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# Trade Openness and Volatility

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**Abstract**

This paper examines the mechanisms through which trade openness affects output volatility using an industry-level panel dataset of manufacturing production and trade. The main results are threefold. First, sectors more open to international trade are more volatile. Second, trade leads to increased specialization. These two forces act to increase aggregate volatility. Third, sectors which are more open to trade are less correlated with the rest of the economy, an effect that acts to reduce overall volatility. The point estimates indicate that each of the three effects has an appreciable impact on aggregate volatility. Added together they imply that the overall effect of trade openness is positive and economically significant. This impact also varies a great deal with country characteristics. We estimate that the same increase in openness raises aggregate volatility five times more in developing countries compared to developed ones. Finally, we find that the marginal impact of openness on volatility roughly doubled in the last thirty years, implying that trade exerts a larger influence on volatility over time.

*JEL Classifications*: F15, F40

*Keywords*: Trade, Output Volatility, Specialization, Comovement, Sector-Level Data

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# 1 Introduction

Macroeconomic volatility is considered an important determinant of a wide variety of economic outcomes. Numerous studies identify its effects on long-run growth (Ramey and Ramey 1995), welfare (Pallage and Robe 2003, Barlevy 2004), as well as inequality and poverty (Gavin and Hausmann 1998, Laursen and Mahajan 2005). The question of what are the main determinants of macroeconomic volatility has thus attracted a great deal of attention in the literature. In particular, it has been argued that trade openness plays a role (Rodrik 1997, ILO 2004). As world trade has experienced exponential growth in recent decades, understanding the relationship between trade and volatility has become increasingly important. Figure 1 shows a scatterplot of trade openness and the volatility of GDP growth in the 1990s for a large sample of countries, after controlling for per capita income. Differences in volatility are pronounced: countries in the 75$^{th}$ percentile of the output volatility distribution exhibit a standard deviation of growth some three times higher than those in the 25$^{th}$ percentile. At the same time, it appears that the correlation between openness and volatility is positive in the data.[1]

There is currently no consensus, either empirically or theoretically, on the nature of the relationship between trade openness and macroeconomic volatility. In part, this is because the mechanisms behind it are not well understood. For instance, does trade affect volatility primarily by exposing industries to external shocks? Or because it changes the comovement properties of the trading sectors with the rest of the economy? Or does trade affect volatility through its impact on the diversification of production across sectors?[2] The main purpose of this paper is to answer these questions by examining the relationship between trade openness and volatility using an industry-level panel dataset on production and trade. The use of industry-level data allows us to look into the individual channels through which trade can affect aggregate volatility.

We begin by testing three hypotheses. The first is that trade openness affects the volatility of individual sectors. For instance, has been suggested that in an economy open to international trade, an industry is more vulnerable to world supply and demand shocks

[1]A number of cross-country empirical studies analyze the relationship between trade openness and volatility. Easterly, Islam and Stiglitz (2001) and Kose, Prasad and Terrones (2003) find that openness increases the volatility of GDP growth. Kose et al. (2003) and Bekaert, Harvey and Lundblad (2004) also find that greater trade openness increases the volatility of consumption growth, suggesting that the increase in output volatility due to trade is not fully insured away. Moreover, Rodrik (1998) provides evidence that higher income and consumption volatility is strongly associated with exposure to external risk, proxied by the interaction of overall trade openness and terms of trade volatility. Recent work by Bejan (2004) and Cavallo (2005) finds that openness decreases output volatility.

[2]Koren and Tenreyro (2006) emphasize that aggregate volatility can arise from volatility of individual sectors, patterns of specialization, and the covariance properties of sectors with the aggregate shocks.

(Newbery and Stiglitz 1984). The second hypothesis is that trade affects aggregate volatility by changing the comovement between sectors. For example, when a sector is very open, it may depend more on global shocks to the industry, and less on the domestic cycle (Kraay and Ventura 2001). This channel has not, to our knowledge, been investigated empirically in the literature. The third hypothesis is that trade changes the pattern of specialization. For instance, if trade leads to a less diversified production structure, aggregate volatility will increase, and vice versa.

The main results can be summarized as follows. First, trade openness increases volatility at the industry level. Second, more trade in a sector results in a lower correlation between growth in that sector and aggregate growth, an effect which leads to a reduction in aggregate volatility, all else equal. Third, trade is associated with greater specialization, which works as a channel for creating increased volatility.[3] The results are remarkably robust for all three channels, over different sized panels, and to the inclusion of a plethora of fixed effects, additional controls, and the use of instrumental variables in the case of the specialization estimates. Indeed, for all three channels, we find that simultaneity is not a major problem.

Having estimated the three effects individually, we would like to establish whether these have an appreciable impact on aggregate volatility. It could be, for instance, that a rise in sector-specific volatility due to trade has a completely negligible impact on aggregate volatility, because on average countries are well diversified across sectors. Thus, we use our point estimates to calculate how important the three effects are quantitatively when it comes to their impact on aggregate volatility. It turns out that an increase in sector-level volatility due to moving from the $25^{\text{th}}$ to the $75^{\text{th}}$ percentile in the distribution of trade openness — equivalent to a movement in the trade-to-output ratio from 40 to 80 percent — raises aggregate volatility by about 10.2% of the average aggregate variance observed in the data, all else held equal. The reduction in comovement due to increased trade leads to a *fall* in aggregate volatility roughly equivalent to 3.9% of its average. Increased specialization in turn implies an increase in aggregate variance of 12.8%. Adding up the three effects, our estimates imply that moving from the $25^{\text{th}}$ to the $75^{\text{th}}$ percentile in trade openness raises aggregate volatility by about 19% of the average aggregate variance observed in the data.

We find that the impact of openness on volatility varies a great deal depending on country characteristics, however. For instance, we estimate that an identical change in trade openness raises aggregate volatility five times more in the average developing country compared to the average developed country. Lastly, we estimate how the impact of trade changes across decades. It turns out that all three channels, as well as the overall effect,

[3]An important caveat is in order when interpreting our results. In this paper, we measure trade openness by actual trade in a sector, rather than by trade barriers.

increase in importance over time: the impact of the same trade opening on aggregate volatility in the 1990s is double what it was in the 1970s. While our approach is silent on how or whether the nature of the underlying shocks has changed over this period, it is clear that trade has become an increasingly important conduit for their transmission through the world economy.[4]

To summarize, all three channels — sector-level volatility, comovement, and specialization — have a sizeable impact on aggregate volatility. It appears, however, that the comovement effect, which acts to reduce volatility, is considerably less important in magnitude than the other two. Thus, the net effect of trade in our data is to increase aggregate volatility, by raising both sector-level volatility and specialization.

We use data on production, quantity indices, employment, and prices for the manufacturing sector from United Nations Industrial Development Organization (2005), and combine them with the World Trade Database (Feenstra et al. 2005) for the period 1970–99. The resulting dataset is a three-dimensional unbalanced panel of 59 countries, 28 manufacturing sectors, and 30 years.[5] Our approach has several advantages over the more traditional country-level analysis. First and foremost, the use of industry-level data makes it possible to estimate the individual channels for the effect of trade on volatility, something which has not been done before in the literature. Second, our three-dimensional panel allows us to include a much richer array of fixed effects in order to control for many possible unobservables and resolve most of the omitted variables and simultaneity concerns in estimation. In addition to country, sector, and time effects, we can control for time-varying sector or country characteristics, or characteristics of individual country-sector pairs. Third, besides looking at the volatility of GDP per capita (the standard measure used in previous studies), we are also able to look at other outcome variables, such as quantity, employment, and price volatility at the industry level to further check robustness.

This paper is part of a growing literature which studies the determinants of volatility, and its subcomponents, using industry-level data. Most papers, however, focus on the determinants of one of the mechanisms we consider. For instance, Imbs and Wacziarg (2003) and Kalemli-Ozcan, Sørensen and Yosha (2003) explore the patterns of specialization, while Raddatz (2005) and Imbs (2006) study sector-level volatility. Krebs, Krishna and Mahoney (2005) use Mexican data at the individual level and examine the impact of trade

[4]Note that this finding is not at all inconsistent with the common observation that aggregate volatility itself has diminished over the same time period, which is also true in our data.

[5]The UNIDO database does not contain information on non-manufacturing sectors. Unfortunately, this limitation most probably leads to an understatement of the impact of openness on volatility for those countries which rely heavily on commodity exports, and are thus more vulnerable to global price shocks (Kose 2001). On the other hand, by examining the manufacturing sector alone we are able to focus on a sector that is generally considered key to a country's development process.

liberalization on wage volatility and its welfare consequences. Koren and Tenreyro (2006) use industry-level data to provide an interesting decomposition of aggregate volatility into several subcomponents, and describe their features. Our paper is unique in its emphasis on trade and its use of trade data along with production. Thus, its contribution is in the comprehensive empirical exploration of multiple channels of the trade-volatility link.

The rest of the paper is organized as follows. Section 2 describes the empirical strategy and the data. Section 3 presents the regression results, while section 4 discusses what these imply about the impact of the three channels on aggregate volatility. Section 5 concludes.

# 2 Empirical Strategy and Data

## 2.1 Empirical Strategy

In an economy comprised of $\mathcal{I}$ sectors, the volatility of aggregate output growth $\sigma_A^2$ can be written as follows:

$$\sigma_A^2 = \sum_{i=1}^{\mathcal{I}} a_i^2 \sigma_i^2 + \sum_{i=1}^{\mathcal{I}} \sum_{\substack{j=1 \\ j \neq i}}^{\mathcal{I}} a_i a_j \sigma_{ij}, \tag{1}$$

where $a_i$ is the share of sector $i$ in total output, $\sigma_i^2$ is the variance of output growth in sector $i$, and $\sigma_{ij}$ is the covariance between sectors $i$ and $j$. Trade can affect overall volatility through changing the variance of each sector separately ($\sigma_i^2$), through changing the covariance properties between the sectors ($\sigma_{ij}$), or through changing the production structure of the economy ($a_i$). This paper analyzes each of these mechanisms in turn.

In particular, using our sector-level panel dataset on production and trade, it is straightforward to estimate the relationship between trade in a sector and the volatility of output in that sector, $\sigma_i^2$. We call this the *Sector Volatility Effect*. Our main empirical specification is:

$$\text{Volatility}_{ict} = \alpha_0 + \alpha_1 \text{Output}_{ict} + \beta \text{Trade}_{ict} + \mathbf{u}_{ict} + \varepsilon_{ict}, \tag{2}$$

where $i$ denotes sector, $c$ denotes country, and $t$ denotes time. The left-hand side, $\text{Volatility}_{ict}$, is the log variance of the annual growth rate of output per worker. In the cross-sectional specifications, the variance is computed over the entire sample period, 1970–99. In panel specifications, the volatility is computed over non-overlapping ten year periods: 1970–79, 1980–89, 1990–99. $\text{Trade}_{ict}$ is imports plus exports divided by output within a sector. The openness measure is the average for the same time periods over which the left-hand side variables are computed, and is always in logs. We proxy for sector-specific, time-varying productivity by including the log of the beginning-of-period output per worker, $\text{Output}_{ict}$, as one of the regressors. We experiment with various configurations of fixed effects $\mathbf{u}_{ict}$. The cross-sectional specifications include both country and sector fixed effects. The panel specifications include country×sector fixed effects, country×time fixed effects, and sector×time fixed effects in alternative specifications.

To analyze the second effect, rewrite equation (1) as:

$$\sigma_A^2 = \sum_{i=1}^{\mathcal{I}} a_i^2 \sigma_i^2 + \sum_{i=1}^{\mathcal{I}} a_i (1 - a_i) \rho_{i,A-i} \sigma_i \sigma_{A-i}, \qquad (3)$$

where the subscript $A-i$ is used to denote the sum of all the sectors in the economy except $i$. Thus, $\rho_{i,A-i}$ is the correlation coefficient of sector $i$ with the rest of the economy, and $\sigma_{A-i}$ is the standard deviation of the aggregate output growth excluding sector $i$. This way, rather than writing the aggregate variance as a double sum of all the covariances of individual sector pairs, equation (3) rewrites it as the sum of covariances of each sector $i$ with the rest of the economy. (Note that we can express aggregate variance this way without any loss of generality.)

