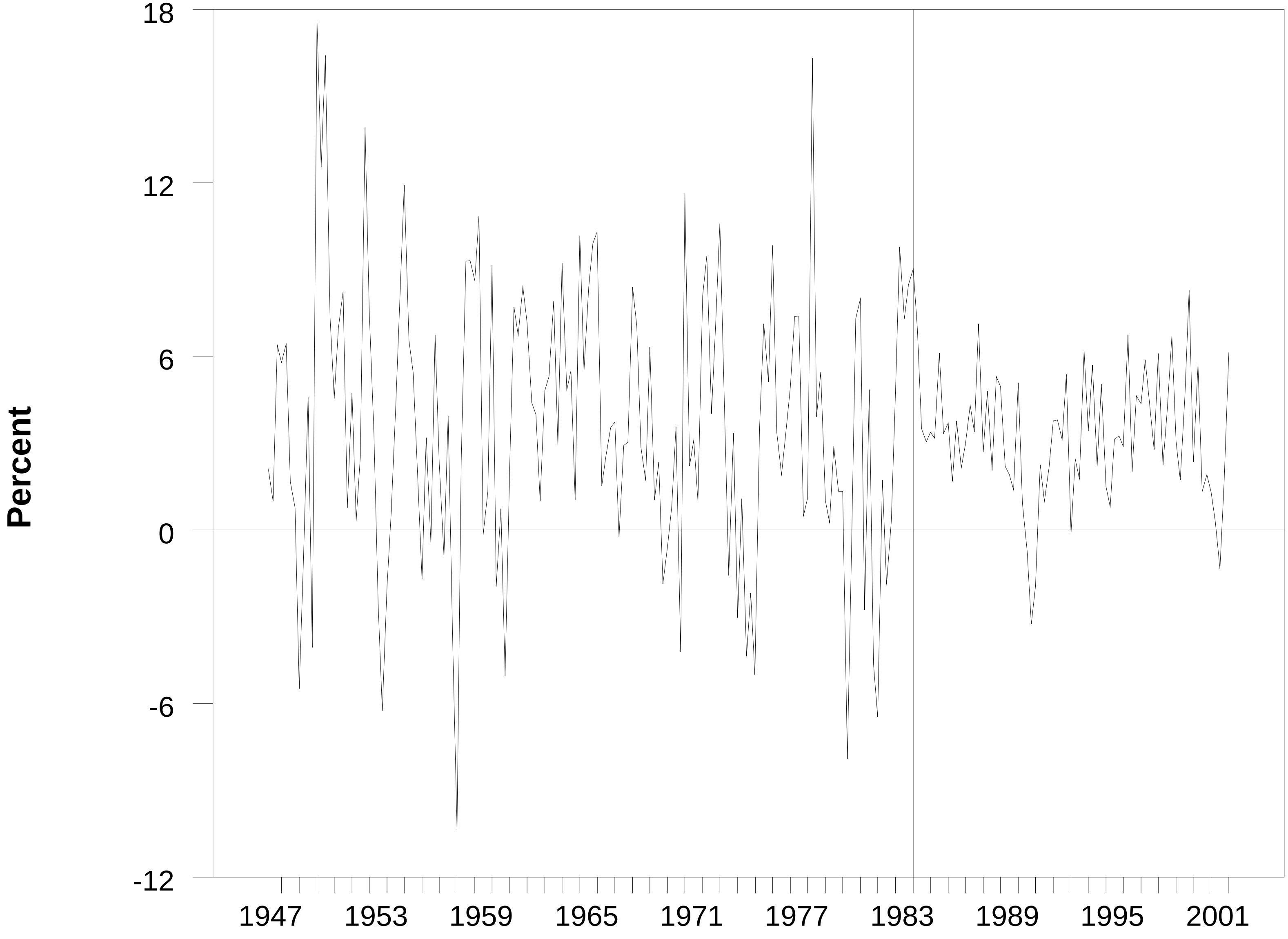
| | Volatility | | Volatility Ratio (Late/ Early) | Share of Aggregate Volatility Change (percent) | |
|---|---|---|---|---|---|
| | Early (67-83) | Late (84-02) | | Total Output | s or $\Delta$i |
| $\Delta\mathrm{Var}(y)$ | 5.64 | 1.35 | .24 | 100.0 | |
| $\sum_j \Delta\mathrm{Var}(y_j)$ | | | | 69.8 | |
| $2\sum_{j\neq k} \Delta\mathrm{Cov}(y_j, y_k)$ | | | | 28.1 | |
| $\Delta\mathrm{Var}(s)$ | 3.78 | .72 | .19 | 42.0 | |
| $\sum_j \Delta\mathrm{Var}(s_j)$ | | | | 5.9 | 14.0 |
| $2\sum_{j\neq k} \Delta\mathrm{Cov}(s_j, s_k)$ | | | | 36.8 | 87.6 |
| $\Delta\mathrm{Var}(\Delta i)$ | 2.08 | .46 | .22 | 51.2 | |
| $\sum_j \Delta\mathrm{Var}(\Delta i_j)$ | | | | 64.4 | 125.8 |
| $2\sum_{j\neq k} \Delta\mathrm{Cov}(\Delta i_j, \Delta i_k)$ | | | | -11.7 | -22.9 |
| $2\Delta\mathrm{Cov}(s, \Delta i)$ | .15 | -.10 | | 6.9 | |

