Volatility and Economic Systems: Evidence from A Large Transitional Economy

Wang, Boqun and Yang, Dennis Tao

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Volatility and Economic Systems: Evidence from A Large Transitional Economy

Boqun Wang[a*] Dennis Tao Yang[b†]

[a]*School of Banking & Finance, University of International Business and Economics;*

China Financial Policy Research Center, Renmin University of China

[b]*Darden School of Business, University of Virginia, Charlottesville, VA 22903, USA*

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Abstract: This is the first paper to study the role played by economic transition in reducing output volatility. A dramatic decline in aggregate output volatility in China from central planning to market-oriented reforms in the past half century is documented in this paper. The output volatility measured by the standard deviation of real gross domestic product (GDP) growth over the specified rolling windows declined by 73% from 1953–1977 to 1978–2008. The sharpest reduction occurred in 1978 when China began to initiate a series of market reforms. Since the inception of these reforms, the volatility continued to decline, dropping more than 30% from 1978–1994 to 1995–2008. During the planning period, the co-movements in the provincial output, which reflected the systemic risks associated with the highly centralized economic and political systems in China, were found to be the primary source of the high output volatility.

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*Corresponding author: Boqun Wang, School of Banking & Finance, University of International Business and Economics; China Financial Policy Research Center, Renmin University of China. Email: bwang27@alumni.jh.edu

†Dennis Tao Yang, Darden School of Business, University of Virginia, Charlottesville, VA 22903, USA, Email: YangD@darden.virginia.edu

1 Introduction

The twentieth century had staged a grand social experiment in which central planning competed against the market system. Initially, the strong economic performance of Soviet Union and China offered aspirations to many poor, developing countries, but eventually the prosperity of the market economies had triggered the central planned economies to adopt massive reforms towards the market system. Much can be learned from these alternative systems for understanding economic history and the determinants of economic performance and growth. This paper joins the vast literature on economic transition by investigating the relationship between macroeconomic volatility and economic systems using data covering six decades of economic development and transition in China.

The relationship between output volatility and economic systems has been an important theme in the writings of classical economists. According to Marx (1867) [19], one of the major contradictions between the forces and relations of production under capitalism is the periodic depressions that are inherent in a capitalist economy. As commented by Schumpeter (1992) [29], Marx is a pioneer in researching businesss cycle and not only see the crisis period but also the logic behind the entire cycle but he did not have a complete business cycle theory by the time he died. Marx followers developed business cycle theory that envisioned capitalism cannot avoid periodic crises, and the increasing volatility in investment and production would eventually lead to the collapse of the system. By contrast, Hayek (1945) [11] held the opposing view. He argued that a monopolistic governmental agency such as a central planner can neither possess the relevant information to coordinate economic activities, nor have the ability to use it correctly; centralized decision making would lead to major economic fluctuations. Schumpeter (1992) [29] is in the middle. He argues that socalism planning can possibly reduce business cycle volatility by reducing the waste of over-production and the unemployment in theory though it may not be achievable in reality. He said "in a socialist society unemployment will be less, mainly in consequence of the elimination of depressions". Despite these influential ideas on economic systems and volatility, limited research has been conducted on this fundamental topic. The main objective of this paper is to fill this void.

The main motivating facts for the current study are the decline in output volatility commonly observed in transitional economies. Figure 1 plots the output volatilities measured as rolling window standard deviation of real GDP growth for four Asian transitional economies as compared with the U.S..[1] To facilitate comparison, we normalize the beginning year of economic reform to zero for the four Asian economies, while using 1984 as the comparable benchmark for the U.S. because that year signifies the inception of the "Great Moderation" identified by McConnell and Perez-Quiros (2000) [20]. While the volatility for the Asian economies was much higher than that of the U.S. before economic reforms, the variability has gradually converged to the U.S. in recent years. Figure 2 presents similar patterns for four European transitional economies. Because of the dissolution of states in Europe, consistent data before the reforms are not available for the European countries except for Poland. What is common across these transitional economies in Asia and Europe is the nearly immediate and continuous decline in output volatility since the inception of economic reforms. Admittedly, other forces and factors may have contributed to the more pronounced decline in GDP fluctuations in the transitional economies relative to market economies. A central task of this paper is to examine whether the changes of economic systems from central planning to a mixed system, and then from a mixed system to a market-oriented regime have contributed significantly to the reduction in volatility.

[Insert Figure 1 here]

[Insert Figure 2 here]

The main hypothesis of this paper is that a centrally planned economy is intrinsically more volatile than a decentralized market system because the implementation of a centralized plan is likely to generate systemic risks within the economy, thus causing nationwide economic fluctuations. In contrast, good and bad decisions under a decentralized framework tend to neutralize each other; and, when disequilibrium occurs in the system, individual agents may quickly adjust their decisions to cope with the situation. We demonstrate these ideas through an illustrative production model of human fallibility in which production decisions can be

[1] The data for all countries including China are from the Pen World Table 8.0.

made either by a central planner and implemented subsequently to lower organizations OR the decisions are made and carried out by decentralized agents. Model simulations suggest that output volatility is significantly higher under the centralized system, and economic transition towards decentralized decision making would lower production variability.

We test the main implications of the model based on panel data from 28 Chinese provinces covering the period from 1952 to 2008. China experienced three types of economic regimes over this historical period: a centrally planned economy between 1952-1978, a mixed system of planning with market adjustments between 1979-1993, and a full-fledged transition towards the market economy between 1994-2008. Our empirical analyses proceed through several stages. First, we document a striking pattern of volatility decline over the five decades of economic planning and transition. The output volatility measured by the rolling window standard deviation of real GDP growth dropped 74% from the period of planning in 1953-1977 to the period of reforms and transition in 1978-2008; and, within the second period, output fluctuations further declined more than 50% from the mixed system in 1978-1994 to the market system in 1995-2008. Contrary to the conjectures of Marx, central planning actually magnified output volatility rather than reduced it. The first phase of volatility reduction was more dramatic, following the inception of economic reforms in 1978, whereas the second phase of moderation was more gradual yet significant, following the acceleration of market reforms started in 1993.

Second, given the observed decline in overall output volatility, we construct a measure of sector-specific (agriculture, industry, and service), province-year output shocks by removing the trend components in the data using Hodrick-Prescott (HP) filters. Our subsequent task is to investigate the sources of these province-year output shocks and examine how much of the volatility reduction is attributable to the transition from planning to market.

As the third stage of analyses, we remove the influence of conventional economic factors, including financial development, openness, inventory management and monetary policy that determine volatility, from the output shocks constructed above. Then, we conduct a variance decomposition of the shocks, NET of the influence of these variables, into national, provincial, sectoral, covariance, and residual components. Through these procedures, we can pin down the sources of volatility reduction that are attributable to central planning. We find that central planning generated systemic shocks at the national and provincial levels in China, which were the main sources of output fluctuations during the centrally planned system. Therefore, subsequent transition from planning towards a mixed and market systems has led to a dramatic moderation in output variability in China.

This paper is related to three strings of literature. The first is on the relationship between economic systems and output volatility, tracing back to the works of Marx (1867) [19] and Hayek (1945) [11]. Li and Yang (2005) [34] is a related paper in which they analyzed the catastrophic event of the Great Leap Forward movement in China between 1958 and 1961, concluding that central planning was the main culprit of the disaster. The second string is the great moderation literature in which studies find significantly persistent decline in output volatility in the US and other OECD countries starting in the mid-1980s (e.g., Kim and Nelson, 1999 [15]; McConnell and Perez-Quiros, 2000 [20]; Blanchard and Simon, 2001 [5]. The third string is on business cycles and output volatility reduction in China (e.g., Brandt and Zhu, 2000 [6]; Wahid and Jalil, 2010 [31]) and during the process of economic development (Koren and Tenreyro, 2007 [16]). To our knowledge, our paper is the first study that examines the relationship between volatility and economic systems - one that investigates the mechanisms of output fluctuations under central planning and documents the decline in output volatility through three stages of economic reforms: from central planning to a mixed system of planning with market adjustments, and from the mixed system towards a full-fledged market system.

The rest of this paper is organized as follows. In Section 2, we present a brief review of the related literature. Based on provincial data set covering the period of 1952 to 2008, we examine the basic features of output volatility in China in Section 3. This section provides a detailed description about our data set, including the sources of GDP data and general price series, both on the provincial and national levels. In Section 4.1, we outline an illustrative model to study the sources of output volatility under two alternative regimes, central planning versus a decentralized market system. In Section 5, we decompose the overall innovations to national, province-specific, and sector-specific shocks and explain what kinds of risks should be responsible for the sharpest drop in output volatility starting in the late 1970s. Empirical evidence suggests that the regime shifts were the major forces behind the drop in output volatility. In Section 6, we present some tentative conclusions.

2 Literature Review

We believe that this is the first paper to discuss the role played by economic transition in reducing output volatility. There are different parts of literature that are related to this paper.

One part of literature studies China's business cycles and output volatility.[2] To the best of our knowledge, studies devoted directly to analyzing output volatility reduction in China are limited. For instances, Zhang and Zhang (2010) [35] and He, Hou, Wang, Zhang (2014) [12] have discussed the matter in some details. Zhang and Zhang (2010) [35] provided a highly detailed analysis on the trend of the volatility of the GDP series in China along with its components. Using the quarterly GDP data during 1978-2009, they find a statistically significant break in the variance of the GDP series in 1993. They also document the secular change in the characteristics of the volatility series of employment, the Total Factor Productivity (TFP), the expenditure GDP components and the provincial GDP growth. He et al. (2014) [12] mainly focused on periods after Chinese economic reform had started, and do not study the regime change due to the economic transition directly.