The effect of trade on the correlation between an individual sector and the rest of the economy, $\rho_{i,A-i}$, is the subject of our second empirical exercise. We call this the *Comovement Effect*.[6] Just like $\sigma_i^2$, we calculate $\rho_{i,A-i}$ for each country, sector, and time period, and thus we can estimate the relationship between trade openness and $\rho_{i,A-i}$ using industry-level data in the cross section and in ten-year panels:

$$\text{Correlation}_{ict} = \alpha_0 + \alpha_1 \text{Output}_{ict} + \beta \text{Trade}_{ict} + \mathbf{u}_{ict} + \varepsilon_{ict}. \qquad (4)$$

The right-hand side variables are the same as in the volatility specifications (see above). The left-hand side variable is the correlation of output per worker growth in sector $i$ with the overall manufacturing excluding that sector, $\rho_{i,A-i}$. In the cross-sectional specifications, these correlations are computed over thirty years. In the panel, we compute correlations over non-overlapping ten-year periods.[7] In contrast to the volatility estimation in the previous section, the left-hand side is in levels rather than in logs because correlation coefficients can be negative. Note also that we use correlation rather than covariance. This is because the correlation coefficient is a pure measure of comovement, whereas changes in the covariance are influenced by changes in the sector-level variance. These are themselves affected by trade, as we show when we estimate the impact of trade on sector-level volatility.

We next analyze whether trade leads to increased specialization in a small number of sectors. Going back to equation (1), we see that aside from its effect on $\sigma_i^2$'s and $\sigma_{ij}$'s,

[6] Note that this effect is different from the cross-country comovement analyzed in the international business cycle literature (Backus, Kehoe and Kydland 1992, Baxter and Kouparitsas 2002, Burstein, Kurz and Tesar 2004, Frankel and Rose 1998, Kose and Yi 2006).

[7] We also estimated five-year panel specifications for both the volatility and correlation regressions. As the conclusions are remarkably similar to the ten-year panel specifications, we report only the cross-sectional and ten-year panel results to conserve space.

trade openness can affect overall volatility through changing the configuration of $a_i$'s. In particular, making the simplifying assumption that all sectors have the same $\sigma^2$, we can rewrite equation (1) as:

$$\sigma_A^2 = h\sigma^2 + \sum_{i=1}^{\mathcal{I}} \sum_{\substack{j=1 \\ j\neq i}}^{\mathcal{I}} a_i a_j \sigma_{ij}, \tag{5}$$

where $h$ is the Herfindahl index of production shares in the economy.[8] A higher value of $h$ represents a more specialized (less diversified) economy, and thus, at a given level of $\sigma^2$, leads to a higher aggregate volatility. We call this the *Specialization Effect*. We use industry-level production data to compute indices of specialization directly at the country level, and relate them to trade openness in the following empirical specification:

$$\text{Specialization}_c = \alpha_0 + \alpha_1 \mathbf{X}_c + \beta \text{Trade}_c + \varepsilon_c. \tag{6}$$

Here, $c$ indexes countries, and the left-hand side variable is the log of the Herfindahl index of production shares of sectors in total manufacturing output, $h$, averaged over the sample period.[9] $\text{Trade}_c$ is the log of total manufacturing trade divided by total manufacturing output in our data. $\mathbf{X}_c$ are controls such as per capita GDP.

#### 2.1.1 Discussion

As mentioned above, we estimate the Sector Volatility and Comovement Effects in both cross-sectional and ten-year panel specifications. The advantage of the cross-sectional specifications is that they allow us to calculate our left-hand side variables – variances and correlations – over a long time series, reducing measurement error. The advantage of the panel specifications is that they make it possible to control for a much richer array of fixed effects.

The ability to employ a variety of fixed effects is a major strength of our empirical approach. Specifically, the fixed effects greatly help in alleviating simultaneity issues by controlling for omitted variables in the variance and correlation regressions. For example, in both cross-sectional and panel specifications, country fixed effects will control for any potential omitted variable that varies at country level, such as overall macroeconomic volatility, level of development, or institutions. Sector fixed effects will do the same for any sector characteristics correlated across countries, such as inherent volatility, factor intensity, or tradability. In the panel specifications, the use of fixed effects becomes even more

[8] The Herfindahl index is defined as the sum of squared shares of each sector in total production: $h = \sum_i a_i^2$.

[9] There are gaps in the sector coverage in some countries and years. We only used country-years in which at least 20 sectors were available to calculate the Herfindahl. Varying this threshold does not affect the results.

powerful, as our panel has three dimensions. In addition to country, sector, and decade fixed effects, we also employ interacted fixed effects rich enough to control for a wide variety of omitted variables. For instance, country×time fixed effects control for time-varying characteristics of countries, such as external and domestic aggregate shocks, overall trade opening, financial liberalization, or any other reforms. Sector×time effects absorb any variation in sector characteristics over time. Finally, the use of country×sector effects allows us to control for unobservable characteristics of each individual sector in each country, and identify the effect of trade purely from the time variation in trade and volatility within a sector. Including a plethora of fixed effects may still not resolve simultaneity problems at the country×sector×time level, however.[10] We therefore reestimate our core specification with the most conservative set of fixed effects, while adding a variety of controls and interaction terms. The list of variables includes terms-of-trade (TOT) volatility, the volatility of trade at the sector level, the share of the manufacturing sector trade to total trade, and a measure of financial development interacted with the Raddatz (2005) sector-level measure of liquidity needs.

As another robustness check, the growth-volatility nexus must also be considered. The macroeconomics literature finds a negative relationship between growth and volatility (Ramey and Ramey 1995), though recent work shows that at sector level the opposite is true (Imbs 2006). In addition, faster growing sectors may also be more open to trade. Therefore, besides including initial output per worker as a proxy for growth potential in the baseline estimations, we also control for average levels and growth rates of output per worker as a further robustness check. Finally, while in our main specifications the dependent variables are variances and correlations of output per worker growth, we also use a quantity index and a constructed sector-level price index to check robustness of the results.

To examine the Specialization Effect, we must rely on cross-country regressions because $h$ is measured at country level. We therefore use the Frankel and Romer (1999) measure of natural openness to instrument for trade in our sample, and also consider numerous controls previously suggested in the literature.

[10]The following example can illustrate what we can and cannot control for using fixed effects. Suppose that a natural disaster damages the petroleum refineries inside a country. This shock temporarily drives down production in the sector. It also forces consumers to substitute from domestic to foreign fuel, increasing imports, and therefore trade openness. Within that period, these effects would push up both volatility of output and average openness simultaneously, biasing the relationship between sector-level volatility and trade openness positively away from zero. If these shocks are frequent (say they occur in each decade in our data), we can capture this feature of the petroleum sector in this particular country using country×sector effects. If, in addition to the petroleum industry, all of the other industries in that country experienced declines in production and increases in trade as a result of that natural disaster, then the impact is economywide and we control for it using country×time effects. However, if neither is the case, and what is driving the observed relationship between volatility and trade are country×sector×time-specific domestic supply shocks, our fixed effects cannot go all the way in helping us identify the impact of trade.

## 2.2 Data and Summary Statistics

Data on industry-level production, quantity indices, employment, and prices come from the 2005 UNIDO Industrial Statistics Database. We use the version that reports data according to the 3-digit ISIC Revision 2 classification for the period 1963–2002 in the best cases. There are 28 manufacturing sectors in total, plus the information on total manufacturing. We use data reported in current U.S. dollars, and convert them into constant international dollars using the Penn World Tables (Heston, Summers and Aten 2002).[11] We also correct inconsistencies between the UNIDO data reported in U.S. dollars and domestic currency. We dropped observations which did not conform to the standard 3-digit ISIC classification, or took on implausible values, such as a growth rate of more than 100% year to year. We also removed countries for which the production data and the trade data were not conformable. The resulting dataset is an unbalanced panel of 59 countries, but we insure that for each country-year we have a minimum of 10 sectors, and that for each country, there are at least 10 years of data.

We combine information on sectoral production with international trade flows from the World Trade Database (Feenstra et al. 2005). This database contains bilateral trade flows between some 150 countries, accounting for 98% of world trade. Trade flows are reported using the 4-digit SITC Revision 2 classification. We convert the trade flows from SITC to ISIC classification and merge them with production data.[12] The final sample is for the period 1970–99, giving us three full decades.

Appendix Table A1 reports the list of countries in our sample, along with some basic descriptive statistics on the average growth rate of output per worker in the manufacturing sector, its standard deviation, its import penetration, and the share of output that is exported. There is some dispersion in the average growth rates of the manufacturing output per worker, with Tanzania at the bottom with a mean growth rate of −3.2% per year over this period, and Pakistan at the top with 5.8% per year. There are also differences in volatility, with the United States having the least volatile manufacturing sector, and Senegal the most. Import penetration and the share of total manufacturing production that gets exported vary a great deal across countries. Appendix Table A2 lists the sectors we use in the analysis, along with the similar descriptive statistics. Growth rates of output per worker across sectors are remarkably similar, ranging from roughly 1% per year for leather products to 4% for industrial chemicals. We can see that individual sectors have much

[11]Using the variable name conventions from the Penn World Tables, this deflation procedure involves multiplying the nominal U.S. dollar value by $(100/P) * (RGDPL/CGDP)$ to obtain the constant international dollar value.

[12]The merge is based on the concordance found on the International Trade Resources website maintained by Jon D. Haveman: `http://www.haveman.org`.

higher volatility than manufacturing as a whole, and differ among themselves as well. The least volatile sector, food products, has an average standard deviation of 11%. The most volatile sector is petroleum refineries, with a standard deviation of 23%.

Using our data, we can calculate the variance of the growth rate of total manufacturing output per worker, and compare it with the variance of per capita GDP growth from Penn World Tables. The scatterplot of that comparison, in logs, is presented in Figure 2, along with a linear regression line. We can see that there is a close relationship between the two, with the correlation coefficient of around 0.7. The volatility of manufacturing output growth from the UNIDO dataset is considerably higher than the volatility of per capita GDP growth from Penn World Tables. This is sensible, because manufacturing output is a subset of GDP. Figure 3 reports a scatterplot of trade openness and volatility of the manufacturing sector for the countries in the sample, along with a regression line. There does seem to be a positive relationship between trade openness and volatility in our sample. We now move on to an in depth analysis of this relationship at the sector level.

# 3 Results

Our results can be summarized as follows: trade openness has (i) a positive effect on sector-level volatility; (ii) a negative effect on sector comovement with the rest of the manufacturing sector; and (iii) a positive effect on a country's specialization. These results are robust across both cross-sectional and panel estimations, as well as to the battery of fixed effects and controls which we use to deal with omitted variables and simultaneity issues.

## 3.1 Trade and Volatility within a Sector

We first analyze the effect of trade on the volatility of output within a sector ($\sigma_i^2$, by estimating equation (2)). Table 1 presents the cross-sectional results. The first column reports the results of the most basic regression, while columns (2) through (4) add progressively more fixed effects. Overall trade openness, measured as the share of exports plus imports to total output in a sector, is always positively related to volatility. This result is robust to the inclusion of any fixed effects and is very statistically significant, with $t$-statistics in the range of 8–10. The point estimates are also quite stable across specifications.

Table 2 reports estimation results for the ten-year panel regressions. We include specifications with no fixed effects, country, sector, time effects separately and together, and then interacted with each other. The most stringent specification, in terms of degrees of freedom, includes country×sector and time fixed effects. The coefficients on trade openness are actually quite stable across specifications, being noticeably lower only in column (7), which includes country×sector fixed effects. Nonetheless, the results are statistically significant at the one percent level in each case. Overall, the cross-sectional and panel results yield remarkably similar conclusions.

The effect of trade on volatility, while highly significant, is not implausibly large quantitatively. In particular, a one standard deviation increase in our right-hand side trade variable, the log of exports plus imports to output, results in an increase in the log variance of output per worker growth of between 0.1 and 0.25 standard deviations, depending on the coefficient estimate used.