Note: $y$, $s$, and $\Delta i$ are growth rates of output, sales, and inventory investment, respectively, and subscripts *j* and *k* denote industries. Shares do not add to 100 because of errors in the chain weight approximation.

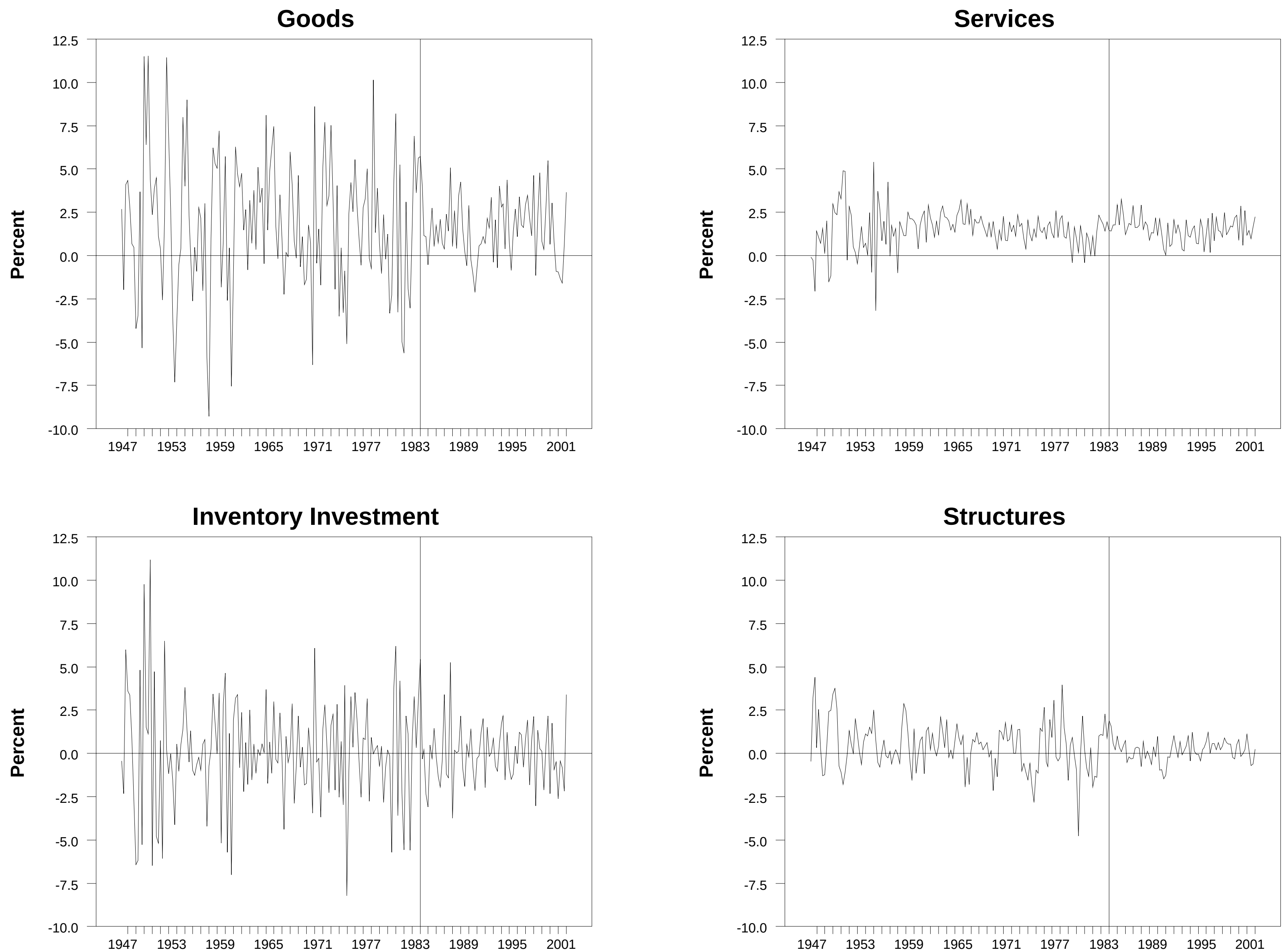
Source: Haver Analytics Inc., BEA NIPA data.