The other part of the literature studied the business cycles and made effort to decompose economic fluctuations into, for example, sectoral, regional and aggregate shocks. But none of the papers in this literature studied output flucturations in regime changes. Our paper is closely related to this literature in terms of the methods we used. For example, Norrbin and Schlagenhauf (1988) [24] decomposed the fluctuations in employment in the US. Other papers include Altonji and Ham (1990) [2], Ghoosh and Wolf (1997) [9], Del Negro (2002) [21], Koren and Tenreyro (2007) [16], Heston and Rouwenhorst (1994) [13] and etc.

Another set of related papers studied the so called "Great moderation" and its possible causes. Those researches examined the trend of business cycle volatility for most industrialized countries after the 1980s. Output volatility in these countries declined dramatically from the 1980s, a phenomenon which was referred to as the "Great Moderation" in the liter-

[2] See Brandt and Zhu (2000) [6], Zhang and Zhang (2010) [35], Wahid and Jalil (2010) and etc.

ature. Most advanced economies, such as the U.S., its fellow members in the G7 and many other industrialized countries, experienced a dramatic reduction in volatility of aggregate economic activities. Volatility reduction is evident for output and employment at the aggregate level and across most industrial sectors and expenditure categories. Inflation level and inflation volatility have also declined dramatically. For instance, the volatility of GDP, total goods production, durable-goods consumption and production, total investment, residential investment, construction output, and imports declined sharply in the mid-1980s in the U.S. (Stock and Watson, 2002 [30]). The question remains as to whether and to what extent this broad phenomenon is related to and shares common features with the output volatility reduction we observed in China. The methods used and the factors considered in the "Great Moderation" literature serve as valuable references to this paper.

The earliest analysis of the volatility reduction is an unpublished internal memorandum at the Board of Governors of the Federal Reserve System written by two staff economists (Gilchrist and Kashyap, 1990 [10]) whose daily job is to track the U.S. economy. In academic journals, the first published studies that identified moderation in volatility were that of Kim and Nelson (1999) [15] and McConnell and Perez-Quiros (2000) [20]. Later on, Blanchard and Simon (2001) [5] and Jaimovich and Siu (2009) [14] find evidence of similar reduction in output volatility in other industrialized countries, such as the members of G7 countries. Japan is the only possible exception because it has actually experienced an increase in output volatility after the 1990s.[3] Inspired by the seminal papers there have been extensive researches on the reduction of volatility many of which published in leading journals.[4] There is much less doubt or dispute about the existence of the reduction in output volatility[5] than on whether the sharp decline in volatility is a sudden brake (McConnell and Perez-Quiros, 2000 [20]) or a continuous trend (Blanchard and Simon, 2001 [5]) as well as on the reasons[6]

[3]The exception, however, might offer clues in understanding the reasons behind the widespread volatility moderation.

[4]See Ahmed, Levin, and Wilson (2004) [1], Dynan, Elmendorf and Sichel (2006) [8], Davis and Kahn (2008) [7], Jaimovich and Siu (2009) [14], and Benati and Surico (2009) [3], among others.

[5]The financial crisis in 2008 may complicate the matter given that highly significant fluctuations happened after most of the papers had been written. Whether "Great Moderation" ended after the 2008 "Great Recession" remains a topic under dispute (see for example Ng and Wright (2015) [22]).

[6]See Stock and Watson (2002) [30], Ahmed, Levin, and Wilson (2004) [1], Dynan, Elmendorf and Sichel

behind such a sharp decline. The two fields of discussions are inevitably interrelated. The explanations behind this moderation depend on whether it was a brake or a trend. For instance, if it were a brake, it should be more reasonable to search for events happening around the date of the brake. Meanwhile, the main reasons behind the moderation would determine whether it happened as a brake or as a continuous trend. If the moderation were the result of a once-and-for-all structural change in the economy toward a more stable one, it would be more likely that a brake in the output volatility would be observed.

One of the reasons why output volatility moderation is interesting to study is that lowered volatility leads to longer expansion even though the expansion only has a moderate magnitude. As alleged by Blanchard and Simon (2001) [5], the large decrease in the standard deviation of output shocks is at the root of the two long expansions the United States has recently experienced. The growth effect of the reduction in volatility can be the results of pure statistical measurement or may possibly come from more complicated resources, such as a reduced systematic risk in the economy. The searching for the actual mechanism, which is part of the theme in this paper, on how reduction in output volatility can enhance economic growth may induce new researches.

On the other hand, as Bernanke (2004) [4] remarks in his discussion of the "Great Moderation": "Explanations of complicated phenomena are rarely clear cut and simple, and each...probably contains elements of truth." It is hardly untrue as changes and transitions happened in the past quarter century largely exceed what happened in the past several centuries. The continuous globalization, the internationally division of labor and specialization, the lowering of economic and political barriers to international trade and finance, the unprecedented improvement in technology may have all contributed to the shift in the way economy operates. To a certain extent, research on the global output moderation is the moon in the mirror, when compared with the studies about the new economies that emerged in the past decades.

(2006) [8], Davis and Kahn (2008) [7], Jaimovich and Siu (2009) [14], Benati and Surico (2009) [3], etc.

3 Reduction of Output Volatility in China

3.1 Data Description

The data of China's GDP and its components are obtained from '*China Compendium of Statistics 1949–2008*', published by National Bureau of Statistics. The database has comprehensive statistics of China both on the national and into the provincial level. Our national nominal GDP and its components decomposed by income approach and expenditure approach data start from 1952 to 2008. The availability of provincial data vary to some extent. Several revisions of the national account data by the Chinese Statistical Bureau exist, particularly the significant revision in 2004 using data from the economic census. The data used are accounted for the revisions. The provincial data set includes 28 provinces in China i.e. Anhui, Beijing, Fujian, Gansu, Guangdong, Guangxi, Guizhou, Hebei, Heilongjiang, Henan, Hubei, Hunan, Inner Mongolia, Jiangsu, Jiangxi, Jilin, Liaoning, Ningxia, Qinghai, Shaanxi, Shandong, Shanghai, Shanxi, Sichuan, Tianjin, Xinjiang, Yunnan, Zhejiang. Chongqing and Tibet are excluded for data consistency. Hainan is excluded because the observations are missing for years before 1978.

3.2 Stylized facts

As a starting point, we employ several simple statistical methods to analyze the basic features of the output volatility series in China. The ups-and-downs before 1980s are frequent and large in scale, when the drop in output growth in 1961 reached 27 percent. The 5-year rolling window standard deviation and the mean of annual real GDP growth by income approach are plotted in Figure 3. The first observation available for the GDP growth is 1953, and so the first observation for the standard deviation and mean of the growth rate is 1956. The existence of a dramatic reduction in output volatility in China is obvious and clear. The volatility of GDP growth dropped from a flat peak in 1960s to a historical low in 1977. After the sharp drop in the late 1970s, the output volatility continued to trend down over time except for a mild up-side deviation from the declining trend in the 1990s. If a similar figure is plotted for the volatility of consumer spending, capital formation and government spending, a highly similar pattern would be observed.[7] The trend in the mean of GDP growth, however, is different. It was more volatile during the 1960s and 1970s and shifted to a rising track after 1977. It then remained at a relatively stable and high level.

Surprisingly, during the central planning era in China, especially years before 1978, the output volatility was much larger than in the later period when more market mechanisms were introduced. In the conventional frame-of-thought,[8] plans set by the central planner in the central planning economy to balance demand and supply, though may be inefficient, can at least maintain reasonable consistency and thus lead to a low volatility. Nevertheless, our empirical results suggest that such man-made plans would result in more volatility as opposed to reducing it. We will offer our explanation later in this paper.

[Insert Figure 3 here]

The rolling window standard deviation is one popular and standard way to measure volatility. But one can think of other ways. It is generally assumed that output time series data have a trend component and potentially several volatile components of different frequencies. Different detrending methods may provide us with the volatile series of different frequencies. As a result, the measured volatility may differ, though not necessarily so. Some alternatives to calculate the volatile series of GDP are, for instance, first difference between the levels of the logarithm of output, a Hodrick-Prescott-filtered (HP) series or a Baxter-King-filtered (BP) series. These alternatives will not change the basic results.

The results of the volatility reduction calculated by using different detrending methods are presented in Table 2. Hodrick-Prescott filter is one of the standard tools used in removing the trend of time series. Recent work of Ravn, and Uhlig (2002) [26] show that the appropriate value of the smooth parameter is 6.25 for annual data when isolating fluctuations at the traditional business cycle frequencies (those higher than eight years) while a smoothing parameter of 100 is used in much of the macroeconomics literature. We report the results

[7] The investigation of the potential relationship between the components of income approach GDP and expenditure approach is beyond this paper. The figure by expenditures is available in the online appendix.

[8] At least with regard to the popular frame-of-thought in Marx' era when central planning was commonly used.

for both choices. We also use the band-pass-filter proposed by Baxter and King to isolate fluctuations between two and eights years in frequency. In addition, we consider real output detrended by first-differencing which amplifies high-frequency fluctuations relative to HP filter. This detrending method is used by Kim and Nelson (1999) [15] and McConnell and Perez-Quiros (2000) [20].