Appendix Tables A3 and A4 present a slew of robustness checks using a variety of different controls and interaction terms. The coefficient of interest remains positive and significant at 1% level across all specifications, and the point estimates do not vary dramatically relative to the baseline estimates in Tables 1 and 2, columns (4) and (7) respectively. First, turning to columns (1) and (2) in Table A3, it is clear that using either average productivity or average growth rates instead of initial output per worker does not alter our results. As discussed above, both of these variables are positively related to volatility at sector level, a result reported in Imbs (2006). Column (3) drops country effects, and uses the volatility of a country's terms of trade (TOT) instead. Terms of trade data are obtained from the Penn World Tables. TOT volatility is indeed positively related to volatility of production, but trade openness itself remains significant. The TOT volatility on its own was controlled for in our baseline regressions by country and country×time effects. However, it could be that TOT volatility affects more open sectors disproportionately, and this effect is driving our results. Column (4) interacts the country-level TOT volatility with total trade in a sector while including country fixed effects, which is a more general specification than including TOT volatility on its own. Our main result is not affected, in fact the coefficient on this interaction is insignificant. It could also be that what really matters is not the average trade openness in a sector, but the volatility of trade in that sector. To see if this is the case, we control for the sector-level volatility of trade in Column (5). It turns out that the coefficient on the volatility of trade is not significant, giving us further confidence that simultaneity is not a major issue.[13] We also interact the level of trade with its volatility in Column (6), but the main result is unchanged. Column (7) uses another country-level variable, the share of manufacturing trade to total trade, instead of country effects. This share is negatively related to the volatility of production, which may simply reflect that the share is greater for industrial countries, which experience less volatility on average.[14]

[13] We also experimented with the volatility of a sector's trade-to-output ratio, but results were similar to using total trade.

[14] We also interacted this variable with sector-level trade. Our results were unchanged.

Raddatz (2005) studies volatility at the sector level using a version of the UNIDO database, and finds that financial development matters more in industries with higher liquidity needs. Column (8) includes the interaction of the Raddatz liquidity needs measure with a country's financial development, where the latter is proxied by private credit as a share of GDP coming from the Beck, Demirgüç-Kunt and Levine (2000) database. The coefficient on trade openness remains significant at 1% level. The negative coefficient on the interaction term in column (8) corresponds to Raddatz (2005).[15] Appendix Table A4 repeats these robustness checks in the panel specifications, and reaches the same conclusion.

### 3.1.1 Sector-Level Volatility in Price and Quantity per Worker

In addition to total output and employment, the UNIDO database also reports sector-level quantity indices. We can therefore construct annual growth rates of the quantity of output per worker, for each sector, and calculate the same volatility measure as we did for output per worker.[16] Furthermore, given that output per worker equals price times quantity per worker, it follows that we can back out the growth rate of the sector-specific price index by subtracting the growth rate of quantity per worker from the growth rate of output per worker.[17] We then calculate the volatility measures for the sector-specific price index.

This rough separation of the growth rates of output per worker into the growth rate of quantity and of price does not help us identify the channels through which trade openness affects volatility. Indeed, no matter what the shock, we would expect both the price and the quantity to move. Nonetheless, examining the effect of trade on quantities and prices serves as a further robustness check on our results, by showing that trade affects the volatility of both. Table 3 presents the baseline volatility regressions for quantity per worker and price. The openness coefficient is positive and significant for both left-hand side variables across all specifications. Furthermore, the quantity-openness elasticity is greater than the price-openness one.[18]

[15] We also interacted the Raddatz's measure with country fixed effects, and the results were unchanged. Note that doing so is a more general specification than using the interaction with financial development.

[16] Another quantity-based measure we used to check for robustness is simply the growth rate of employment. The effect of trade on the volatility of employment is equally significant as its effect on our headline measure, output per worker. The full set of results is available upon request.

[17] Namely, if $\text{OUTPUT}_{ict}$ is nominal output, and $\text{INDPROD}_{ict}$ is the index number of industrial production, then the sector-specific growth rate of prices is $\text{GrowthP}_{ict} = \log((\text{OUTPUT}_{ict}/\text{OUTPUT}_{ic(t-1)})/(\text{INDPROD}_{ict}/\text{INDPROD}_{ic(t-1)}))$.

[18] Panel estimations are similar to the cross-sectional ones, and are thus omitted to conserve space. They are available from the authors upon request.

### 3.2 Trade and Sector Comovement

We next estimate equation (4), the effect of trade on the correlation of a sector's output growth with the rest of the manufacturing sector ($\rho_{i,A-i}$). Table 4 presents the cross-sectional results. Intriguingly, more trade in a sector reduces the correlation of that sector with the rest of the economy. This negative effect is robust across specifications, although the significance level is typically not as high as in the volatility regressions, and the magnitude of coefficients not as stable. It is clear that increased exposure to the world cycle for a sector decouples it from the domestic economy. This covariance effect acts to reduce the overall variance in the economy, ceteris paribus. Table 5 presents results for the ten-year panel estimation. The results are broadly in line with those of the cross section, and robust to the entire battery of fixed effects which we employ. Overall, the effect of trade on comovement is economically significant, and plausible in magnitude. A one standard deviation increase in the overall trade results in a decrease in correlation of between 0.07 and 0.14 standard deviations, depending on the coefficient estimate used.

Appendix Tables A5 and A6 present numerous robustness checks using a variety of different controls and interaction terms. The openness coefficient remains negative and significant across all specifications, and the point estimates do not vary dramatically relative to the baseline estimates in Tables 4 and 5, columns (4) and (7) respectively. The properties of sector-level correlation with the aggregate growth have not been previously studied in the literature. Therefore, it is much less clear than in the case of sector-level volatility which additional controls it is important to include alongside the fixed effects. Our approach here is to use the same battery of robustness checks as we employed in estimating the sector volatility regressions. We control for average level and growth rate of output, TOT volatility (both as main effect and interacted with sector-level trade), sector-level volatility of trade, share of manufacturing trade in total trade, and Raddatz's interaction of liquidity needs and financial development. Since we used these before, we do not discuss them in detail. The coefficient of interest is robust to all of the alternative specifications. We also run the correlation specifications on the price and quantity per worker variables separately. Table 6 presents the baseline correlation regressions for quantity per worker and price. The openness coefficients are all negative and significant. Interestingly, the ranking of the elasticities of these two variables with respect to trade openness is reversed relative to the volatility regressions.[19]

[19] Panel estimations are similar to the cross-sectional ones, and are available from the authors upon request.

### 3.3 Trade and Specialization

Finally, we estimate the impact of trade on specialization ($h$), equation (6). Table 7 reports the estimation results. Column (1) is the bivariate OLS regression of trade openness on the Herfindahl index, while column (2) controls for log per capita PPP-adjusted GDP from Penn World Tables. The coefficient on trade is significant at the one percent level. Since trade openness is likely endogenous to diversification, columns (3) and (4) repeat the exercise instrumenting for trade using natural openness from Frankel and Romer (1999). Results are unchanged, and the magnitude of the coefficient is not affected dramatically. In order to probe further into this finding, we also analyze more directly how the export patterns are related to industrial specialization. We construct the Herfindahl index of export shares in a manner identical to our index of production concentration. The results are presented in column (5). The coefficient on trade openness decreases by about one third, but remains significant at the one percent level. The coefficient on the Herfindahl of export shares is highly significant as well.

We illustrate these results in Figure 4, which presents partial correlations between trade openness and the Herfindahl index of sector shares for the available countries, once per capita income has been netted out. It is clear that there is a positive relationship between trade and specialization. The effect of trade openness and export concentration on the specialization of production is sizeable. A one standard deviation change in log trade openness is associated with a change in the log Herfindahl of production equivalent to about 0.53 of a standard deviation. A one standard deviation change in export specialization is associated with a change in the log Herfindahl of production of roughly 0.65 standard deviations.

Appendix Table A7 presents further robustness checks. Breaking up the sample into developed and developing countries in columns (1) and (2), we see that the phenomenon is especially prevalent in the developing countries. Column (3) checks whether our results are driven by outliers. Dropping outliers improves the fit of the regression, and the results remain significant. Columns (4)-(6) repeats the three previous exercises while including the Herfindahl index of export shares. The trade openness coefficient remains positive and significant. Columns (7) and (8) check if the results are robust to an alternative measure of trade openness. We use total trade openness as a share of GDP from the Penn World Tables instead of total manufacturing trade as a share of manufacturing output from our data. It is clear that the main result is not driven by our particular measure of trade openness. Finally, the specification in column (9) is based on the work of Kalemli-Ozcan et al. (2003), and includes a wide variety of other controls, such as population density, population, share of mining in GDP, and share of agriculture in GDP. Two points are worth mentioning here. First, we do not control for the amount of risk sharing across countries, but this omission is not crucial given the common finding in the literature that economies do not share risk at the country level (cf. Backus et al. 1992, Kalemli-Ozcan et al. 2003). Second, we follow Imbs and Wacziarg (2003) and include GDP per capita and its square to capture the U-shaped pattern of diversification over the development process. This specification does not significantly affect our results.

# 4 The Impact on Aggregate Volatility

In the preceding section we estimated the effect of trade on the variance of individual sectors ($\sigma_i^2$), the correlation coefficient between an individual sector and the rest of the economy ($\rho_{i,A-i}$), and the Herfindahl index of sectoral concentration of production shares ($h$). In this section we use our estimates to quantify the impact of each of the three effects on aggregate volatility, as well as their combined impact.

We do this in a number of ways. First, we calculate the effect of moving from the 25$^{\text{th}}$ to the 75$^{\text{th}}$ percentile in the distribution of trade openness we observe in our sample. This exercise is meant to capture mainly the consequences of cross-sectional variation in trade across countries. Second, we calculate the average increase in trade openness in our sample over time, from the 1970s to the 1990s, and use it to calculate the expected impact of this trade expansion on aggregate volatility, through each channel as well as combined. Third, we calculate how the estimated impact of trade openness on aggregate volatility differs across countries based on observed characteristics of these countries. The final exercise we perform is to examine how the nature of the relationship between trade and volatility has changed over time. To do so, we reestimate the three sets of equations from the previous section by decade. We then use the decade-specific coefficients to calculate how the impact of trade on aggregate volatility changes over time.

The aggregate variance, $\sigma_A^2$, can be written as a function of $\sigma_i^2$ and $\rho_{i,A-i}$ as in equation (3), which we reproduce here:

$$\sigma_A^2 = \sum_{i=1}^{\mathcal{I}} a_i^2 \sigma_i^2 + \sum_{i=1}^{\mathcal{I}} a_i(1-a_i)\rho_{i,A-i}\sigma_i\sigma_{A-i}. \quad (7)$$

In order to evaluate the estimated effect of trade-induced changes in $\sigma_i^2$, $\rho_{i,A-i}$, and $h$, we assume for simplicity that for all sectors, the variances and correlations are equal: $\sigma_i^2 = \sigma^2$, $\rho_{i,A-i} = \rho$, and $\sigma_{A-i} = \sigma_{A-}$ for all $i$. This allows us to write equation (7) in terms of $\sigma^2$, $\rho$, and $h$ as:

$$\sigma_A^2 = h\sigma^2 + (1-h)\rho\sigma\sigma_{A-}. \quad (8)$$

Using a Taylor approximation, the effect of changes in the three variables ($\Delta\sigma^2$, $\Delta\rho$, and $\Delta h$) on the aggregate volatility is:

$$\Delta\sigma_A^2 \approx \frac{\partial\sigma_A^2}{\partial\sigma^2}\Delta\sigma^2 + \frac{\partial\sigma_A^2}{\partial\rho}\Delta\rho + \frac{\partial\sigma_A^2}{\partial h}\Delta h. \tag{9}$$

We can compute the partial derivatives using equation (8):

$$\Delta\sigma_A^2 \approx \underbrace{\left(h + (1-h)\rho\frac{\sigma_{A-}}{2\sigma}\right)\Delta\sigma^2}_{\text{[1] Sector Volatility Effect}} + \underbrace{(1-\ h)\sigma\sigma_{A-}\Delta\rho}_{\text{[2] Comovement Effect}} + \underbrace{(\sigma^2 -\ \rho\sigma\sigma_{A-})\Delta h}_{\text{[3] Specialization Effect}}. \tag{10}$$

Each of the three terms represents the partial effect of the three channels we estimated on the aggregate volatility, and their sum is the combined impact.