**Figure 1**

**Real U.S. GDP Growth**



# Figure 2
# Contributions to Real GDP Growth



# Figure 3
## M&T Growth Rates in Gross Production and in NIPA Goods Value Added

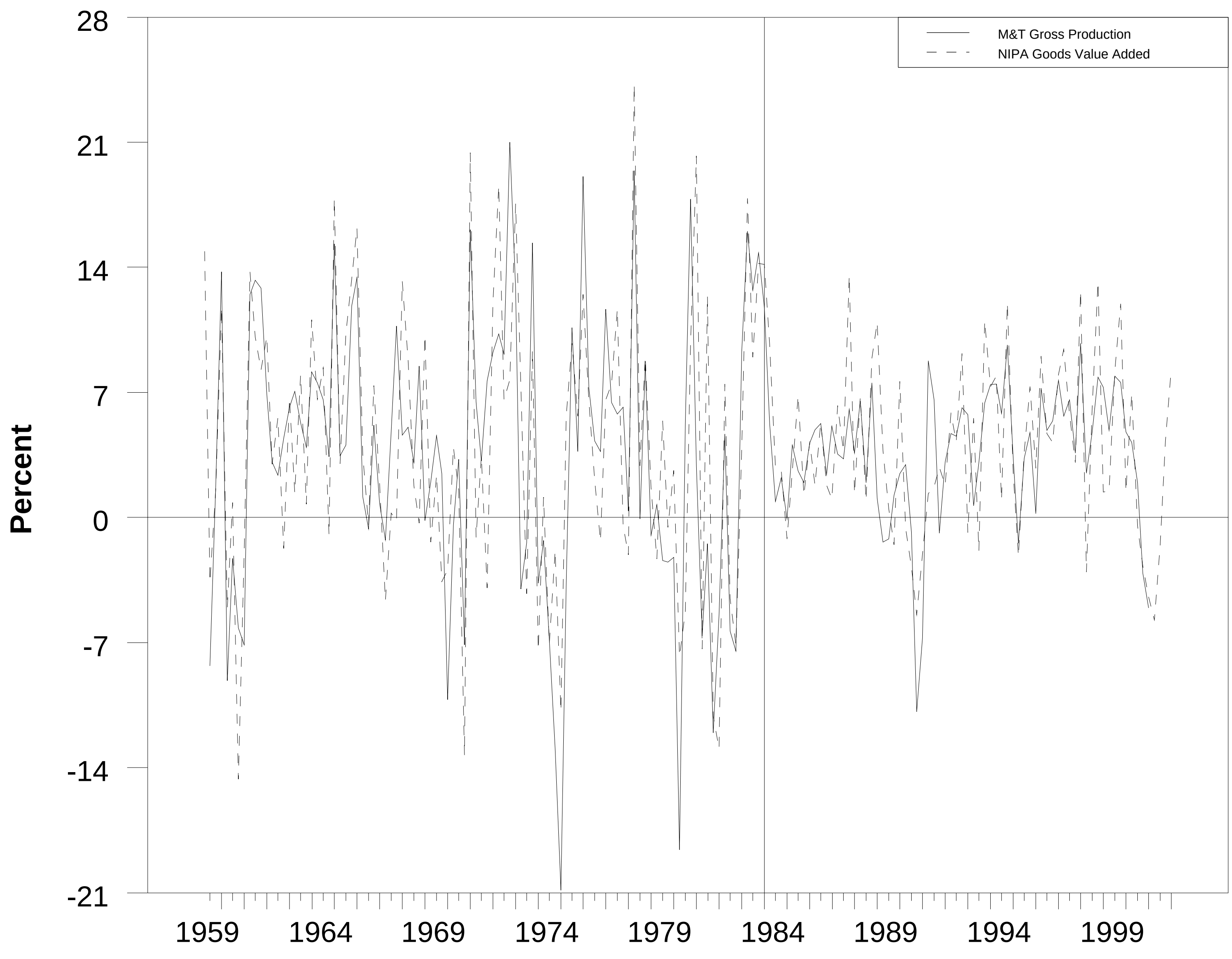