The reduction in output volatility from 1955-1977 to 1978-2006 is around 75% regardless of the employed detrending method. The reduction in output volatility from 1978-1994 to 1995-2006 is approximately around 60% for three methods we have considered. Though the reduction in output volatility measure by HP100 is much lower to be less than 40%, it is still considerable.

[Insert Table 2 here]

While the simple graph analysis already revealed facts that are of significant interest, a more structural method can be used. Now, we may go one step further by investigating in details the process generating the output movement observed in Figure 3.

The large drop in output volatility leads to an interesting question whether this reduction in output volatility is a sudden brake or a declining trend as inquired in the literature. As a first cut, we regress the real GDP growth rate on a constant and a time trend. The time trend is negative and insignificant. This insignificance of the trend term is robust to the use of the first difference of GDP growth rather than the level, as well as to the inclusion of a lagged dependent variable. According to McConnell and Perez-Quiros (2000) [20], this insignificance is a preliminary evidence of instability in the mean GDP growth rate. Besides, we further test the existence of such a structural brake in the GDP series. Before proceeding to the statistical test, we first present some candidates for the brake dates. The evolution of the Chinese economy suggests several possible periods of rapid shift in economic structure that will likely cause the structural breaks in the GDP series: 1978-1980 when the Cultural Revolution ended and China started to transform from a central planning economy to a market economy; 1992 to 1994 when Deng visited the southern part of China and then afterward, the special economic zones were set up in south China and substantial reforms were introduced to the tax and foreign exchange system. This allows us to perform the standard Chow test for the break points.[9] First, we fit the GDP growth series with an AR(1) process and then use the Chow test to test a break point in 1980 and 1994 jointly. The null hypothesis of no break point can be rejected at the 5% confidential level (See Table 1).

[Insert Table 1 here]

[Insert Figure 4 here]

[Insert Figure 5 here]

4 Some Discussion on Regime Change and Volatility Reduction

Shortly after the establishment of the Peoples's Republic of China (PRC) in 1949, China finished the socialism transformation and created a central planning economy in the Soviet style. Peasants were organized into cooperatives and later people's communes. Enterprises and commerce were nationalized, which in effect made private market useless. Under central planning regime, quotas and administration control were the tools used by the government to organize economic activities. The economic reform gave the decision making back to economic agents, such as firms, farmers and consumers, and brought back free market and market prices. The economic reform started from the agriculture. One well-known reform was to replace cooperatives with Household Responsibility System (HRS). At the same time, free market was allowed so that peasants can sell their grain after they fulfilled the required quotas. Lin (1992) [18] documented that the agricultural reform resulted in remarkable

[9] Perez-Quiros (2000) [20] provided sophisticated econometric methods in testing the existence of a break in the GDP volatile series. Zhang and Zhang (2010) [35] demonstrated a highly detailed test using quarterly GDP data during 1978-2009 for the breaks in the mean GDP growth rate, the volatility of GDP growth rate and the different GDP subcomponents. They did find a significant brake in the volatility of GDP growth in 1993.

agricultural growth. The rapid growth in agriculture was the motor of China's growth right after the reform in the 1980s. Then the growth of the township-village enterprises (TVEs) were the main driving force until early 1990s. The new entries of firms in the first fifteen year of reforms were mostly TVEs, and they drove China's growth in that period (Qian, 2002 [25]). The economic reforms that establish free markets and let economic agents competes in the free markets turn out to not only bring high economic growth but also be volatility reducing.

The governance structure of China is hierarchical, but the structure of regional government is similar to the central government (Xu (2011) [33]). Each region is self-contained, and controls similar functions, such as personnel, finance, industry, and agriculture. Xu (2011) [33] calls the China's institution a regionally decentralized authoritarian system (RDA), and argue that it can explain why China could have high economic growth despite of ill-suited institutions. What we discover in this paper is that the decentralization that happened after the economic reforms also explain the huge reduction in output volatility in the past decades. The discussion on reforms of delegating power to the local governments actually started as early as in the 1960s (Wu, 2005 [32]). But the later radical political movement made it impossible to turn much of the discussion into practice.

4.1 An illustrative model of transition

One of the most important changes from central planning to market economy is decision making decentralization both from central government to provincial governments and from provincial governments to local governments and individual economic agents. Decentralization of decision making reduced the risk of making policy errors.[10] A simple illustrative model of two-tier governments is helpful to get the idea. A key ingredient of this model is human fallibility as modeled by Sah and Stiglitz (1991) [28] and Sah (1991) [27]. The governors of the government have limited capacity to collect and process information. As a consequence, they could make mistakes in making important economic decisions. This simple economy has one central government and 28 provincial governments. In the centralized regime, the central government determines the projects in all the provinces. In the

[10] Part of the intuition is similar to risk diversification in portfolio theory. Do not put all your eggs in one basket.

decentralized regime, each province can make their own decisions. The production takes the common Cobb-Douglas form

$$Y_t = A_t K_t^{\alpha} L_t^{1-\alpha}$$

where Y_t is the gross domestic product, K_t is capital, L_t is labor, and A_t is the economic efficiency in period t. A_t will depend on the quality of projects pursued by the governments. There are two types of governors, who can either have high (h) or low (l) ability. The quality of the public projects is a random variable g_i ($i = h, l$). The high ability governors can choose projects of quality g^* with probability p_h, and g_* with with probability $1 - p_h$. Similarly, low ability governors can choose projects of quality g^* with probability p_l, and g_* with with probability $1 - p_l$. We assume that $g^* > g_*$ and $p_h > p_l$. Although no one has the perfect information to choose the better projects, the high ability governors can choose a good project with a higher probability. Local competition is thought to be a key contributor to the sucess of Chinese economic reform (Li and Zhou, 2005 [17]). In this simple setting, we can also test whether local competition contributes to the reduction of volatility. The local competition could either help select better governors or help improve the quality of the public projects.

Another observation is that the provincial governments could be more politically radical than the central government's original planning because, for example, the provincial officials want to show their loyalty to the party. With this political radicalism measured by α being greater than 1, output could fluctuate more widely. With a radical provincial government, the projects of quality g^* will become $\alpha * g^*$ and the projects of quality g_* will become g_*/α. In another word, a radical provincial government can make good projects better while make bad projects worse.

The economic efficiency A_t is a function of the projects governments choose. The function form is

$$\begin{aligned} A_t &= f(g) \\ &= \left[\sum_{j=1}^{J} \frac{1}{J} g(j)^{\rho} \right]^{1/\rho} \end{aligned}$$

where J is the number of provinces. The function form is following Nishimura (2006) [23].

In the central planning regime, one governor is chosen by the central government and he or she will determine the projects for all the provinces. In the decentralized regime, each province will have its own governor and each provincial governor will choose the project for each province.

The result of such a decentralization is a substantial reduction in output volatility in the economy (see Figure 6). The national output volatility stepped down after the reform. In each simulation, before 1978 is considered to be central planning period. Capital and labor are assumed to grow at a constant rate, and the growth rates are calibrated to China's average during this period i.e. 9% for capital and 2.4% for labor. The volatility is measured as 5-year rolling window standard deviation of HP-filtered volatile series. The intuition for this volatility reduction is straightforward. The mistakes made by different provinces can offset each other. As a result, a large negative shock, such as the Great Leap Forward mistake, can not widely spread across provinces as what could happen during the central planing period.

[Insert Figure 6 here]

Local competition could also help reduce the output volatility in some cases but not in all cases. If there is a higher probability of choosing a good governor, the output volatility will be lower. However, the magnitude of the reduction in output volatility is much smaller than the decentralization channel (see Figure 7).

[Insert Figure 7 here]

If only the quality of the bad project is improved, the output volatility will be reduced. But if only the quality of the good project is improved, the output volatility will actually increase. This suggests that the quality differences between good projects and bad projects also matter. In the first case when only the quality of the bad project is improved, the quality gap is also narrow but the in the second case, the quality gap is enlarged (see Figure 8). With this simple model in mind, we can move on to test whether the real data behave as our simple illustrative model has predicted.

[Insert Figure 8 here]

5 Output Volatility Drop from Central-planning to Economic transition

As we have documented in the previous sections, the volatility reduction is an important feature of the China's economy over the decades. The dramatic regime changes not only produced a high economic growth, but, at the same time, also muted the output volatility, the biggest cycles being in the pre-reform era. In this section, we provide evidences to explain why the regime changes from central planning to market economy will cause output volatility to decline as a natural next-step.[11] Here we are going to uncover what may account for the decline in output volatility in China, and the explanation should have important implications for other transitional economies, too. Before attacking this problem in a general and formal way, a case study that can be abstracted from Li and Yang (2005) [34] would provide insightful clues. The Great Chinese Famine was the driven reason behind the hike in the volatility observed in Figure 3 in the 1960s. According to Li and Yang (2005) [34], the government's mistake in resource allocation was the most important reason behind that famine, and a major reason that central government made the grave mistake was because the information it had was greatly wrong. The central government diverted massive resource from the agricultural sector to manufacture and industry creating huge food shortage in the rural area in the misperception that the food problem was eternally solved. As China started its market reform, the entity to make resource allocation decision changed from government to the market. As a result, this eliminated the possibility of huge policy mistakes, which

[11] The change of composition of different industries will not explain the reduction in volatility. In online appendix, we exclude this composition change hypothesis by doing a counterfactual exercise. Assuming that sectoral share stayed at the old level, the reduction of volatility is not changed. In Figure 4, the three industries experience the same trend of output volatility reduction. This is why autonomously fixing the output shares of the different sectors yields essentially the same decline in the volatility as using the actual, changing shares.

would cause a disastrous drop in output as happened in the Great Chinese Famine.