We obtain the values of $\Delta\sigma^2$, $\Delta\rho$, and $\Delta h$ as a function of changes in openness from our estimated equations as follows:

$$\Delta\sigma^2 = \widehat{\beta}_\sigma\sigma^2\Delta\text{Log(Openness)} \tag{11}$$

$$\Delta\rho = \widehat{\beta}_\rho\Delta\text{Log(Openness)} \tag{12}$$

$$\Delta h = \widehat{\beta}_h h\Delta\text{Log(Openness)}, \tag{13}$$

where $\widehat{\beta}_\sigma$ is the coefficient on the trade openness variable in equation (2), $\widehat{\beta}_\rho$ is the coefficient on trade openness obtained from estimating equation (4), and $\widehat{\beta}_h$ comes from estimating our specialization equation (6).[20]

The various exercises we perform in this section differ only in the kinds of values we plug in for $\Delta$Log(Openness), $\sigma^2$, $\rho$, $h$, $\sigma_{A-}$, $\widehat{\beta}_\sigma$, $\widehat{\beta}_\rho$, and $\widehat{\beta}_h$.

## 4.1 The Impact Across Countries and Over Time

In the first two exercises, we use the average values of $\sigma^2$, $\rho$, and $h$ found in our sample. These are reported in the first row of Table T1. The average Herfindahl index in our sample is $h = 0.12$. The average comovement of a sector with the aggregate, $\rho = 0.35$. The average variance of a sector, $\sigma^2 = 0.038$. For the variance of the entire economy minus one sector, $\sigma_{A-}^2$, we simply use the average aggregate volatility in our sample of countries, which is 0.0086. This is a sensible approximation of the volatility of all the sectors except one, since the mean share of an individual sector in total manufacturing is just under 0.04, and thus on average, subtracting an individual sector from the aggregate will not make much difference.

The dispersion in the overall manufacturing trade as a share of output in our sample implies that moving from the 25$^{\text{th}}$ to the 75$^{\text{th}}$ percentile in overall trade openness is equivalent to an increase in total trade to manufacturing output from about 40 percent (e.g.,

[20]Note that in the estimation equations (2) and (6) the left-hand-side variable is in logs. Hence, in order to get the change in its level in equations (11) and (13), we must multiply the estimated coefficients by the average level of the variable.

**Table T1.** Summary Statistics Used in Magnitude Calculations

| Sample | $\sigma^2$ | $\rho$ | $h$ | $\sigma^2_A$, $\sigma^2_{A-}$ |
|---|---|---|---|---|
| Full | 0.038 | 0.346 | 0.120 | 0.009 |
| | | | | |
| Developed | 0.014 | 0.427 | 0.096 | 0.003 |
| Developing | 0.052 | 0.295 | 0.134 | 0.012 |
| | | | | |
| 1970s | 0.037 | 0.378 | 0.121 | 0.011 |
| 1980s | 0.035 | 0.358 | 0.112 | 0.008 |
| 1990s | 0.039 | 0.350 | 0.113 | 0.007 |

Notes: This table reports the averages of the variables used to calculate the three effects in equation (10) for the full sample and the various subsamples. $\sigma^2$ is the average sector-level volatility, $\rho$ is the average correlation coefficient between an individual sector and the aggregate less that sector, $h$ is the average Herfindahl index, and $\sigma^2_{A-}$ is the average volatility of the aggregate minus one sector, which we approximate by the aggregate volatility.

the United Kingdom) to 80 percent (e.g., Indonesia). This change in overall trade leads to a change in sector-level variance of $\Delta\sigma^2 = 0.0045$. Using equation (10), we calculate that this increase in sector-level volatility raises aggregate volatility by 0.0009, which is of course considerably smaller than the sector-level increase, due to diversification among sectors. This change is sizeable, however, relative to the magnitudes of aggregate volatility we observe. In particular, it is equivalent to about 10.2% of the average aggregate variance found in our data.

Moving on to the Comovement Effect, our regression estimates indicate that the same increase in trade results in a reduction of correlation between the sector and the aggregate equal to $\Delta\rho = 0.021$. Plugging this into equation (10) and evaluating the partial derivative, we obtain a reduction in the aggregate variance due to decreased comovement equal to $-0.00033$. This is about one third the magnitude of the sectoral volatility effect, and amounts to a reduction equivalent to 3.9% of the mean aggregate variance observed in our data. Finally, according to our estimates, the change in overall trade openness equivalent to moving from the 25$^{\text{th}}$ to the 75$^{\text{th}}$ percentile leads to a change in the Herfindahl index of $\Delta h = 0.035$. The resulting change in aggregate volatility from this increased specialization is $\Delta\sigma^2_A = 0.0011$. Thus, increased specialization raises aggregate volatility by about 12.8% of its mean.

These calculations, summarized in the first two rows of Table 9, imply changes in aggregate volatility resulting from trade that are relatively modest and plausible in magnitude.

Two of the effects imply increased volatility, while the other leads to a reduction. Adding up the three effects, we obtain the overall change in aggregate volatility as implied by equation (10) of $\Delta\sigma_A^2 \approx 0.0016$, or about 19% of average variance of the manufacturing sector observed in our data over the sample period, 1970–99.

The previous exercise was informative of the kind of differences in aggregate volatility we can expect from the dispersion of trade openness found in the cross section. That is, we computed the expected differences in volatility as a function of differences in trade openness across countries. Alternatively, we can ask how the increase in trade over time within our sample period is expected to affect aggregate volatility. To learn this, we calculate the mean difference in the total trade to manufacturing output between the 1970s and the 1990s in our sample. It turns out that trade openness increased by about 30 percentage points over the period, going from below 60 percent in the 1970s to 90 percent in the 1990s. The change in trade openness of this magnitude implies an estimated increase in aggregate volatility of roughly 0.001. Since in this calculation we are using the same mean values of $\sigma^2$, $\rho$, $h$, $\sigma_{A-}$, and the same $\widehat{\beta}_\sigma$, $\widehat{\beta}_\rho$, and $\widehat{\beta}_h$, the relative importance of the three effects is the same as in the first exercise: the sectoral volatility effect raises aggregate volatility by about 0.0006, the comovement effect lowers it by $-0.0002$, and the specialization effect raises it by about 0.0007.

How sizeable is this effect? Relative to what we observe in the cross section, this implied change in volatility is equivalent to 12 percent of the average aggregate variance in our sample. Alternatively, we can also ask how it compares with the changes in aggregate volatility which occurred between the 1970s and the 1990s. It turns out that on average, aggregate volatility has decreased by 0.0035 over this period. By this metric, the implied increase in volatility of 0.001 due to growing trade is equivalent to more than a quarter of the observed decrease in aggregate volatility. Trade has therefore counteracted the general tendency of the smoothing out of business cycles over time.[21]

## 4.2 Country Characteristics and the Impact on Aggregate Volatility

The two calculations above imply that the average effect of trade openness on aggregate volatility acting through the three channels is appreciable but modest. However, these are based on sample averages of $\sigma^2$, $\rho$, $h$, and $\sigma_{A-}$, and clearly the estimated impact of trade will differ depending on these country characteristics. For instance, the sectoral volatility effect would be significantly less important in a highly diversified economy (low $h$), while the comovement effect will be magnified in a country with a high volatility ($\sigma^2$ and $\sigma_{A-}$).

[21]See Stock and Watson (2003) for evidence on the fall in volatility in the U.S. and Cecchetti, Flores-Lagunes and Krause (2006) for cross-country evidence.

Thus, we would like to get a sense of how the magnitudes change as we vary these country characteristics.

We do this in two ways. First, we calculate the averages of $\sigma^2$, $\rho$, $h$, and $\sigma_{A-}$ for the developed and developing country subsamples, and use them to calculate the impact of trade on these two groups of countries.[22] The subsample averages of $\sigma^2$, $\rho$, $h$, and $\sigma_{A-}$ are summarized in Table T1. Developing countries are considerably more volatile, somewhat less diversified, and have lower average comovement of sectors. Table 9 presents the comparison of the impact of trade on the developed and developing countries. In these calculations, we keep the magnitude of the trade opening and the $\beta$'s the same for both. The differences in the impact of trade between the two groups are pronounced. It turns out that the same change in openness raises aggregate volatility by 0.0005 in the average developed country, but by 0.0025, or five times as much, in the average developing country. As a share of the average aggregate volatility in the two groups of countries, however, the effect is stronger in developed ones: the increase corresponds to 40% of the average aggregate volatility found in the developed subsample, compared to 28% in for the developing subsample. The relative importance of the three individual effects does not differ greatly between the two samples, as evident from Table 9. Perhaps surprisingly, the sector-level volatility and comovement effects are relatively less important in the developing country sample. The specialization effect, while still the largest quantitatively, is less important in the developed country sample.

The developed and developing countries differ significantly along every variable that goes into calculating our magnitudes. However, we might also like to know how changes in an individual variable affect these magnitudes. To do this, we go back to the full sample baseline calculation of the previous subsection, and vary $\sigma^2$, $\rho$, and $h$ individually. Table 10 reports the results. In this table, rather than evaluating the three effects using the sample means of $\sigma^2$, $\rho$, and $h$ as we had done above, we evaluate them using each of these at the $25^{\text{th}}$ and the $75^{\text{th}}$ percentile of its distribution, one by one. Thus, this table allows us to see how the sizes of the Sector Volatility Effect, the Comovement Effect, and the Specialization Effect differ between countries at the $25^{\text{th}}$ and the $75^{\text{th}}$ percentile in the distribution of $\sigma^2$, for example.

It turns out that moving from the $25^{\text{th}}$ to the $75^{\text{th}}$ percentile in the distribution of sector-level volatility more than quadruples the overall effect of trade opening. What is interesting here is that the strongest effect of changing $\sigma^2$ is not on the Sector Volatility Effect itself, but on the Specialization Effect: while the magnitude of the former triples, the latter increases by a factor of 4.4. The increase in $\sigma^2$ also doubles the magnitude of

[22]Countries included in the developed subsample are denoted by a * in Appendix Table A1.

the comovement effect. By contrast, moving from the 25$^{\text{th}}$ to the 75$^{\text{th}}$ percentile in the distribution of $\rho$ hardly changes anything. The net effect is positive, but the increase in overall volatility due to trade is only 5 percent higher for the more correlated country. Differences in $h$ change the impact of trade appreciably, but much less than differences in $\sigma^2$: moving from the 25$^{\text{th}}$ to the 75$^{\text{th}}$ percentile in the distribution of $h$ increases the overall impact of trade by a factor of 1.6.

To summarize, the impact of trade opening on aggregate volatility varies a great deal depending on country characteristics. For instance, the impact of the same trade opening is likely to be five times higher in absolute terms for a typical developing country compared to a typical developed country. Furthermore, the country characteristic that is by far most responsible for the differences in estimated impact of trade is sector-level volatility. The impact of trade on aggregate volatility is highest for countries whose sectors are already most volatile on average. Its magnitude is such that it cannot be ignored when considering the effects of trade opening in developing countries. Note that this estimated impact of trade is obtained controlling for a wide variety of country characteristics, such as institutions, macroeconomic policies, or the overall level of development.

### 4.3 Changes in the Impact on Aggregate Volatility across Decades

The final exercise we perform is to estimate how the impact of trade on aggregate volatility changes over time. For this calculation, we reestimate our three baseline specifications in the previous section by decade. This allows us to obtain potentially different coefficients for $\widehat{\beta}_\sigma$, $\widehat{\beta}_\rho$, and $\widehat{\beta}_h$ to use in our magnitude calculations. We also evaluate $\sigma^2$, $\rho$, $h$, and $\sigma_{A-}$ at their means within each individual decade. The results of estimating the $\beta$'s by decade are presented in Table 8, while the summary statistics by decade are given in Table T1. Examining the coefficients, it appears that the effect of trade on all three determinants of volatility rises over time. Each coefficient roughly doubles in magnitude between the 1970s and the 1990s, with the 1980s somewhere in between. When it comes to summary statistics, there is a clear decrease in aggregate volatility in our sample. The other variables, $\sigma^2$, $\rho$, and $h$, do not change significantly across the three decades.