Figure 4
Frequency Distributions of Volatility Ratios

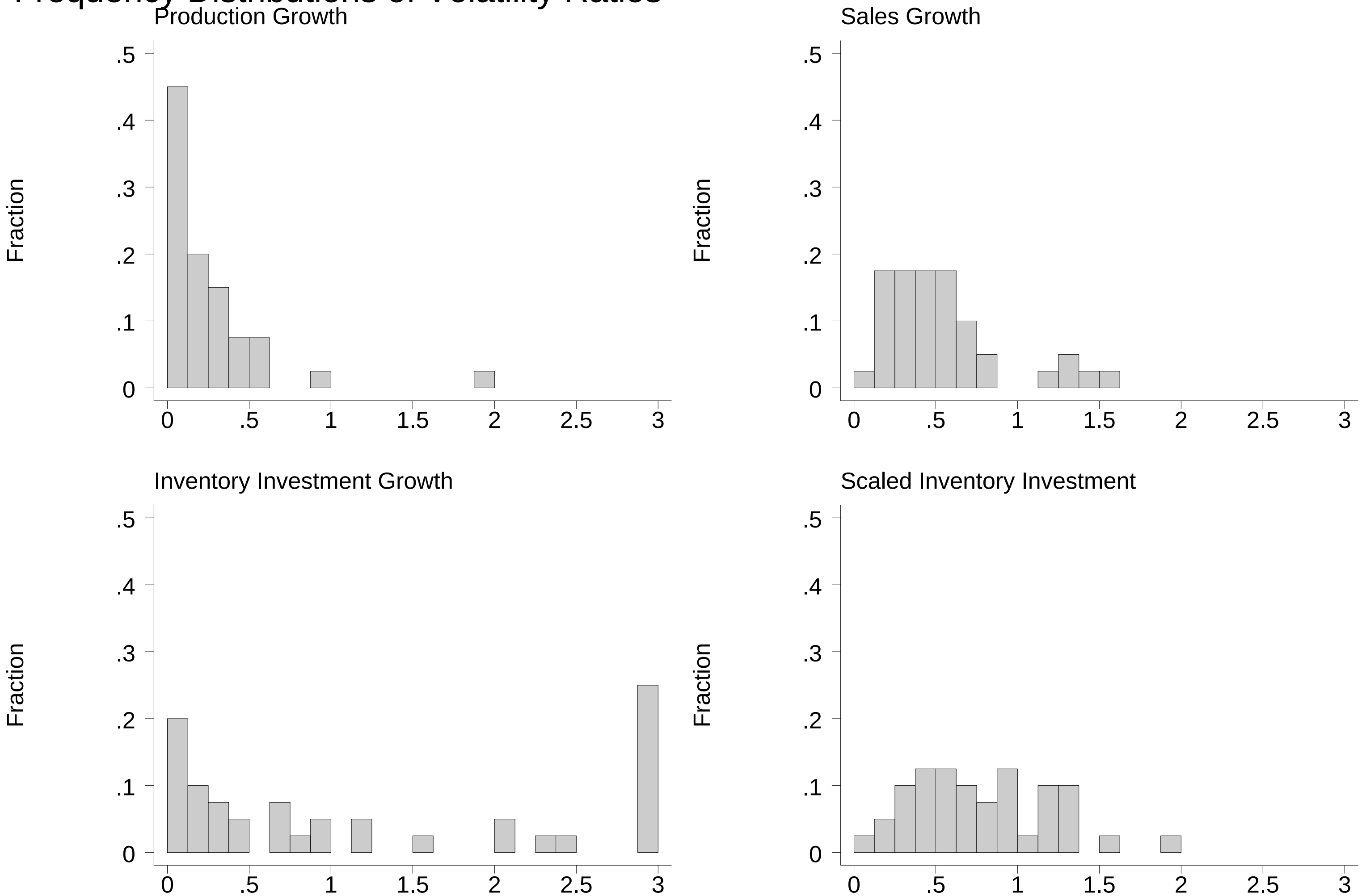


Figure 5
Industry Size and Change in Volatility of Production
Excluding SIC 504 & 509