It turns out that the observation obtained from the Great Chinese Famine is more general as we will show in this section. The mechanism illustrated in Section 4.1 is a central transformation from central planning to market economy. We argue that the regime change which reduced the direct influence of the government on economic activities was the main reason behind the decline in volatility. As illustrated in the introduction, the effect of economic transition that successfully establishes a market system on output volatility is not unique in China. In this section, we conduct a formal decomposition analysis to test the observation from the Great Chinese Famine.

5.1 Methodology

Our model of China consists of different provinces and different sectors, which are subject to different shocks and, therefore, subject to different risks that are associated with the shocks.

Our method of decomposing total innovations to different shocks is similar to Koren and Tenreyro (2007) [16]. But we extend their framework in multiple dimensions. Most importantly, we use a residual approach to produce the shocks series for decomposition. We want to measure the effects of regime changes on volatility controlling for other factors. As suggested by the "Great Moderation" literature, a number of factors may contribute to the decline in output volatility. Monetary policy, financial intermediaries and inventory management are thought to be possible reasons to explain the "Great Moderation" in industrial countries. Following the literature, inflation is used as a proxy to measure monetary policy; loan over GDP is used to measure shocks related to financial intermediaries; and inventory change over GDP is used to measure inventory management. Before the economic reform, China was nearly a close economy. Economic reform opened the door of China , and world economic shocks should have a bigger effect on the output volatility in China thereafter. Trade openness measured as export plus import over GDP is used to control for this effect. Meanwhile, we extend Koren and Tenreyro (2007)'s [16] decomposition strategy from a cross-country context to a cross-province context. In addition, we introduce one more type of shocks. They have a country-specific shock and a sector-specific shock, while we have a province-specific shock, a sector-specific shock and a national shock.

We first run a control regression on four factors, and collect the residual of the control regressions as our measure of the shocks to the economy which will be used later for decomposition. We control for the effect of monetary policy, the credit shocks, the trade openness and the inventory changes. Let Y_{jst} be a measure of the total shocks in province j and sector s at time t. In our basic specification Y_{jst} is computed as the HP-filtered volatile series of log real GDP of province j and sector s. This total shocks Y_{jst} is then regressed on four controls, and the residuals y_{jst} are collected. Since all of our control variables are provincial, a provincial regression is done for every sector. All the independent variables are lagged to control for potential endogeneity problems. The control regressions are reported in Table 4. Column 1 through Column 3 are regressions for primary, secondary and tertiary sector. The summary statistics for the control variables are reported in Table 3.

[Insert Table 3 here]

[Insert Table 4 here]

After running the control regressions, we get the residual shock y_{jst}. The total residual shock y_{jst} can be decomposed into different types of shocks. We assume that there are three types of different shocks, a national shock, a province-specific shock, and a sector-specific shock. Thus, y_{jst} is broken down into four components:

$$y_{jst} = C_t + \lambda_{st} + \mu_{jt} + \varepsilon_{jst} \tag{1}$$

where C_t is the national shock common to all provinces; μ_{jt} is specific to a province but common to all sectors; λ_{st} is specific to a sector but common to all provinces; ε_{jst} captures the unexplained residual. One important advantage of this decomposition strategy is that it is cross-sectional, and the method is able to capture the effect of the important regime changes in China. Since the effects of other factors have been controlled, the reason that those shocks changes should primarily be regime changes.

By a first-order approximation, the residual innovation q_{jt} can be expressed as the weighted sum of the innovations in every sector y_{jst}.

$$q_{jt} = \sum_{s=1}^{S} a_{jst} y_{jst}; q_{jt} = a'_{jt} \mathbf{y}_{jt} \quad (2)$$

What we are interested in is the change of volatility measured as the variance of q_{jt}. In matrix form, the variance of q_{jt} is expressed as:

$$Var(q_j) = a'_j E\left(\mathbf{y}_j \mathbf{y}'_j\right) a_j$$

Given the decomposition in equation (1), we can break $E\left(\mathbf{y}_j \mathbf{y}'_j\right)$ down to several parts:

$$E\left(\mathbf{y}_j \mathbf{y}'_j\right) = \Omega_N + \Omega_\lambda + \omega^2_{\mu_j} + \Omega_{\varepsilon_j} + Cov_j + Cov_s + \Gamma_j$$

where $\Omega_N = E\left(C^2 \mathbf{11}'\right)$ collects variance of the national shocks; $\Omega_\lambda = E\left(\lambda\lambda'\right)$ is the sector-specific variance covariance matrix; Ω_{ε_j} collects the variances of the sector- and province-specific residuals; $\omega^2_{\mu_j} = E\left(\mu_j^2 \mathbf{11}'\right)$ collects the province-specific variance; $Cov_j = 2E\left(C\mu_j \mathbf{11}'\right)$ collects the covariances of national shocks with the province-specific shocks, $Cov_s = E\left(C\mathbf{1}\lambda' + C\lambda\mathbf{1}'\right)$ collects the covariances of national shocks with the sector-specific shocks, and $\Gamma_j = E\left[C\mathbf{1}\varepsilon'_j + C\varepsilon_j\mathbf{1}' + \mu_j\lambda\mathbf{1}' + \mu_j\mathbf{1}\lambda' + \varepsilon_j\lambda' + \lambda\varepsilon'_j + \mu_j\varepsilon_j\mathbf{1}' + \mu_j\mathbf{1}\varepsilon'_j + crossprod\left(\varepsilon_j\varepsilon'_j\right)\right]$ collects the remaining terms. Detailed derivations of the above decomposition are left to the appendix.

We can therefore decompose the variance of q_{jt} into a number of variance and covariance terms. Furthermore, those variance and covariance terms can be sorted into different risk factors.

$$Var(q_j) = SYS + PROV + COV + RES$$

where $SYS = a'_j\left(\Omega_N + \Omega_\lambda\right) a_j$; $PROV = a'_j \omega^2_{\mu_j} a_j$; $COV = a'_j\left(Cov_j + Cov_s\right) a_j$; $RES = a'_j\left(\Omega_{\varepsilon_j} + \Gamma_j\right) a_j$. SYS, $PROV$, COV, and RES are the four risk factors. SYS is the risk associated with the variance of national and sector-specific shocks. We call it the systematic risk because it is common to all provinces. The type of risk is going to cause output to fall in all provinces. Our conjecture is that this type of risk is largely the result of central government policies, which is the main interest of this paper. $PROV$ is the risk associated with a specific province. This risk should largely be attributed to the different interpretations of the central government policies by the provincial government and the provinces' own policies. It also captures whether there is political radicalism at the provincial level. COV is the covariance risk between national and province-specific and between national and sector-specific shocks. RES is the idiosyncratic part of the risk. It includes the variance of idiosyncratic shocks and various covariance terms. As we will later see in Section 5.3, the observed pattern of the reduction in volatility between economic regimes is mainly driven by SYS and $PROV$. We believe that SYS captures the effect of regime changes. It is measuring how national shocks and sector shocks, probably the results of government policy errors, are driving the volatility before and after the reforms. The reduction of $PROV$ also contributes to the decline of output volatility, but to a less extent. The provincial governments largely resemble the central government.

5.2 Estimation

Empirically, there are two equivalent ways to estimate the various shocks. In this statistical specification, the three types of shocks, namely the national shocks, the province-specific shocks, the sector-specific shocks are estimated as follows. National shocks are measured as the cross-province and cross-sector average of y_{jst}. Province-specific shocks are then identified as the within province average of y_{jst} using only the portion not explained by national shocks. Lastly, sector-specific shocks are measured as the cross-province average of y_{jst} using only the portion not explained by nation-specific and province-specific shocks. Formally, the analytical expressions are:

$$\widehat{C}_t = \frac{1}{PS} \sum_{j=1}^{P} \sum_{s=1}^{S} y_{jst}$$

$$\widehat{\mu}_{jt} = \frac{1}{S} \sum_{s=1}^{S} \left(y_{jst} - \widehat{C}_t - \widehat{\lambda}_{st} \right)$$

$$\widehat{\lambda}_{st} = \frac{1}{P} \sum_{j=1}^{P} \left(y_{jst} - \widehat{C}_t - \widehat{\mu}_{jt} \right)$$

where $\widehat{C}_t$, $\widehat{\mu}_{jt}$ and $\widehat{\lambda}_{st}$ are the estimates for the national shocks, the province-specific shocks, and the sector-specific shocks.

The above statistical specification has an equivalent econometric representation. The statistical decomposition strategy is equivalent to run a constrained OLS regression on the set of province and sector dummies every year cross-sectionally. The proof of the equivalence is provided in the appendix. Formally the econometric specification is given as following:

$$y_{jst} = C_t + \lambda_{1t}d_1 + \ldots + \lambda_{St}d_S + \mu_{1t}h_1 + \ldots + \mu_{Pt}h_P + \varepsilon_{jst}$$
$$s.t. \sum_{i=1}^{S} \lambda_{it} = 0, \sum_{i=1}^{J} \mu_{it} = 0$$

where d_i are dummies for each sector, h_j are dummies for each province, and ε_{jst} is the regression residual.