The results are summarized in Table 9. Not surprisingly, the rising $\beta$'s in our regressions over time imply that the estimated impact of trade openness increases substantially. In the 1970s and 1980s, increasing trade openness from the 25$^{\text{th}}$ to the 75$^{\text{th}}$ percentile (roughly from 40 to 80 percent of total output) increases aggregate volatility by 0.0009. In the 1990s, the same increase in trade openness raises aggregate volatility by 0.0019, more than double the absolute impact. As a share of aggregate volatility, the effect goes from less than 10% of the average in the 1970s to almost 28% in the 1990s.

Also worth noting is how the relative importance of the three effects changes over time. In the cross-sectional exercise using 30-year averages, we found that the Specialization and the Sector Volatility Effects are the two most important ones, while the Comovement Effect is small in magnitude. It turns out that this pattern varies somewhat across decades, even as all three effects become larger in magnitude over time. In the 1970s, the Sector Volatility Effect is substantially greater than the other two, while the Specialization Effect is much weaker than in the full sample. Furthermore, relative to the full sample, the Comovement Effect is more important in the 1970s as well. Intriguingly, in the 1980s all three effects are more or less equal in absolute value, and only in the 1990s do we see the Comovement Effect falling substantially behind the other two.

The result that the impact of trade has become stronger over time is distinct from the simple observation that trade has increased over the period. The increase in trade itself need not imply that the relationship between trade and volatility would have strengthened. Perhaps more interestingly, this finding is not at all inconsistent with the fall in overall macroeconomic volatility over this period. What seems to be happening is that while aggregate volatility has decreased, differences between the volatilities of country-sectors are better explained by the variation in trade openness. These quantitative results are valuable in their own right as they reveal the changing nature of trade's impact on the macroeconomy over time. Furthermore, they provide a rich set of facts to build upon in future empirical and theoretical work aiming to better understand the nature of the global business cycle. For example, in the macroeconomics literature sector-level dynamics underlying aggregate business cycles have been explored in a closed economy,[23] and recent work has moved to the firm level.[24] Our results can help provide a foundation for future work in the open economy setting.

## 5 Conclusion

Whether increased trade openness has contributed to rising uncertainty and exposed countries to external shocks remains a much debated topic. In this paper, we use industry-level data to document several aspects of the relationship between openness and volatility. Our main conclusions can be summarized as follows. First, higher trade in a sector raises its volatility. Second, more trade also implies that the sector is less correlated with the rest of the economy. Third, higher overall trade openness increases specialization in the economy. The sum of these effects implies that moving from the 25$^{\text{th}}$ to the 75$^{\text{th}}$ percentile in the dis-

[23]For an early contribution see Long and Plosser (1983).
[24]See Gabaix (2005) and references within.

tribution of trade openness raises volatility of the aggregate manufacturing sector by about 19% of the average aggregate variance observed in our sample. The estimated impact differs a great deal between countries and over time however. Trade raises aggregate volatility roughly five times more in a typical developing country than in a typical developed country. Over time, the impact of trade acting through all three channels has become stronger.

While the results in this paper are informative, our understanding of the trade-volatility relationship can be improved along many dimensions. For instance, the exercise in this paper imposes symmetry between sectors, and thus does not allow us to investigate whether some countries tend to specialize systematically in more or less risky sectors, something that could be another channel for the relationship between trade and volatility. The change over time in the impact of trade on volatility also deserves much more careful study. In particular, the increasing impact of trade, together with growing trade itself, needs to be analyzed jointly with the well-documented fact that business cycle volatility has actually decreased over the same period. Finally, this paper remains silent on the relationship between trade and growth. This relationship must also be considered if we wish to make any claims on the welfare consequences of opening to trade. We consider these to be promising avenues for future research.

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**Table 1.** Volatility of Annual Output Growth per Worker: Cross-Sectional Results

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Trade/Output | 0.250** | 0.270** | 0.200** | 0.160** |
| | (0.025) | (0.030) | (0.020) | (0.028) |
| Output per worker | 0.022 | -0.474** | 0.361** | 0.019 |
| | (0.039) | (0.053) | (0.033) | (0.048) |
| Observations | 1518 | 1518 | 1518 | 1518 |
| $R^2$ | 0.065 | 0.240 | 0.620 | 0.712 |
| $\mu_c$ | no | no | yes | yes |
| $\mu_i$ | no | yes | no | yes |

Notes: Robust standard errors in parentheses. + significant at 10%; * significant at 5%; ** significant at 1%. The sample period is 1970–99. The dependent variable is the log variance of the growth rate of output per worker, 1970–99. All regressors are in natural logs, trade/output is the period average, and output per worker is the period's initial value. $\mu_c$ denotes the country fixed effects. $\mu_i$ denotes the sector fixed effects. All specifications are estimated using OLS.

**Table 2.** Volatility of Annual Output Growth per Worker: Panel Results

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| Trade/Output | 0.191** | 0.195** | 0.156** | 0.148** | 0.131** | 0.192** | 0.093** |
| | (0.015) | (0.018) | (0.014) | (0.018) | (0.018) | (0.020) | (0.027) |
| Output per worker | -0.058* | -0.633** | 0.290** | -0.013 | 0.036 | 0.009 | -0.210** |
| | (0.028) | (0.041) | (0.026) | (0.043) | (0.043) | (0.043) | (0.070) |
| Observations | 4287 | 4287 | 4287 | 4287 | 4287 | 4287 | 4287 |
| $R^2$ | 0.049 | 0.183 | 0.422 | 0.486 | 0.580 | 0.498 | 0.672 |
| $\mu_t$ | yes | yes | yes | yes | no | no | yes |
| $\mu_c$ | no | no | yes | yes | yes | no | no |
| $\mu_i$ | no | yes | no | yes | no | yes | no |
| $\mu_c \times \mu_i$ | no | no | no | no | no | no | yes |
| $\mu_c \times \mu_t$ | no | no | no | no | no | yes | no |
| $\mu_i \times \mu_t$ | no | no | no | no | yes | no | no |

Notes: Robust standard errors in parentheses. + significant at 10%; * significant at 5%; ** significant at 1%. The sample period is 1970–99. The dependent variable is the log variance of the growth rate of output per worker over ten-year periods: 1970–79, 1980–89, 1990–99. All regressors are in natural logs, trade/output is averaged over the ten-year periods, and output per worker is the ten-year period's initial value. $\mu_c$ denotes the country fixed effects. $\mu_i$ denotes the sector fixed effects. All specifications are estimated using OLS.

**Table 3.** Volatility of Annual Growth of Quantity per Worker and of Prices: Cross-Sectional Results

| | | | | |
|---|---|---|---|---|
| | *I. Quantity per Worker* | | | |
| | (1) | (2) | (3) | (4) |
| Trade/Output | 0.275** | 0.285** | 0.262** | 0.218** |
| | (0.025) | (0.030) | (0.020) | (0.032) |
| Output per worker | -0.248** | -0.540** | 0.008 | -0.066 |
| | (0.043) | (0.057) | (0.033) | (0.051) |
| Observations | 1345 | 1345 | 1345 | 1345 |
| $R^2$ | 0.123 | 0.224 | 0.616 | 0.698 |
| $\mu_c$ | no | no | yes | yes |
| $\mu_i$ | no | yes | no | yes |
| | *II. Price* | | | |
| | (1) | (2) | (3) | (4) |
| Trade/Output | 0.192** | 0.200** | 0.189** | 0.180** |
| | (0.024) | (0.030) | (0.021) | (0.033) |
| Output per worker | -0.104* | -0.370** | 0.114** | 0.015 |
| | (0.043) | (0.057) | (0.039) | (0.059) |
| Observations | 1342 | 1342 | 1342 | 1342 |
| $R^2$ | 0.070 | 0.185 | 0.519 | 0.602 |
| $\mu_c$ | no | no | yes | yes |
| $\mu_i$ | no | yes | no | yes |

Notes: Robust standard errors in parentheses. + significant at 10%; * significant at 5%; ** significant at 1%. The sample period is 1970–99. The dependent variable is the log variance of the growth rate of quantity per worker or prices, 1970–99. All regressors are in natural logs, trade/output is the period average, and output per worker is the period's initial value. $\mu_c$ denotes the country fixed effects. $\mu_i$ denotes the sector fixed effects. All specifications are estimated using OLS.

**Table 4.** Correlation of Annual Output Growth per Worker with the Rest of the Manufacturing Sector: Cross-Section Results

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Trade/Output | -0.026** | -0.057** | -0.004 | -0.028** |
| | (0.007) | (0.009) | (0.007) | (0.010) |
| Output per worker | 0.007 | 0.013 | -0.021* | -0.046** |
| | (0.010) | (0.014) | (0.010) | (0.017) |
| Observations | 1515 | 1515 | 1515 | 1515 |
| $R^2$ | 0.013 | 0.097 | 0.306 | 0.371 |
| $\mu_c$ | no | no | yes | yes |
| $\mu_i$ | no | yes | no | yes |

Notes: Robust standard errors in parentheses. + significant at 10%; * significant at 5%; ** significant at 1%. The sample period is 1970–99. The dependent variable is the correlation of the growth rate of output per worker with the rest of the manufacturing sector, 1970–99. All regressors are in natural logs, trade/output is the period average, and output per worker is the period's initial value. $\mu_c$ denotes the country fixed effects. $\mu_i$ denotes the sector fixed effects. All specifications are estimated using OLS.

**Table 5.** Correlation of Annual Output Growth per Worker with the Rest of the Manufacturing Sector: Panel Results

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| Trade/Output | -0.029** | -0.043** | -0.026** | -0.043** | -0.037** | -0.056** | -0.021* |
| | (0.005) | (0.006) | (0.005) | (0.007) | (0.007) | (0.008) | (0.010) |
| Output per worker | -0.019+ | 0.005 | -0.046** | -0.049** | -0.068** | -0.043* | -0.007 |
| | (0.010) | (0.014) | (0.011) | (0.018) | (0.018) | (0.018) | (0.025) |
| Observations | 4161 | 4161 | 4161 | 4161 | 4161 | 4161 | 4161 |
| $R^2$ | 0.009 | 0.041 | 0.174 | 0.202 | 0.271 | 0.215 | 0.672 |
| $\mu_t$ | yes | yes | yes | yes | no | no | yes |
| $\mu_c$ | no | no | yes | yes | yes | no | no |
| $\mu_i$ | no | yes | no | yes | no | yes | no |
| $\mu_c \times \mu_i$ | no | no | no | no | no | no | yes |
| $\mu_c \times \mu_t$ | no | no | no | no | no | yes | no |
| $\mu_i \times \mu_t$ | no | no | no | no | yes | no | no |

Notes: Robust standard errors in parentheses. + significant at 10%; * significant at 5%; ** significant at 1%. The sample period is 1970–99. The dependent variable is the correlation of the growth rate of output per worker with the rest of the manufacturing sector over ten-year periods: 1970–79, 1980–89, 1990–99. All regressors are in natural logs, trade/output is averaged over the ten-year periods, and output per worker is the ten-year period's initial value. $\mu_c$ denotes the country fixed effects. $\mu_i$ denotes the sector fixed effects. All specifications are estimated using OLS.