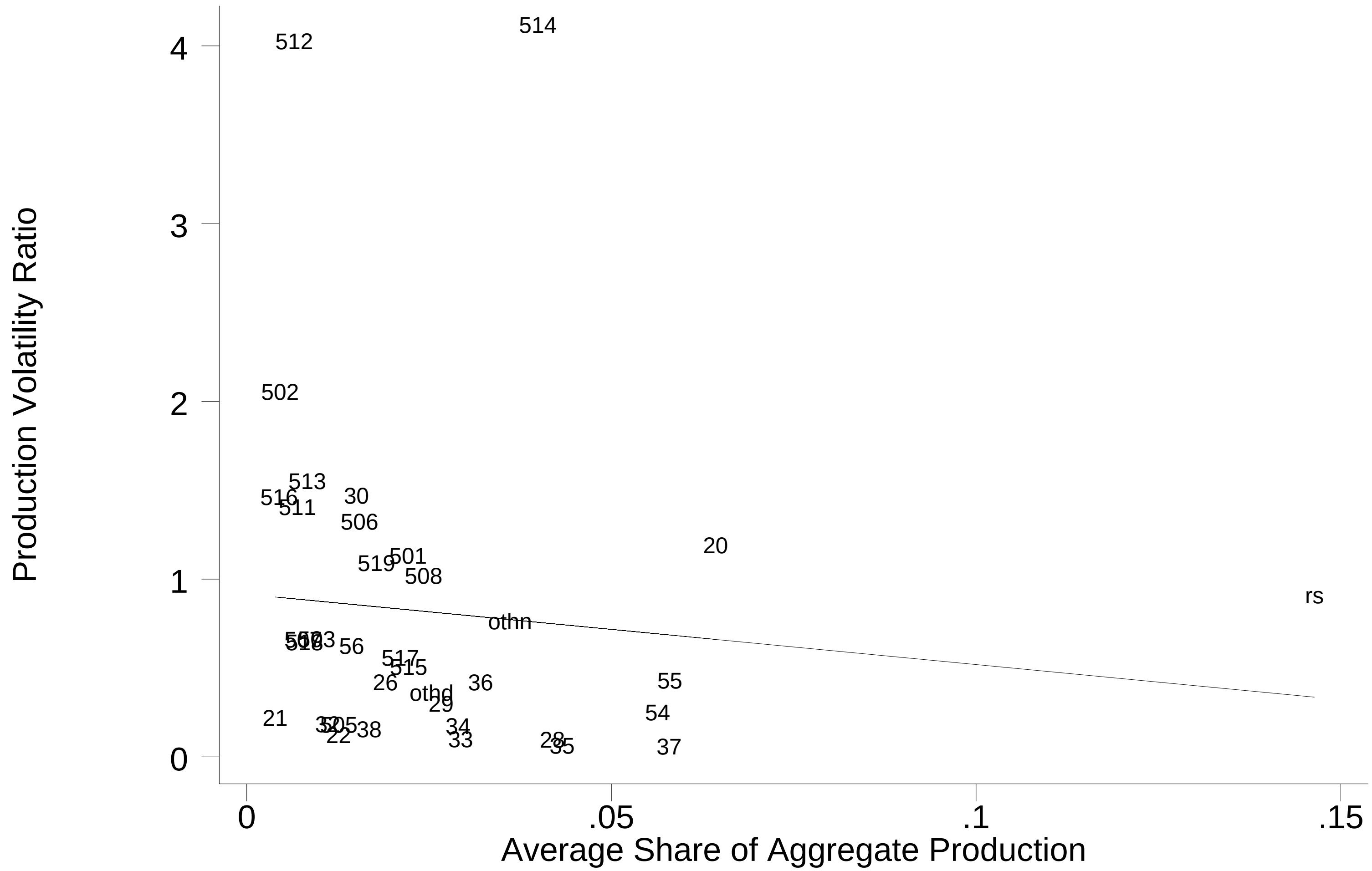


Figure 6
Change in Production Volatility vs. Change in Average I/S