The econometric specification is close to the specification in Heston and Rouwenhorst (1994) [13], but the research question in Heston and Rouwenhorst (1994) [13] was different. In the econometric specification, the shocks are estimated coefficients on the dummies. In Figure 9, the estimated national shocks are plotted. There are huge ups and downs in the 1960s and 1970s. The big negative national shocks in 1961 was a reflection of the disastrous Great Leap Forward and the Great Chinese Famine. The magnitude of national shocks is much smaller after the economic reform. Especially, the national shocks was tamed after a small cycle in the 1990s. Figure 10 shows the province-specific shocks which are averaged to regional level, mainly for a better visual comparison. The four regions are defined as following. The coastal region includes Beijing, Fujian, Guangdong, Hebei, Jiangsu, Shandong, Shanghai, Tianjin, and Zhejiang; the northeast region includes Heilongjiang, Jilin, Liaoning; the interior region includes Anhui, Guangxi, Guizhou, Henan, Hubei, Hunan, Inner Mongolia, Jiangxi, Shaanxi, Shanxi, Sichuan, Yunnan; and the far west region include Gansu, Ningxia, Qinghai, and Xinjiang. The province-specific shocks are also much smaller in later years, and the magnitude of province-specific shocks are much smaller than national shocks, about one tenth of the national shocks. Figure 11 plots the estimated sector-specific shocks. The disastrous negative shocks in primary sector in the 1960s and the mirror shocks in secondary sector tell precisely the same story as describe in Li and Yang (2005) [34].

Government diverted massive resources from primary sector to secondary sector.

[Insert Figure 9 here]

[Insert Figure 10 here]

[Insert Figure 11 here]

With the estimated shocks, the variance and covariance matrixes in 5.1 are estimated by their sample counterparts, Analytically,

$$\widehat{\Omega}_N = \frac{1}{T}\sum_{t=1}^{T}\widehat{C}_t^2$$

$$\widehat{\Omega}_\lambda = \frac{1}{T}\sum_{t=1}^{T}\widehat{\lambda}_t\widehat{\lambda}_t'$$

$$\widehat{Cov}_j = \frac{2}{T}\sum_{t=1}^{T}\widehat{C}_t\widehat{\mu}_{jt}$$

$$\widehat{Cov}_s = \frac{1}{T}\sum_{t=1}^{T}\left(\widehat{C}_t\mathbf{1}\widehat{\lambda}_t' + \widehat{C}_t\widehat{\lambda}_t\mathbf{1}'\right)$$

$$\widehat{\omega}_{\mu_j} = \frac{1}{T}\sum_{t=1}^{T}\widehat{\mu}_{jt}^2$$

and the elements in Ω_{ε_j} is estimated by $\widehat{\sigma}_{js}^2 = \frac{1}{T}\sum_{t=1}^{T}\widehat{\varepsilon}_{jst}^2$. In the actual estimation, the sample is divided into three regimes. The variance covariance matrixes are estimated separately for each regime.

With the estimated variance covariance matrixes, we can evaluate the importance of different kinds of risks.

5.3 Volatility Accounting

The risk factors derived from of decomposition strategy play different roles in the reduction of volatility. In this section, the contributions of different risk factors are analyzed quantitatively.[12] As China went from central planning to a transitional market economy, the magnitude of various risk factors decreased substantially (Figure 13, Figure 14 and Figure 15). The estimated total risk is plotted in Figure 12. In all figures, each point represents a province in the specific year. There are significant drops when regimes change. The discontinuity is because the variance covariance matrixes are estimated separately for the three regimes. The systematic risk reduces substantially going from the central-planning regime to the market regime (Figure 13). Similar reductions happen in the provincial risk as well (Figure 14).

[Insert Figure 12 here]

[Insert Figure 13 here]

[Insert Figure 14 here]

[Insert Figure 15 here]

We then do an accounting exercise by attributing the total reduction in the volatility of q_j to changes in different risk factors. The changes in the variance of q_j can be decomposed into changes in four different risk factors.

$$\Delta Var\left(q_j\right) = \Delta SYS + \Delta PROV + \Delta COV + \Delta RES \tag{3}$$

Divide both side of Equation (3) by $\Delta Var\left(q_j\right)$, the total reduction is decomposed into parts explained by different risk factors.

[12] Results from an exercise decomposing the economy into 6 sectors are reported in the online appendix.

$$1 = \frac{\Delta SYS}{\Delta Var\left(q_j\right)} + \frac{\Delta PROV}{\Delta Var\left(q_j\right)} + \frac{\Delta COV}{\Delta Var\left(q_j\right)} + \frac{\Delta RES}{\Delta Var\left(q_j\right)} \tag{4}$$

Then, apply the above decomposition of variance to every province, and take average. The result is shown in Table 5. SYS, $PROV$, COV, and RES are the four types of risk factors. EXP adds up the contribution of SYS, $PROV$, COV, and RES. Regime change 1 is comparing before 1978 with after 1978 but before 1993, which is the regime change from central planning to market transition. Regime change 2 is comparing 1978-1993 with after 1993. The concern that the effects of the changes of sector weights may be important is explicitly accounted for in the next section. For the regime change from before 1978 to after 1978, systematic risk is a major contributor to the decline. The reduction of volatility from central planning to market economy mainly came from the reduction in systematic risk and provincial risk. As we have show in the illustrative model, the local competition also also contributes to reduction in output volatility and we think that these effects will be captured by the provincial risk. 56% of the reduction in the first regime change can be attributed to systematic risk. For the second regime change, systematic risk accounts for 67% of the reduction.

[Insert Table 6 here]

5.4 Mean sector share changes

The changes of the variance of the residual innovation q_j, $\Delta Var\left(q_j\right)$ and the changes of the three major risk factors, $\Delta SYS, \Delta PROV, \Delta COV$, can be further decomposed into two components. The first is the changes in the mean sector shares a_j; the second is the changes of the variance-covariance matrix $E\left(\mathbf{y}_j\mathbf{y}_j'\right)$. Let us consider the changes from regime 1 to regime 2 as an example; the calculation for changes from regime 2 to regime 3 is identical. One possible concern is that the reduction of the variance may come from the changes in the sector shares a_j. Let $\bar{a}_j^2$ and $\bar{a}_j^1$ be the average sector share in regime 2 and regime 1. Changes of the variance of the residual innovation q_j, $\overline{\Delta Var\left(q_j\right)}$ between regime 1 and regime 2 can be calculated using Equation 5. By adding a term and subtracting the term $\bar{a}_j^1 E\left(\mathbf{y}_j^2\mathbf{y}_j^{2\prime}\right)\bar{a}_j^1$, the total changes are decomposed into two parts: the first two terms in Equation (6) gives the contribution from the changes of the mean sector shares $\bar{a}_j$; the second two terms in Equation (6) gives the contribution from the changes in the variance-covariance matrix $E\left(\mathbf{y}_j\mathbf{y}_j'\right)$.

$$\overline{\Delta Var\left(q_j\right)} = \bar{a}_j^2 E\left(\mathbf{y}_j^2\mathbf{y}_j^{2\prime}\right)\bar{a}_j^2 - \bar{a}_j^1 E\left(\mathbf{y}_j^1\mathbf{y}_j^{1\prime}\right)\bar{a}_j^1 \quad (5)$$

$$= \bar{a}_j^2 E\left(\mathbf{y}_j^2\mathbf{y}_j^{2\prime}\right)\bar{a}_j^2 - \bar{a}_j^1 E\left(\mathbf{y}_j^2\mathbf{y}_j^{2\prime}\right)\bar{a}_j^1 + \bar{a}_j^1 E\left(\mathbf{y}_j^2\mathbf{y}_j^{2\prime}\right)\bar{a}_j^1 - \bar{a}_j^1 E\left(\mathbf{y}_j^1\mathbf{y}_j^{1\prime}\right)\bar{a}_j^1 \quad (6)$$

Table (6) reports the results from this decomposition. For example, SysShare gives the changes in SYS due to the changes in the mean sector share; and SysCov gives the changes in SYS due to the changes in the variance-covariance matrix. The contributions of the mean sector share changes are negligible. Because the variance-covariance matrix for PROV is but a scalar, the mean share change does not affect the PROV at all. The results here confirm our previous discussion in Section 5 that the changes of the composition of different industries will not explain the reduction in volatility.

[Insert Table 6 here]

6 Conclusion

In this paper, we document the dramatic two-phase moderation in output volatility in China from 1949-2008. We show that China's output volatility measured by the standard deviation of real gross domestic product (GDP) growth over the specified rolling windows exhibit an unambiguous declining trend. The magnitude of the reduction in China is comparable with the "Great Moderation" in most industrialized economies. We find that the output volatility experiences the sharpest decline when transforming from a central planning economy to a transitional market economy. We explain why this sharpest decline in output volatility occurred in 1978. The strong central government control imposes systematic risk on the economy. Policy errors transformed into large drops in the output of all provinces. When the government finally realized their errors, the correction of these errors will create, on the opposite, a significant rebound in output of all provinces. This process, therefore, resulted in the high output volatility at the national level during the central planning era. By deviating away from central planning, the decrease in provincial co-movement, thus, reduced the output volatility.

In the end, although evidences of the striking moderation in output fluctuation in China during the past half century and the past twenty to thirty years are clear, the explanations for this moderation are still not complete. We provide one possible explanation for the sudden drop in the 1970s, which we think play a critical role. But there might be other explanations. Our research, therefore, should be considered as a first step. More researches employing better and more rigorous econometric models or using new available dataset that go beyond what we have addressed above are, needless to say, in high demand in order to better understand the moderation in China. At the same time, researches about China's moderation can also be helpful in the understanding of China's great economic success in general.