**Table 6.** Correlation of Annual Growth of Quantity per Worker and of Prices with Rest of the Manufacturing Sector: Cross-Sectional Results

| | *I. Quantity per Worker* | | | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| Trade/Output | -0.038** | -0.053** | -0.018** | -0.017+ |
| | (0.007) | (0.008) | (0.007) | (0.010) |
| Output per worker | -0.026* | 0.024+ | -0.057** | -0.021 |
| | (0.011) | (0.014) | (0.011) | (0.019) |
| Observations | 1345 | 1345 | 1345 | 1345 |
| $R^2$ | 0.028 | 0.114 | 0.245 | 0.303 |
| $\mu_c$ | no | no | yes | yes |
| $\mu_i$ | no | yes | no | yes |
| | *II. Price* | | | |
| | (1) | (2) | (3) | (4) |
| Trade/Output | -0.046** | -0.056** | -0.042** | -0.047** |
| | (0.006) | (0.008) | (0.006) | (0.009) |
| Output per worker | 0.013 | 0.081** | -0.044** | -0.016 |
| | (0.010) | (0.014) | (0.010) | (0.018) |
| Observations | 1341 | 1341 | 1341 | 1341 |
| $R^2$ | 0.054 | 0.153 | 0.399 | 0.459 |
| $\mu_c$ | no | no | yes | yes |
| $\mu_i$ | no | yes | no | yes |

Notes: Robust standard errors in parentheses. + significant at 10%; * significant at 5%; ** significant at 1%. The sample period is 1970–99. The dependent variable is the correlation of the growth rate of quantity per worker or prices with the rest of the manufacturing sector, 1970–99. All regressors are in natural logs, trade/output is the period average, and output per worker is the period's initial value. $\mu_c$ denotes the country fixed effects. $\mu_i$ denotes the sector fixed effects. All specifications are estimated using OLS.

**Table 7.** Specialization and Trade Openness at the Country Level

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Manuf. Trade/Output | 0.338** | 0.335** | 0.331* | 0.389** | 0.202** |
| | (0.084) | (0.093) | (0.127) | (0.114) | (0.052) |
| Herfindahl of exports | | | | | 0.473** |
| | | | | | (0.133) |
| GDP per capita | | -0.106+ | | -0.100+ | 0.033 |
| | | (0.057) | | (0.057) | (0.068) |
| Constant | -2.030** | -1.102* | -2.042** | -1.124* | -1.675** |
| | (0.092) | (0.457) | (0.119) | (0.467) | (0.392) |
| Observations | 57 | 56 | 55 | 55 | 56 |
| $R^2$ | 0.215 | 0.261 | – | – | 0.558 |
| Sample | full | full | full | full | full |
| Estimation | OLS | OLS | IV | IV | OLS |

Notes: Robust standard errors in parentheses. + significant at 10%; * significant at 5%; ** significant at 1%. The sample period is 1970–99. The dependent variable is the log Herfindahl index of manufacturing production shares (averaged over the period). All regressors are in natural logs and are period averages. In the instrumental variables regressions, the instrument for trade openness is the natural openness from Frankel and Romer (1999).

**Table 8.** Volatility, Correlation and Specialization Coefficients Across Decades

| | | *Sector Volatility* | |
|---|---|---|---|
| | (1) | (2) | (3) |
| | 1970s | 1980s | 1990s |
| Trade/Output | 0.131** | 0.148** | 0.246** |
| | (0.028) | (0.033) | (0.045) |
| Observations | 1401 | 1455 | 1431 |
| $R^2$ | 0.622 | 0.674 | 0.495 |
| | | *Comovement* | |
| | (1) | (2) | (3) |
| | 1970s | 1980s | 1990s |
| Trade/Output | -0.030* | -0.060** | -0.064** |
| | (0.012) | (0.016) | (0.018) |
| Observations | 1378 | 1379 | 1404 |
| $R^2$ | 0.270 | 0.288 | 0.288 |
| | | *Specialization* | |
| | (1) | (2) | (3) |
| | 1970s | 1980s | 1990s |
| Trade/Output | 0.180 | 0.342** | 0.468** |
| | (0.130) | (0.120) | (0.136) |
| Observations | 52 | 51 | 50 |
| $R^2$ | – | – | – |

Notes: Robust standard errors in parentheses. + significant at 10%; * significant at 5%; ** significant at 1%. Sector volatility and comovement decade regressions run with country and sector fixed effects, corresponding to column (4) of Tables 1 and 4. Specialization decade regressions run using IV, corresponding to column (3) of Table 7.

**Table 9.** Cross-Country and Cross-Decade Impacts of Changes in Openness

| | Effect | | | |
|---|---|---|---|---|
| Sample | Sector Volatility | Comovement | Specialization | Total |
| *Full* | | | | |
| $\Delta\sigma_A^2$ | 0.0009 | -0.0003 | 0.0011 | 0.0016 |
| $\Delta\sigma_A^2/\sigma_A^2$ | 0.1016 | -0.0389 | 0.1281 | 0.1908 |
| *Developed* | | | | |
| $\Delta\sigma_A^2$ | 0.0003 | -0.0001 | 0.0003 | 0.0005 |
| $\Delta\sigma_A^2/\sigma_A^2$ | 0.2432 | -0.0945 | 0.2517 | 0.4005 |
| *Developing* | | | | |
| $\Delta\sigma_A^2$ | 0.0012 | -0.0004 | 0.0018 | 0.0025 |
| $\Delta\sigma_A^2/\sigma_A^2$ | 0.1367 | -0.0503 | 0.1971 | 0.2834 |
| *1970s* | | | | |
| $\Delta\sigma_A^2$ | 0.0008 | -0.0004 | 0.0005 | 0.0009 |
| $\Delta\sigma_A^2/\sigma_A^2$ | 0.0717 | -0.0369 | 0.0451 | 0.0799 |
| *1980s* | | | | |
| $\Delta\sigma_A^2$ | 0.0007 | -0.0007 | 0.0008 | 0.0009 |
| $\Delta\sigma_A^2/\sigma_A^2$ | 0.0909 | -0.0837 | 0.1045 | 0.1118 |
| *1990s* | | | | |
| $\Delta\sigma_A^2$ | 0.0013 | -0.0007 | 0.0013 | 0.0019 |
| $\Delta\sigma_A^2/\sigma_A^2$ | 0.1865 | -0.1015 | 0.1918 | 0.2767 |

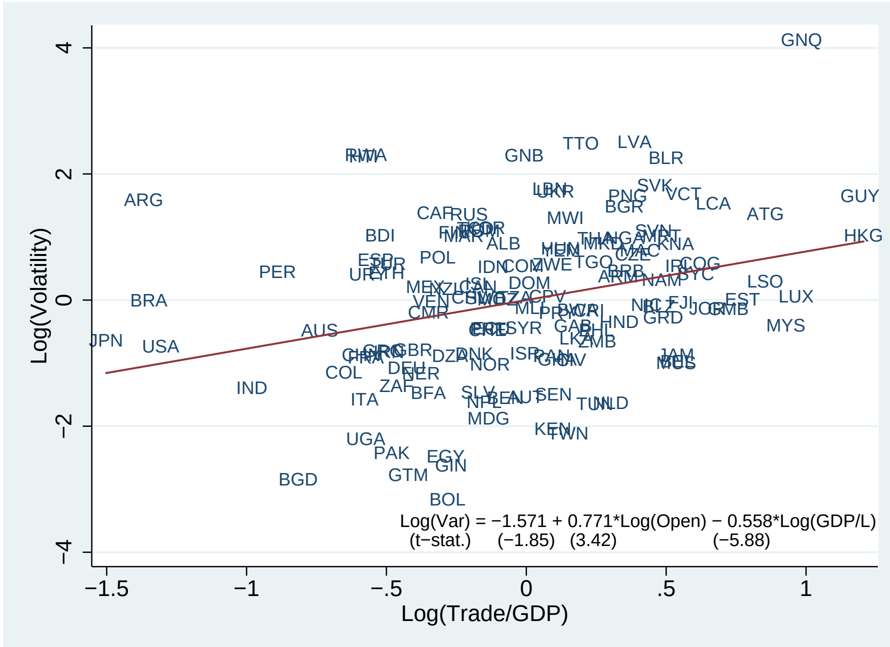
Notes: This table reports the estimated change in aggregate volatility, in absolute terms ($\Delta\sigma_A^2$), and relative to the average aggregate volatility in the sample ($\Delta\sigma_A^2/\sigma_A^2$). The first three columns report the individual effects, and the last column the combined effect. The trade opening used in this table is equivalent to moving from the 25$^{\text{th}}$ to 75$^{\text{th}}$ percentile of trade openness in the sample.

**Table 10.** The Impact of Changes in Openness Evaluated at Different Percentiles of the Data

| | Effect | | | |
|---|---|---|---|---|
| | Sector Volatility | Comovement | Specialization | Total |
| *Baseline* | 0.0009 | -0.0003 | 0.0011 | 0.0016 |
| *Sector Volatility* ($\sigma_i^2$) | | | | |
| $25^{\text{th}}$ pctile | 0.0004 | -0.0002 | 0.0004 | 0.0006 |
| $75^{\text{th}}$ pctile | 0.0013 | -0.0004 | 0.0018 | 0.0027 |
| Ratio $75^{\text{th}}/25^{\text{th}}$ | 2.90 | 1.95 | 4.44 | 4.22 |
| *Comovement* ($\rho_{i,A-i}$) | | | | |
| $25^{\text{th}}$ pctile | 0.0008 | -0.0003 | 0.0012 | 0.0016 |
| $75^{\text{th}}$ pctile | 0.0010 | -0.0003 | 0.0010 | 0.0017 |
| Ratio $75^{\text{th}}/25^{\text{th}}$ | 1.29 | 1.00 | 0.87 | 1.05 |
| *Specialization* ($h$) | | | | |
| $25^{\text{th}}$ pctile | 0.0007 | -0.0004 | 0.0007 | 0.0011 |
| $75^{\text{th}}$ pctile | 0.0009 | -0.0003 | 0.0011 | 0.0017 |
| Ratio $75^{\text{th}}/25^{\text{th}}$ | 1.28 | 0.95 | 1.60 | 1.60 |

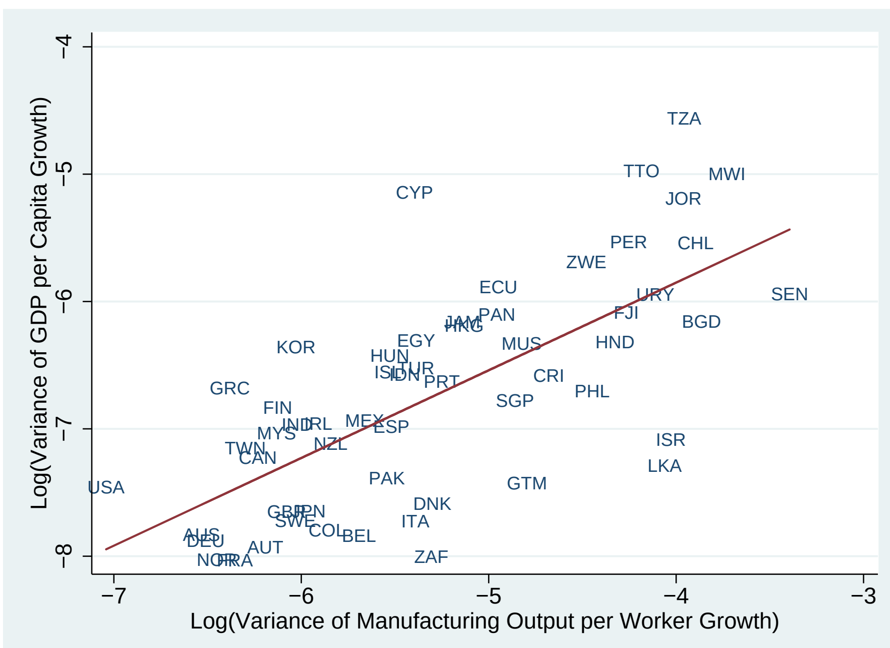
Notes: This table reports the estimated change in aggregate volatility in absolute terms ($\Delta\sigma_A^2$), while evaluating $\sigma^2$, $\rho$, and $h$ at the $25^{\text{th}}$ and $75^{\text{th}}$ percentiles of their respective distributions. It also reports the ratio of the two. The trade opening used in this table is equivalent to moving from the $25^{\text{th}}$ to $75^{\text{th}}$ percentile of trade openness in the sample.