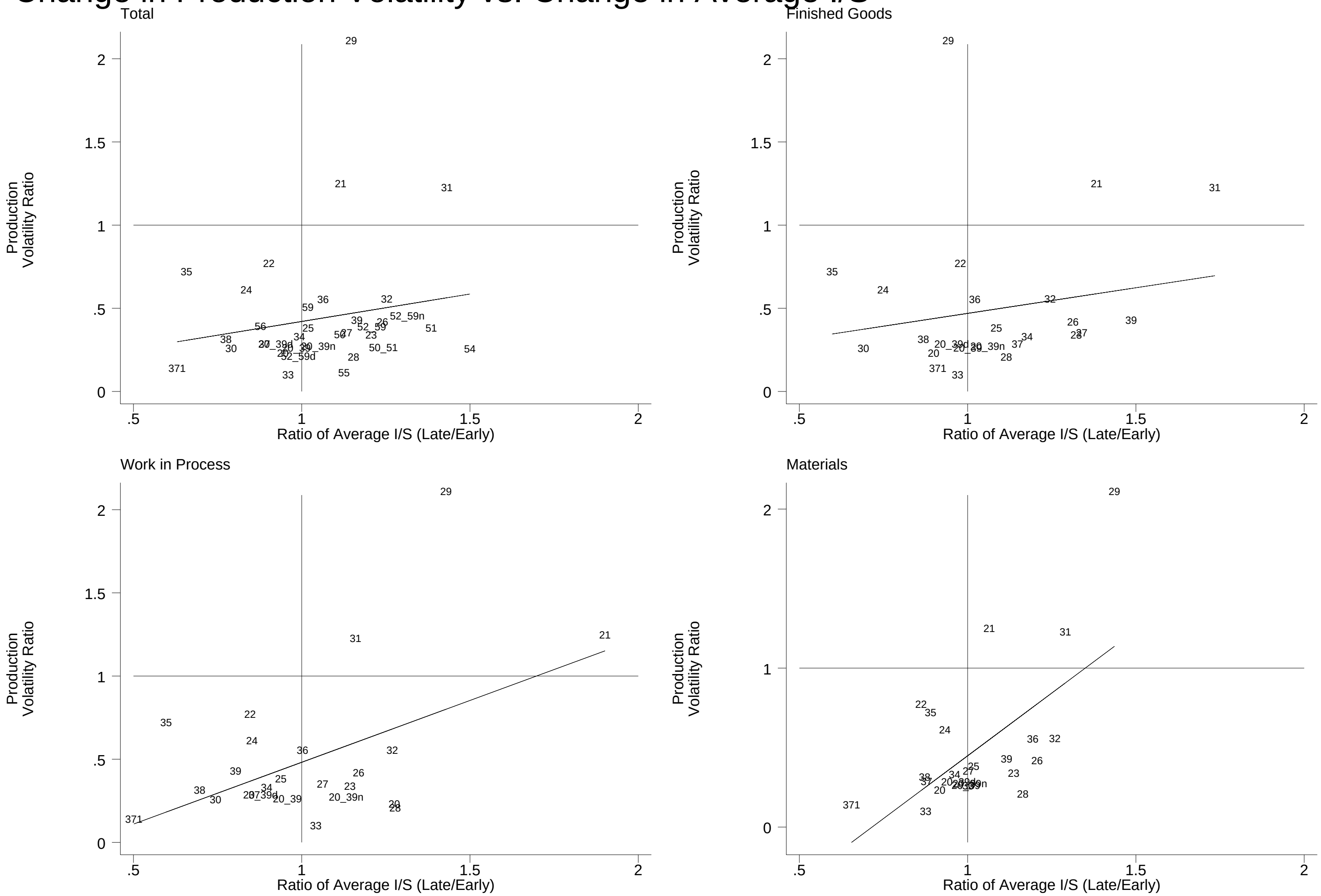


Figure 7
Change in Inventory Investment Growth Volatility vs. Change in I/S