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7 Appendix

We extend Koren and Tenreyro (2007)'s [16] estimation strategy from a cross-country decomposition to a within country cross-province decomposition. In terms of the econometric specification, our method is more similar to Heston and Rouwenhorst (1994) [13]. Let innovations in province j be denoted q_j. By a first-order approximation, it can be expressed as the weighted sum of the innovations in every sector y_{js}.

$$q_{jt} = \sum_{s=1}^{S} a_{jst} y_{jst}; q_{jt} = a'_{jt}\mathbf{y}_{jt} \tag{7}$$

y_{jst} is innovation in province j and sector s at time t after controlling for other factors. To separate the common national risk from that of the geographic and sectoral composition, we can further break down y_{jst} into four components:

$$y_{jst} = C_t + \lambda_{st} + \mu_{jt} + \varepsilon_{jst}$$

where C_t is the national shock common to all provinces; μ_{jt} is specific to a province but common to all sectors; λ_{st} is specific to a sector but common to all provinces; ε_{jst} captures the unexplained residual. Note that this decomposition is cross-sectional and time t is fixed.

7.1 Statistical specification

In the statistical specification, we measure national shocks as the cross-province and cross-sector average of y_{jst}. Province-specific shocks are then identified as the within province average of y_{jst} using only the portion not explained by national shocks. Sector-specific shocks as the cross-province average of y_{jst} using only the portion not explained by nation-specific and province-specific shocks. Formally:

$$\widehat{C}_t = \frac{1}{PS} \sum_{j=1}^{P} \sum_{s=1}^{S} y_{jst}$$

$$
\begin{aligned}
\widehat{\mu}_{jt} &= \frac{1}{S}\sum_{s=1}^{S}\left(y_{jst}-\widehat{C}_t-\widehat{\lambda}_{st}\right) \\
&= \frac{1}{S}\sum_{s=1}^{S}\left(y_{jst}-\widehat{C}_t\right)
\end{aligned}
$$

where the second equality holds because later we will prove that $\sum_{s=1}^{S}\widehat{\lambda}_{st}=0$.

$$
\begin{aligned}
\widehat{\lambda}_{st} &= \frac{1}{P}\sum_{j=1}^{P}\left(y_{jst}-\widehat{C}_t-\widehat{\mu}_{jt}\right) \\
&= \frac{1}{P}\sum_{j=1}^{P}\left(y_{jst}-\widehat{C}_t\right)
\end{aligned}
$$

where the second equality holds because we will prove that $\sum_{j=1}^{P}\widehat{\mu}_{jt}=0$ later.

$$
\widehat{\varepsilon}_{jst}=y_{jst}-\widehat{C}_t-\widehat{\mu}_{jt}-\widehat{\lambda}_{st}
$$

To decompose the overall volatility, rewrite the innovations in matrix notation. Denote $\mathbf{y}_j$ the vector of sectoral innovations in province j; a_j the vector of sectoral shares in province j. Write the decomposition in matrix form:

$$
\mathbf{y}_j = C\mathbf{1}+\lambda+\mu_j\mathbf{1}+\varepsilon_j \tag{8}
$$

Therefore, using equation (7) the variance of the total innovations is given by:

$$
Var\left(q_j\right)=a_j'E\left(\mathbf{y}_j\mathbf{y}_j'\right)a_j
$$

Using the decomposition equation (8), we can calculate the $\mathbf{y}_j\mathbf{y}_j'$:

$$
\begin{aligned}
\mathbf{y}_j\mathbf{y}_j' &= \left(C\mathbf{1}+\lambda+\mu_j\mathbf{1}+\varepsilon_j\right)\left(C\mathbf{1}'+\lambda'+\mu_j\mathbf{1}'+\varepsilon_j'\right) \\
&= C^2\mathbf{1}\mathbf{1}'+\lambda\lambda'+\mu_j^2\mathbf{1}\mathbf{1}'+\varepsilon_j\varepsilon_j'+C\mathbf{1}\lambda'+C\mathbf{1}\mu_j\mathbf{1}'+C\mathbf{1}\varepsilon_j' \\
&\quad +\lambda C\mathbf{1}'+\lambda\mu_j\mathbf{1}'+\lambda\varepsilon_j'+\mu_j\mathbf{1}C\mathbf{1}'+\mu_j\mathbf{1}\lambda'+\mu_j\mathbf{1}\varepsilon_j' \\
&\quad +\varepsilon_j C\mathbf{1}'+\varepsilon_j\lambda'+\varepsilon_j\mu_j\mathbf{1}'
\end{aligned}
$$

Take expectation and introduce some notations:

$$E\left(\mathbf{y}_j\mathbf{y}_j'\right) = \Omega_N + \Omega_\lambda + \omega_{\mu_j}^2 + \Omega_{\varepsilon_j} + Cov_j + Cov_s + \Gamma_j$$

where $\Omega_N = E\left(C^2\mathbf{11'}\right)$ collects variance of the national shocks; $\Omega_\lambda = E\left(\lambda\lambda'\right)$ is the sector-specific variance covariance matrix; Ω_{ε_j} collects the variances of the sector- and province-specific residuals; $\omega_{\mu_j}^2 = E\left(\mu_j^2\mathbf{11'}\right)$ collects the province-specific variance; $Cov_j = 2E\left(C\mu_j\mathbf{11'}\right)$ collects the covariances of national shocks with the province-specific shocks, $Cov_s = E\left(C\mathbf{1}\lambda' + C\lambda\mathbf{1'}\right)$ collects the covariances of national shocks with the sector-specific shocks, and $\Gamma_j = E[C\mathbf{1}\varepsilon_j' + C\varepsilon_j\mathbf{1'} + \mu_j\lambda\mathbf{1'} + \mu_j\mathbf{1}\lambda' + \varepsilon_j\lambda' + \lambda\varepsilon_j' + \mu_j\varepsilon_j\mathbf{1'} + \mu_j\mathbf{1}\varepsilon_j' + crossprod\left(\varepsilon_j\varepsilon_j'\right)]$ collects the remaining terms.

Therefore, the total variance thus can be decomposed into the following parts:

$$Var\left(q_j\right) = SYS + PROV + COV + RES$$

where $SYS = a_j'\left(\Omega_N + \Omega_\lambda\right)a_j$; $PROV = a_j'\omega_{\mu_j}^2 a_j$; $COV = a_j'\left(Cov_j + Cov_s\right)a_j$; $RES = a_j'\left(\Omega_{\varepsilon_j} + \Gamma_j\right)a_j$

The variance covariance matrices are estimated by the corresponding sample variance and covariance, and are given as following:

$$\widehat{\Omega}_N = \frac{1}{T}\sum_{t=1}^{T}\widehat{C}_t^2$$

$$\widehat{\Omega}_\lambda = \frac{1}{T}\sum_{t=1}^{T}\widehat{\lambda}_t\widehat{\lambda}_t'$$

$$\widehat{Cov_j} = \frac{2}{T}\sum_{t=1}^{T}\widehat{C}_t\widehat{\mu}_{jt}$$

$$\widehat{Cov_s} = \frac{1}{T}\sum_{t=1}^{T}\left(\widehat{C}_t\mathbf{1}\widehat{\lambda}_t' + \widehat{C}_t\widehat{\lambda}_t\mathbf{1'}\right)$$

$$\widehat{\omega}_{\mu_j} = \frac{1}{T}\sum_{t=1}^{T}\widehat{\mu}_{jt}^2$$

and the elements in $\widehat{\Omega}_{\varepsilon_j}$ is estimated by $\widehat{\sigma}^2_{js} = \frac{1}{T}\sum_{t=1}^{T}\widehat{\varepsilon}^2_{jst}$.Given the estimates of all the variance covariance matrix, the four risk factors can be computed $SYS_t = a'_{jt}\left(\widehat{\Omega}_N + \widehat{\Omega}_\lambda\right)a_j$; $PROV = a'_{jt}\widehat{\omega}^2_{\mu_j}a_{jt}$; $COV_t = a'_{jt}\left(\widehat{Cov}_j + \widehat{Cov}_s\right)a_{jt}$; $RES_t = a'_j\left(\widehat{\Omega}_{\varepsilon_j} + \widehat{\Gamma}_j\right)a_j$.

7.2 Econometric Specification

The above statistical specification can also be expressed equivalently in an econometric specification as following:

$$y_{jst} = C_t + \lambda_{1t}d_1 + \ldots + \lambda_{St}d_S + \mu_{1t}h_1 + \ldots + \mu_{Pt}h_P + \varepsilon_{jst}$$

$$s.t. \sum_{i=1}^{S}\lambda_{it} = 0, \sum_{i=1}^{J}\mu_{it} = 0$$

where d_i are dummies for each sector, h_j are dummies for each province, and ε_{jst} is the regression residual.

This constrained OLS is then carried out for every year to generate the respective $\widehat{C}_t$, $\widehat{\mu}_{jt}$ and $\widehat{\lambda}_{st}$. The results are identical to the statistical specification. The proof is as follows.