**Figure 1.** Volatility and Openness in the 1990s



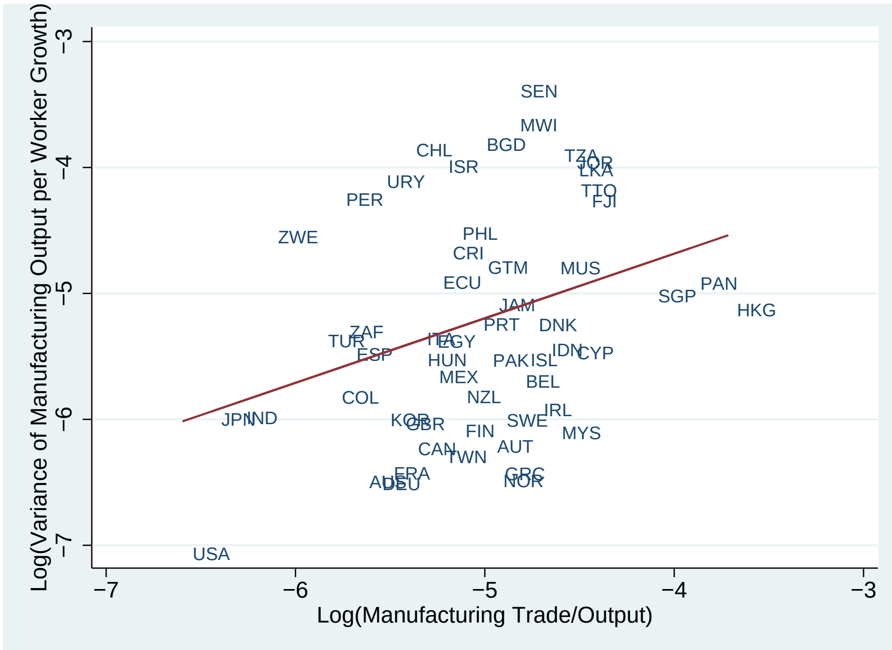

Notes: Source: Penn World Tables. Volatility is calculated using annual growth rates over 1990–99 for per-capita GDP, and trade openness is the average of imports plus exports divided by GDP over the same period.

**Figure 2.** Comparison of Manufacturing and Aggregate Volatility



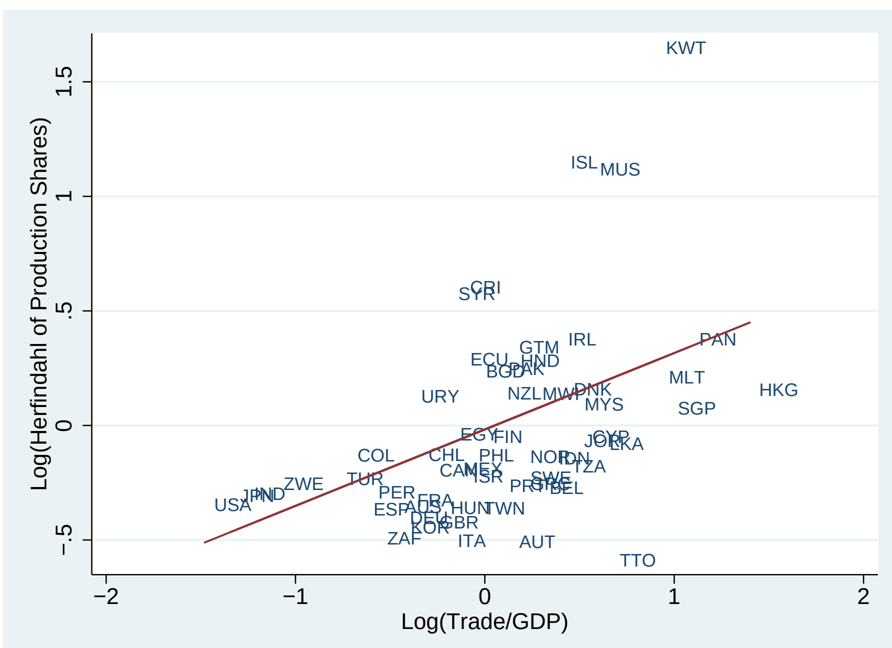

Notes: Volatility is calculated using annual growth rates over 1970–99 for manufacturing output per worker and per-capita GDP from the Penn World Tables, respectively.

**Figure 3.** Manufacturing Output Volatility and Openness




Notes: Manufacturing output volatility is calculated using annual growth rates over 1970–99, and the manufacturing trade-to-output ratio is an average over 1970–99.

**Figure 4.** Trade and Specialization




Notes: The Herfindahl of production shares and the manufacturing trade-to-output measures ratio are averages for 1970-99. The graph reports partial correlations with GDP per capita netted out.

**Table A1.** Country Summary Statistics: 1970–99

| | Growth | | Imports/ | Exports/ | | Growth | | Imports/ | Exports/ |
|---|---|---|---|---|---|---|---|---|---|
| Country | Avg. | St. Dev. | Output | Output | Country | Avg. | St. Dev. | Output | Output |
| Australia* | 0.028 | 0.038 | 0.172 | 0.161 | Korea | 0.055 | 0.049 | 0.178 | 0.186 |
| Austria* | 0.027 | 0.045 | 0.319 | 0.293 | Malawi | 0.057 | 0.155 | 0.713 | 0.329 |
| Bangladesh | -0.008 | 0.145 | 0.405 | 0.191 | Malaysia | 0.032 | 0.047 | 0.471 | 0.506 |
| Belgium* | 0.042 | 0.058 | 0.339 | 0.384 | Malta | 0.054 | 0.074 | 0.989 | 0.388 |
| Canada* | 0.024 | 0.044 | 0.136 | 0.263 | Mauritius | -0.008 | 0.090 | 0.437 | 0.628 |
| Chile | 0.041 | 0.143 | 0.197 | 0.226 | Mexico | 0.017 | 0.059 | 0.146 | 0.473 |
| China,P.R.:Hong Kong | 0.050 | 0.077 | 1.837 | 0.784 | New Zealand* | 0.011 | 0.054 | 0.250 | 0.327 |
| Colombia | 0.022 | 0.053 | 0.198 | 0.079 | Norway* | 0.026 | 0.040 | 0.363 | 0.284 |
| Costa Rica | -0.026 | 0.096 | 0.373 | 0.184 | Pakistan | 0.058 | 0.063 | 0.358 | 0.294 |
| Cyprus | 0.020 | 0.067 | 0.875 | 0.202 | Panama | 0.013 | 0.084 | 2.071 | 0.504 |
| Denmark | 0.012 | 0.071 | 0.414 | 0.397 | Peru | -0.027 | 0.119 | 0.154 | 0.154 |
| Ecuador | 0.027 | 0.084 | 0.409 | 0.099 | Philippines | 0.013 | 0.108 | 0.296 | 0.261 |
| Egypt | 0.017 | 0.068 | 0.340 | 0.149 | Poland | 0.044 | 0.082 | 0.229 | 0.184 |
| Fiji | -0.007 | 0.118 | 0.656 | 0.471 | Portugal* | 0.021 | 0.072 | 0.344 | 0.260 |
| Finland* | 0.032 | 0.047 | 0.218 | 0.317 | Senegal | -0.022 | 0.183 | 0.532 | 0.241 |
| France* | 0.038 | 0.042 | 0.170 | 0.187 | Singapore | 0.037 | 0.088 | 0.851 | 0.646 |
| Germany* | 0.028 | 0.039 | 0.139 | 0.204 | South Africa | 0.009 | 0.070 | 0.177 | 0.144 |
| Greece* | 0.026 | 0.041 | 0.465 | 0.197 | Spain* | 0.030 | 0.063 | 0.154 | 0.134 |
| Guatemala | 0.006 | 0.091 | 0.450 | 0.255 | Sri Lanka | 0.011 | 0.131 | 0.767 | 0.364 |
| Honduras | -0.013 | 0.115 | 0.526 | 0.259 | Sweden* | 0.025 | 0.049 | 0.279 | 0.367 |
| Hungary | 0.038 | 0.063 | 0.231 | 0.217 | Syrian Arab Republic | 0.033 | 0.166 | 0.372 | 0.162 |
| Iceland* | 0.030 | 0.063 | 0.406 | 0.395 | Taiwan | 0.036 | 0.043 | 0.179 | 0.352 |
| India | 0.043 | 0.049 | 0.092 | 0.094 | Tanzania | -0.032 | 0.138 | 0.725 | 0.282 |
| Indonesia | 0.049 | 0.066 | 0.532 | 0.306 | Trinidad and Tobago | 0.042 | 0.123 | 0.447 | 0.679 |
| Ireland* | 0.043 | 0.052 | 0.390 | 0.419 | Turkey | 0.037 | 0.068 | 0.159 | 0.101 |
| Israel | 0.030 | 0.133 | 0.353 | 0.276 | United Kingdom* | 0.029 | 0.048 | 0.207 | 0.196 |
| Italy* | 0.036 | 0.067 | 0.198 | 0.245 | United States* | 0.021 | 0.030 | 0.086 | 0.034 |
| Jamaica | 0.017 | 0.076 | 0.454 | 0.236 | Uruguay | 0.022 | 0.128 | 0.173 | 0.206 |
| Japan* | 0.035 | 0.051 | 0.039 | 0.101 | Zimbabwe | 0.056 | 0.107 | 0.097 | 0.111 |
| Jordan | 0.028 | 0.138 | 0.866 | 0.138 | | | | | |

Notes: 'Growth' is the real manufacturing output per worker growth rate computed annually over 1970–99. Imports and exports to output are averages of total manufacturing imports and exports divided by total manufacturing output. These summary statistics are calculated based on the sample used in the cross-sectional regressions of Table 1. A * indicates a country in the developed subsample.

**Table A2.** Sector Summary Statistics: 1970–99

| | | Growth | | Imports/ | Exports/ |
|---|---|---|---|---|---|
| ISIC | Sector Name | Avg. | St. Dev. | Output | Output |
| 311 | Food products | 0.015 | 0.108 | 0.107 | 0.124 |
| 313 | Beverages | 0.029 | 0.129 | 0.062 | 0.036 |
| 314 | Tobacco | 0.034 | 0.166 | 0.030 | 0.021 |
| 321 | Textiles | 0.021 | 0.120 | 0.238 | 0.214 |
| 322 | Wearing apparel, except footwear | 0.018 | 0.113 | 0.108 | 0.236 |
| 323 | Leather products | 0.013 | 0.163 | 0.288 | 0.291 |
| 324 | Footwear, except rubber or plastic | 0.021 | 0.150 | 0.179 | 0.178 |
| 331 | Wood products, except furniture | 0.021 | 0.159 | 0.145 | 0.124 |
| 332 | Furniture, except metal | 0.022 | 0.149 | 0.148 | 0.116 |
| 341 | Paper and products | 0.028 | 0.143 | 0.328 | 0.089 |
| 342 | Printing and publishing | 0.031 | 0.124 | 0.103 | 0.036 |
| 351 | Industrial chemicals | 0.040 | 0.181 | 0.617 | 0.198 |
| 352 | Other chemicals | 0.028 | 0.124 | 0.353 | 0.089 |
| 353 | Petroleum refineries | 0.037 | 0.230 | 0.155 | 0.075 |
| 354 | Misc. petroleum and coal products | 0.026 | 0.225 | 0.094 | 0.041 |
| 355 | Rubber products | 0.017 | 0.149 | 0.179 | 0.056 |
| 356 | Plastic products | 0.023 | 0.131 | 0.131 | 0.041 |
| 361 | Pottery, china, earthenware | 0.031 | 0.162 | 0.240 | 0.113 |
| 362 | Glass and products | 0.033 | 0.142 | 0.282 | 0.117 |
| 369 | Other non-metallic mineral products | 0.035 | 0.128 | 0.087 | 0.048 |
| 371 | Iron and steel | 0.028 | 0.175 | 0.408 | 0.142 |
| 372 | Non-ferrous metals | 0.022 | 0.199 | 0.450 | 0.299 |
| 381 | Fabricated metal products | 0.023 | 0.135 | 0.283 | 0.087 |
| 382 | Machinery, except electrical | 0.029 | 0.158 | 1.022 | 0.178 |
| 383 | Machinery, electric | 0.032 | 0.141 | 0.352 | 0.075 |
| 384 | Transport equipment | 0.033 | 0.172 | 0.813 | 0.154 |
| 385 | Professional & scientific equipment | 0.025 | 0.178 | 1.676 | 0.457 |
| 390 | Other manufactured products | 0.020 | 0.166 | 0.637 | 0.367 |

Notes: 'Growth' is the real manufacturing output per worker growth rate computed annually over 1970–99. Imports and exports to output are averages of total manufacturing imports and exports divided by total manufacturing output. These summary statistics are calculated based on the sample used in the cross-sectional regressions of Table 1.