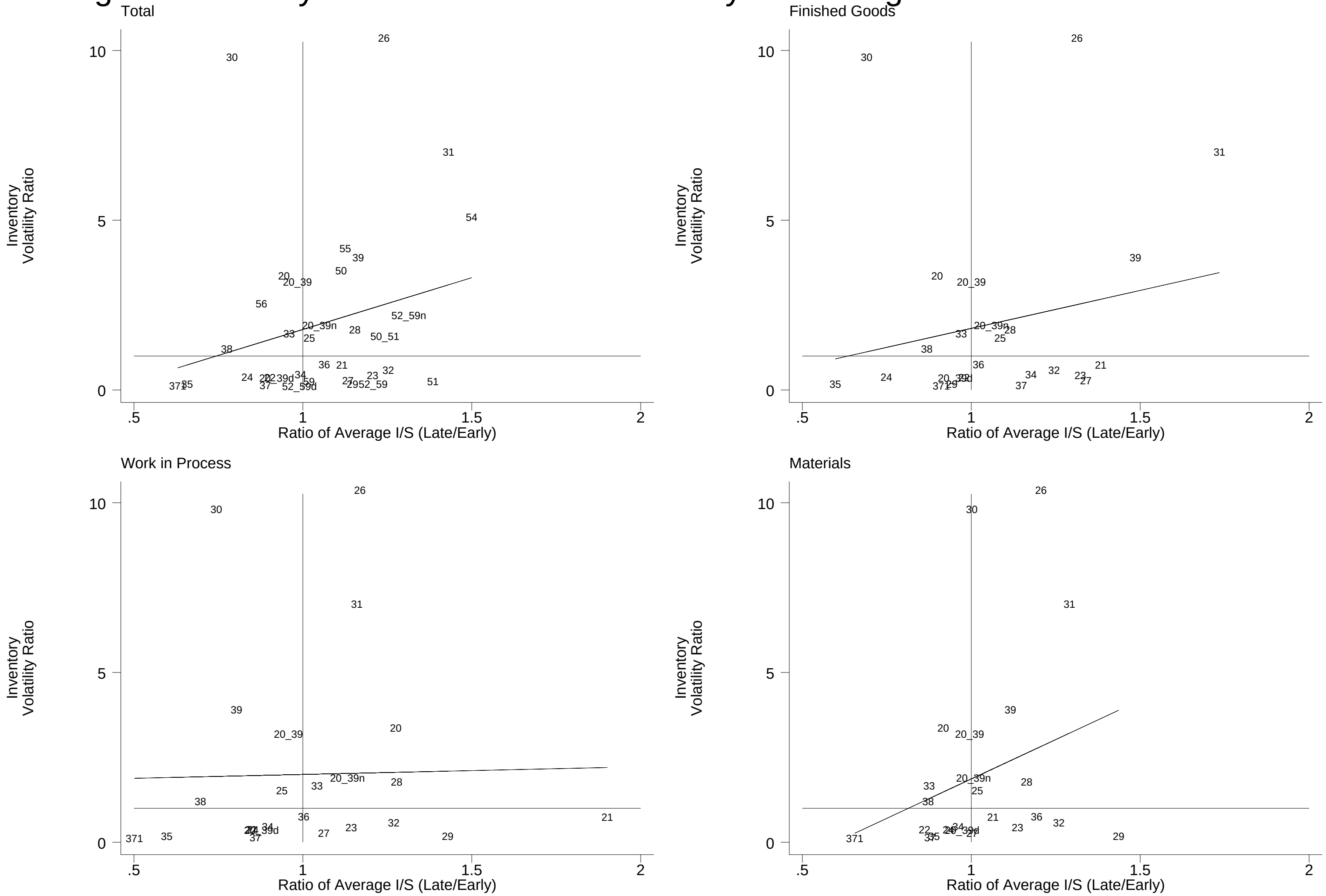


Figure 8
Change in Scaled Inventory Investment Volatility vs. Change in I/S