The econometric specification solves the following least-square error problem:

$$\begin{aligned} & \min\left[Y - D\begin{pmatrix} C \\ \lambda \\ \mu \end{pmatrix}\right] \\ s.t.\ 1'\lambda &= 0, 1'\mu = 0 \end{aligned}$$

where Y is the $JS \times 1$ vector of shocks (stacking the S sector of province 1 on S sectors of province 2 etc) and D is the $JS \times (1 + S + J)$ vector of sectors and provinces dummies.

$$D = \begin{pmatrix} 1 & 1 & 0 & \cdots & 1 & 0 & \cdots \\ 1 & 0 & 1 & \cdots & 1 & 0 & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ 1 & 1 & 0 & \cdots & 0 & 1 & \cdots \\ 1 & 0 & 1 & \cdots & 0 & 1 & \cdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \end{pmatrix}$$

The first order condition requires:

$$D'D \begin{pmatrix} C \\ \lambda \\ \mu \end{pmatrix} = D'Y$$

$$1'\lambda = 0, 1'\mu = 0$$

Let $l = \sum_{j=1}^{P} y_j$ denote the $S \times 1$ vector of the sum of shocks across provinces, m denote the $J \times 1$ vector of the sum of shocks across sectors within a province; and $g = 1'l$ denote the overall sum of shocks i.e. the sum of shocks across provinces and across sectors. Direct calculation show

$$D'Y = \begin{pmatrix} g \\ l \\ m \end{pmatrix}$$

$$D'D = \begin{pmatrix} JS & J1'_J & S1'_S \\ J1_J & JI_S & 0 \\ S1_S & 0 & SI_J \end{pmatrix}$$

We then need to verify that $\widehat{C}_t$, $\widehat{\lambda}_t$, $\widehat{\mu}_t$ is a solution to the first order condition.

$$\begin{aligned} D'D \begin{pmatrix} \widehat{C}_t \\ \widehat{\lambda}_t \\ \widehat{\mu}_t \end{pmatrix} &= \begin{pmatrix} JS & J1'_S & S1'_J \\ J1_S & JI_S & 0 \\ S1_J & 0 & SI_J \end{pmatrix} \begin{pmatrix} \widehat{C} \\ \widehat{\lambda} \\ \widehat{\mu} \end{pmatrix} \\ &= \begin{pmatrix} JS\widehat{C} + J1'_S\widehat{\lambda} + S1'_J\widehat{\mu} \\ J1_S\widehat{C} + JI_S\widehat{\lambda} \\ S1_J\widehat{C} + SI_J\widehat{\mu} \end{pmatrix} \\ &= \begin{pmatrix} g \\ l \\ m \end{pmatrix} \end{aligned}$$

It is easy and straightforward to verify that $\widehat{\mu}_{jt}$ sum to zero

$$\begin{aligned}\sum_{j=1}^{P}\widehat{\mu}_{jt} &= \sum_{j=1}^{P}\left[\frac{\sum\limits_{s=1}^{S}y_{jst}}{S}-\widehat{C}_t\right] \\ &= P\widehat{C}_t - P\widehat{C}_t \\ &= 0\end{aligned}$$

Similarly for $\widehat{\lambda}_{st}$

$$\begin{aligned}\sum_{s=1}^{S}\widehat{\lambda}_{st} &= \sum_{s=1}^{S}\left[\frac{1}{P}\sum_{j=1}^{P}\left(y_{jst}-\widehat{C}_t-\widehat{\mu}_{jt}\right)\right] \\ &= S\widehat{C}_t - S\widehat{C}_t \\ &= 0\end{aligned}$$

Therefore, $\widehat{C}_t$, $\widehat{\lambda}_t$, $\widehat{\mu}_t$ does solve the first order condition. We have by far proved that the statistical specification is identical to the econometric specification. We also show this equivalence in our programs quantitatively.

7.3 Regime Change

The most important feature of Chinese economy over the past fifty year is regime changes. Shortly after the establishment of the new Chinese government, it adopted a Soviet style of central planning. In 1978, China started its decades long transition into a market economy. In 1992, after the famous southern tour of Deng Xiaoping and the third plenary session of the fourteenth central committee, the pace of Chinese economic reform accelerated. We want to capture those dramatic changes. So in our estimation, Y_{jst} is calculated using three separate regime periods i.e. 1953-1977 & 1978-1994 & 1995-2008.

Chow Breakpoint Test: 1980 1994

Null Hypothesis: No breaks at specified breakpoints			
Equation Sample: 1953 2008			
F-statistic	2.629912	Prob. F(4,50)	0.0452
Log likelihood ratio	10.69293	Prob. Chi-Square(4)	0.0302
Wald Statistic	10.57919	Prob. Chi-Square(4)	0.0317

Table 1: Chow Test

Changes in Output Volatility: Different Detrending Methods

	Standard Deviation						
	1955-1977	1978-1994	1995-2006	1978-2006	C12 Change	C23 Change	C14 Change
HP 100	0.119	0.038	0.025	0.033	-0.684	-0.348	-0.723
HP 6.25	0.085	0.024	0.009	0.019	-0.718	-0.622	-0.775
BP	0.081	0.022	0.009	0.018	-0.722	-0.603	-0.777
Log D	0.112	0.032	0.014	0.026	-0.717	-0.565	-0.773

Note: each row uses different detrending methods. HP100: HP-filter with parameter 100 for annual series; HP6.25: HP-filter with parameter 6.25 for annual series; BP: Baxter-King filter with 2-8 years cycle periods; Log D: log difference.

Table 2: Different Detrending Methods

Summary stats: controls

Variable	Mean	Std	N
Regime 1			
CPI inflation	0.012	0.056	432
(Deposit+Loan)/NGDP	0.786	0.441	706
(Export+Import)/NGDP	0.040	0.056	428
Inventory change/NGDP	0.077	0.065	661
Regime 2			
CPI inflation	0.086	0.075	409
(Deposit+Loan)/NGDP	1.350	0.450	476
(Export+Import)/NGDP	0.163	0.448	463
Inventory change/NGDP	0.097	0.063	476
Regime 3			
CPI inflation	0.034	0.049	378
(Deposit+Loan)/NGDP	2.246	0.751	392
(Export+Import)/NGDP	0.273	0.368	392
Inventory change/NGDP	0.067	0.076	385

Table 3: Summary Stats: Controls

Control Regressions

	(1)	(2)	(3)
VARIABLES	Y1	Y2	Y3
Lag1 Inflation	-0.114*	-0.521***	-1.021***
	(0.0646)	(0.108)	(0.175)
Regime1 Lag1 Inflation interaction	0.0865	0.555***	0.891***
	(0.0697)	(0.117)	(0.189)
Regime2 Lag1 Inflation interaction	0.102	0.514***	0.959***
	(0.0710)	(0.119)	(0.192)
Lag1 CreditRation	0.287***	0.325***	0.983***
	(0.0532)	(0.0890)	(0.144)
Regime1 Lag1 CreditRation interaction	-0.213**	-0.231*	-1.125***
	(0.0835)	(0.140)	(0.226)
Regime2 Lag1 CreditRation interaction	-0.331***	-0.298**	-0.956***
	(0.0827)	(0.138)	(0.224)
Lag1 Openness	0.514	0.391	1.632*
	(0.365)	(0.612)	(0.991)
Regime1 Lag1 Openness interaction	-0.600	-0.395	-1.517
	(0.373)	(0.624)	(1.010)
Regime2 Lag1 Openness interaction	-0.532	-0.353	-1.627
	(0.373)	(0.624)	(1.010)
Lag1 Inventory	0.326***	1.669***	1.642***
	(0.0881)	(0.148)	(0.239)
Regime1 Lag1 Inventory interaction	-0.442***	-1.795***	-1.899***
	(0.152)	(0.254)	(0.411)
Regime2 Lag1 Inventory interaction	-0.401***	-1.660***	-1.619***
	(0.153)	(0.255)	(0.414)
Constant	0.00112	0.00101	0.00719
	(0.00189)	(0.00317)	(0.00513)
Observations	935	935	935
R-squared	0.073	0.195	0.182

Note: Lags of independent variables and interactions with regime dummies are included. Inflation is calculated using CPI; CreditRation is measured as (Deposit+Loan)/NGDP; openness is measured as (Export+Import)/NGDP; inventory variable is measured as Inventory change/NGDP. Detrend method for others: hp filter. Standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 4: Control Regressions

	CTR	SYS	PROV	COV	RES	EXP
R1	1.000	0.561	0.492	-0.080	0.007	0.980
R2	1.000	0.672	0.486	-0.099	-0.140	0.919

Table 5: Volatility Reduction Accounting

	SysCov	SysShare	ProvCov	ProvShare	CovCov	CovShare
R1	0.564	0.005	0.513	0.000	-0.212	-0.033
R2	0.652	-0.006	0.499	0.000	-0.101	0.010