**Table A3.** Volatility of Annual Output Growth per Worker: Cross-Sectional Robustness Results

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| Trade/Output | 0.175** | 0.149** | 0.296** | 0.166** | 0.158** | 0.143** | 0.276** | 0.157** |
| | (0.028) | (0.024) | (0.030) | (0.043) | (0.028) | (0.027) | (0.029) | (0.028) |
| Output per worker | | | -0.469** | 0.014 | 0.018 | 0.014 | -0.412** | 0.023 |
| | | | (0.052) | (0.047) | (0.048) | (0.048) | (0.052) | (0.048) |
| Avg. output per worker | 0.173** | | | | | | | |
| | (0.064) | | | | | | | |
| Growth of output per worker | | 8.491** | | | | | | |
| | | (0.656) | | | | | | |
| Var(TOT) | | | 0.038** | | | | | |
| | | | (0.011) | | | | | |
| Var(TOT)×Trade/Output | | | | -0.001 | | | | |
| | | | | (0.007) | | | | |
| Var(Trade) | | | | | -0.009 | -0.024+ | | |
| | | | | | (0.011) | (0.014) | | |
| Var(Trade)×Trade/Output | | | | | | -0.017* | | |
| | | | | | | (0.007) | | |
| Share of manuf. trade | | | | | | | -1.651** | |
| | | | | | | | (0.170) | |
| Liq. needs×Private credit/GDP | | | | | | | | -2.660* |
| | | | | | | | | (1.300) |
| Observations | 1518 | 1518 | 1496 | 1496 | 1518 | 1518 | 1490 | 1490 |
| $R^2$ | 0.714 | 0.771 | 0.254 | 0.726 | 0.712 | 0.713 | 0.273 | 0.716 |
| $\mu_c$ | yes | yes | no | yes | yes | yes | no | yes |
| $\mu_i$ | yes | yes | yes | yes | yes | yes | yes | yes |

Notes: Robust standard errors in parentheses. + significant at 10%; * significant at 5%; ** significant at 1%. The sample period is 1970–99. The dependent variable is the log variance of the growth rate of output per worker, 1970–99. All variables are in natural logs except for Liq. needs×Private credit/GDP and Output per worker growth. 'Liq. needs' stands for Raddatz (2005)'s sector-level measure of liquidity needs, which is inventories over sales, calculated using COMPUSTAT data. All variables are period averages, except for output per worker which is the period's initial value. $\mu_c$ denotes the country fixed effects. $\mu_i$ denotes the sector fixed effects. All specifications are estimated using OLS.

**Table A4.** Volatility of Annual Output Growth per Worker: Panel Robustness Results

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| Trade/Output | 0.108** | 0.092** | 0.229** | 0.130** | 0.242** | 0.083** |
| | (0.028) | (0.025) | (0.019) | (0.031) | (0.019) | (0.030) |
| Output per worker | | | -0.624** | -0.195** | -0.552** | -0.293** |
| | | | (0.042) | (0.071) | (0.042) | (0.079) |
| Avg. output per worker | 0.053 | | | | | |
| | (0.083) | | | | | |
| Growth of output per worker | | 5.890** | | | | |
| | | (0.415) | | | | |
| Var(TOT) | | | -0.006 | | | |
| | | | (0.007) | | | |
| Var(Trade) | | | | 0.003 | | |
| | | | | (0.013) | | |
| Share of manuf. trade | | | | | -1.325** | |
| | | | | | (0.122) | |
| Liq. needs×Private credit/GDP | | | | | | -0.273 |
| | | | | | | (0.909) |
| Observations | 4287 | 4283 | 4241 | 4219 | 4218 | 3927 |
| $R^2$ | 0.670 | 0.708 | 0.196 | 0.672 | 0.216 | 0.693 |
| $\mu_t$ | yes | yes | no | yes | no | yes |
| $\mu_c \times \mu_i$ | yes | yes | no | yes | no | yes |
| $\mu_i \times \mu_t$ | no | no | yes | no | yes | no |

Notes: Robust standard errors in parentheses. + significant at 10%; * significant at 5%; ** significant at 1%. The sample period is 1970–99. The dependent variable is the log variance of the growth rate of output per worker, 1970–99. AAll variables are in natural logs except for Liq. needs×Private credit/GDP and Output per worker growth. 'Liq. needs' stands for Raddatz (2005)'s sector-level measure of liquidity needs, which is inventories over sales, calculated using COMPUSTAT data. All variables are period averages, except for output per worker which is the period's initial value. $\mu_c$ denotes the country fixed effects. $\mu_i$ denotes the sector fixed effects. All specifications are estimated using OLS.

**Table A5.** Correlation of Annual Output Growth per Worker with Rest of the Manufacturing Sector: Cross-Sectional Robustness Results

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| Trade/Output | -0.033** | -0.024* | -0.052** | -0.033* | -0.027** | -0.022* | -0.059** | -0.028** |
| | (0.010) | (0.010) | (0.008) | (0.014) | (0.010) | (0.011) | (0.009) | (0.010) |
| Output per worker | | | 0.029* | -0.042* | -0.045** | -0.043** | 0.000 | -0.043* |
| | | | (0.014) | (0.017) | (0.017) | (0.017) | (0.014) | (0.017) |
| Avg. output per worker | -0.085** | | | | | | | |
| | (0.020) | | | | | | | |
| Growth of output per worker | | -0.130 | | | | | | |
| | | (0.272) | | | | | | |
| Var(TOT) | | | -0.010** | | | | | |
| | | | (0.003) | | | | | |
| Var(TOT)×Trade/Output | | | | 0.001 | | | | |
| | | | | (0.002) | | | | |
| Var(Trade) | | | | | 0.006 | 0.011* | | |
| | | | | | (0.005) | (0.005) | | |
| Var(Trade)×Trade/Output | | | | | | 0.006* | | |
| | | | | | | (0.003) | | |
| Share of manuf. trade | | | | | | | 0.307** | |
| | | | | | | | (0.052) | |
| Liq. needs×Private credit/GDP | | | | | | | | -1.500** |
| | | | | | | | | (0.425) |
| Observations | 1515 | 1515 | 1495 | 1495 | 1515 | 1515 | 1487 | 1515 |
| $R^2$ | 0.376 | 0.367 | 0.108 | 0.373 | 0.372 | 0.375 | 0.118 | 0.406 |
| $\mu_c$ | yes | yes | no | yes | yes | yes | no | yes |
| $\mu_i$ | yes | yes | yes | yes | yes | yes | yes | yes |

Notes: Robust standard errors in parentheses. + significant at 10%; * significant at 5%; ** significant at 1%. The sample period is 1970–99. The dependent variable is the correlation of the growth rate of output per worker with the rest of the manufacturing sector, 1970–99. All variables are in natural logs except for Liq. needs×Private credit/GDP and Output per worker growth. 'Liq. needs' stands for Raddatz (2005)'s sector-level measure of liquidity needs, which is inventories over sales, calculated using COMPUSTAT data. All variables are period averages, except for output per worker which is the period's initial value. $\mu_c$ denotes the country fixed effects. $\mu_i$ denotes the sector fixed effects. All specifications are estimated using OLS.

**Table A6.** Correlation of Annual Output Growth per Worker with Rest of the Manufacturing Sector: Panel Robustness Results

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| Trade/Output | -0.022* | -0.021* | -0.048** | -0.026* | -0.053** | -0.018+ |
| | (0.010) | (0.010) | (0.007) | (0.010) | (0.007) | (0.011) |
| Output per worker | | | 0.008 | -0.022 | -0.020 | -0.004 |
| | | | (0.014) | (0.026) | (0.014) | (0.027) |
| Avg. output per worker | -0.019 | | | | | |
| | (0.031) | | | | | |
| Growth of output per worker | | -0.010 | | | | |
| | | (0.124) | | | | |
| Var(TOT) | | | -0.002 | | | |
| | | | (0.003) | | | |
| Var(Trade) | | | | 0.000 | | |
| | | | | (0.004) | | |
| Share of manuf. trade | | | | | 0.470** | |
| | | | | | (0.046) | |
| Liq. needs×Private credit/GDP | | | | | | 0.812** |
| | | | | | | (0.309) |
| Observations | 4161 | 4147 | 4117 | 4094 | 4133 | 3809 |
| $R^2$ | 0.672 | 0.672 | 0.055 | 0.684 | 0.078 | 0.712 |
| $\mu_t$ | yes | yes | no | yes | no | yes |
| $\mu_c \times \mu_i$ | yes | yes | no | yes | no | yes |
| $\mu_i \times \mu_t$ | no | no | yes | no | yes | no |

Notes: Robust standard errors in parentheses. + significant at 10%; * significant at 5%; ** significant at 1%. The sample period is 1970–99. The dependent variable is the correlation of the growth rate of output per worker with the rest of the manufacturing sector, 1970–99. All variables are in natural logs except for Liq. needs×Private credit/GDP and Output per worker growth. 'Liq. needs' stands for Raddatz (2005)'s sector-level measure of liquidity needs, which is inventories over sales, calculated using COMPUSTAT data. All variables are period averages, except for output per worker which is the period's initial value. $\mu_c$ denotes the country fixed effects. $\mu_i$ denotes the sector fixed effects. All specifications are estimated using OLS.

**Table A7.** Specialization and Trade Openness at the Country Level: Robustness Results

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| Manuf. Trade/Output | 0.378+ | 0.297** | 0.196** | 0.230* | 0.181** | 0.166** | | | 0.229** |
| | (0.183) | (0.095) | (0.045) | (0.086) | (0.062) | (0.044) | | | (0.063) |
| Total Trade/GDP | | | | | | | 0.242** | 0.362** | |
| | | | | | | | (0.068) | (0.110) | |
| Herfindahl of exports | | | | 0.481** | 0.479* | 0.209+ | | | 0.483** |
| | | | | (0.153) | (0.217) | (0.113) | | | (0.125) |
| GDP per capita | 0.276 | -0.057 | -0.179** | -0.080 | 0.041 | -0.103+ | -0.154** | -0.167** | 0.440 |
| | (0.327) | (0.098) | (0.036) | (0.166) | (0.103) | (0.056) | (0.056) | (0.053) | (0.717) |
| (GDP per capita)$^2$ | | | | | | | | | -0.007 |
| | | | | | | | | | (0.042) |
| Pop. density | | | | | | | | | -0.001 |
| | | | | | | | | | (0.001) |
| Population | | | | | | | | | 0.000 |
| | | | | | | | | | 0.000 |
| Mining GDP share | | | | | | | | | 0.386 |
| | | | | | | | | | (1.306) |
| Agr. GDP share | | | | | | | | | 0.025+ |
| | | | | | | | | | (0.012) |
| Constant | -4.807 | -1.501+ | -0.611+ | -0.553 | -1.745** | -0.965** | -0.737 | -0.562 | -4.994 |
| | (3.017) | (0.763) | (0.325) | (1.645) | (0.572) | (0.338) | (0.462) | (0.449) | (3.251) |
| Observations | 20 | 36 | 53 | 20 | 36 | 53 | 56 | 55 | 53 |
| $R^2$ | 0.253 | 0.162 | 0.430 | 0.721 | 0.408 | 0.505 | 0.156 | – | 0.605 |
| Sample | Developed | Developing | no outliers | Developed | Developing | no outliers | full | full | full |
| Estimation | OLS | OLS | OLS | OLS | OLS | OLS | OLS | IV | OLS |

Notes: Robust standard errors in parentheses. + significant at 10%; * significant at 5%; ** significant at 1%. The sample period is 1970–99. The dependent variable is the log Herfindahl index of manufacturing production shares (averaged over the period). All regressors are in natural logs (except Pop. density, Population, Mining and Agr.) and are period averages. In the instrumental variables regressions, the instrument for trade openness is the natural openness from Frankel and Romer (1999).