Table 6: Volatility Reduction Accounting: mean sector share changes

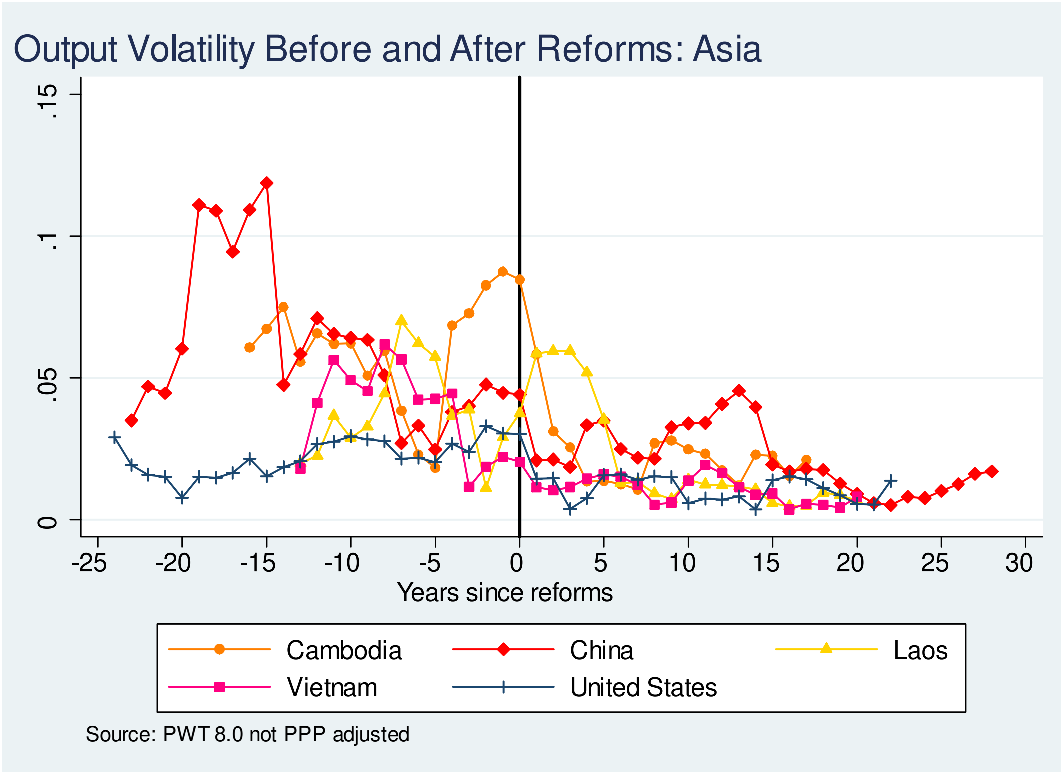

Figure 1: Asian transitional economies

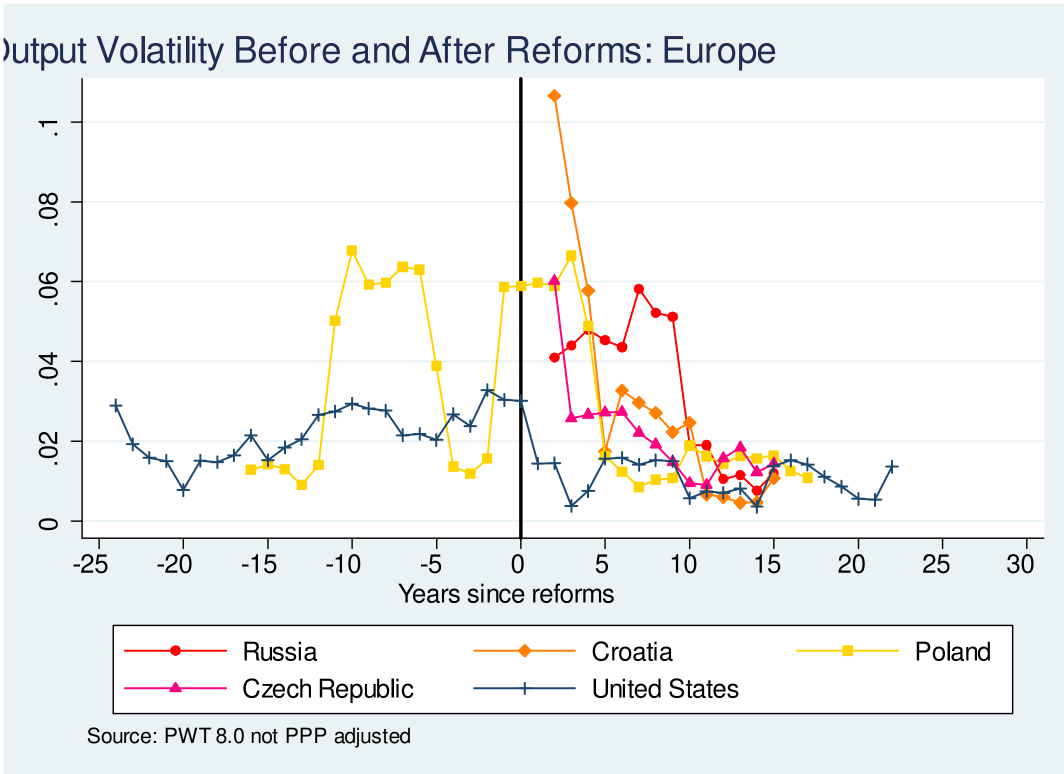

Figure 2: European transitional economies

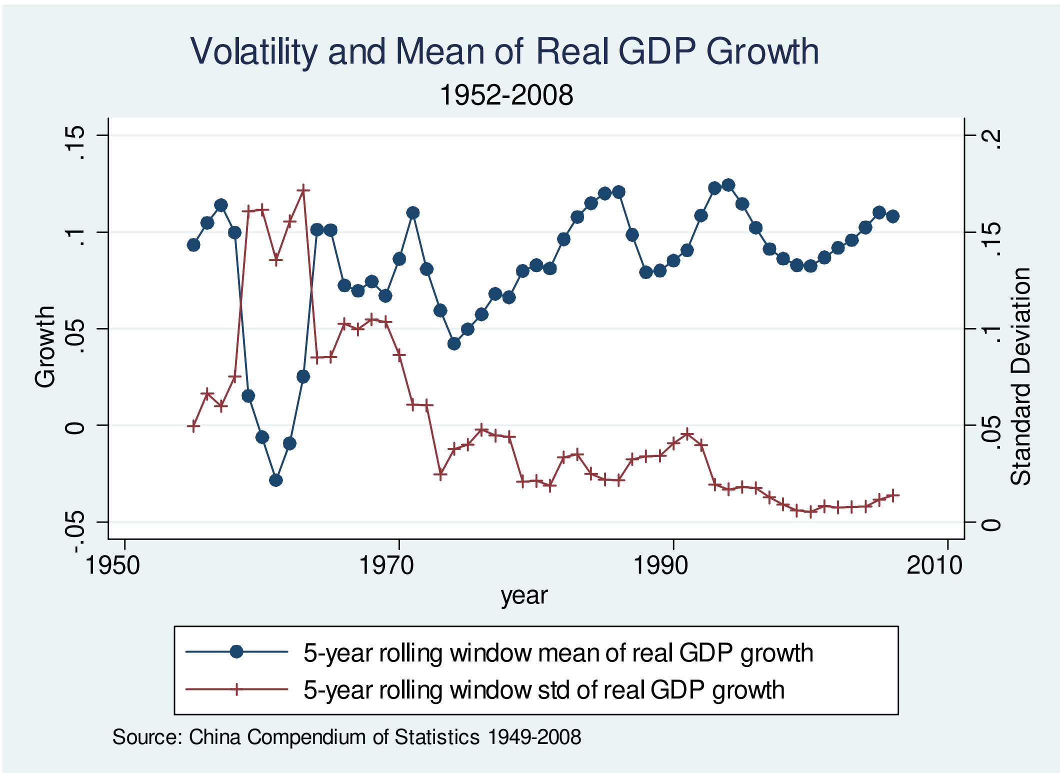

Figure 3: 5-year rolling window volatility

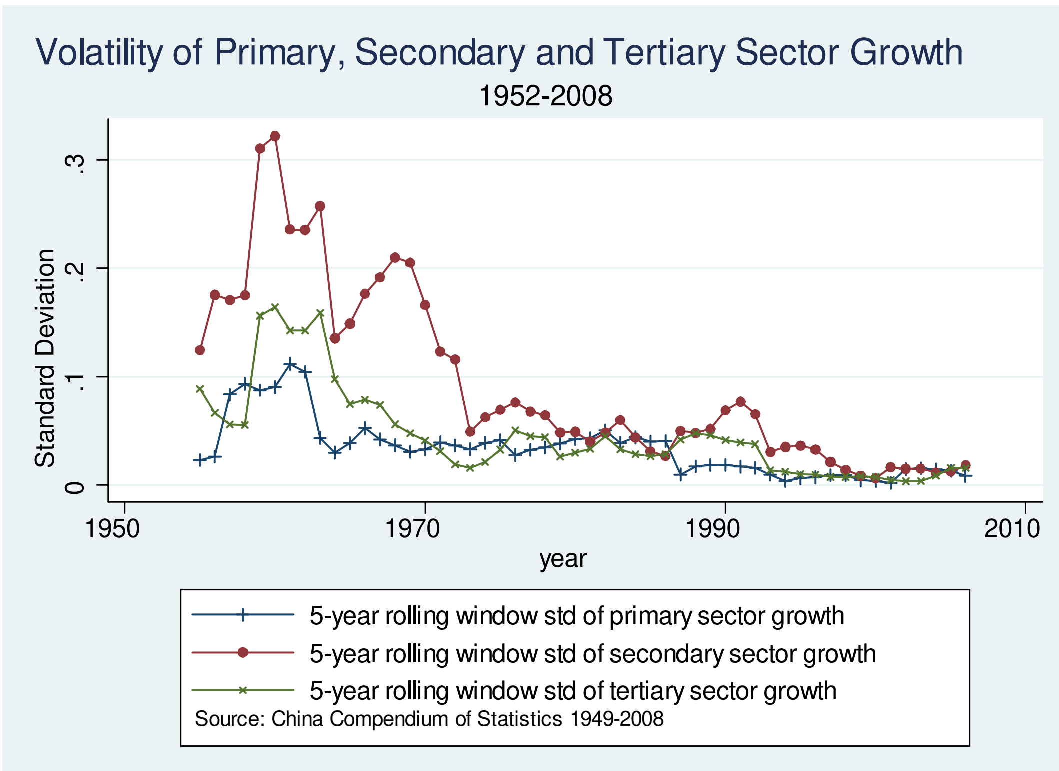

Figure 4: Output Volatility by Sectors

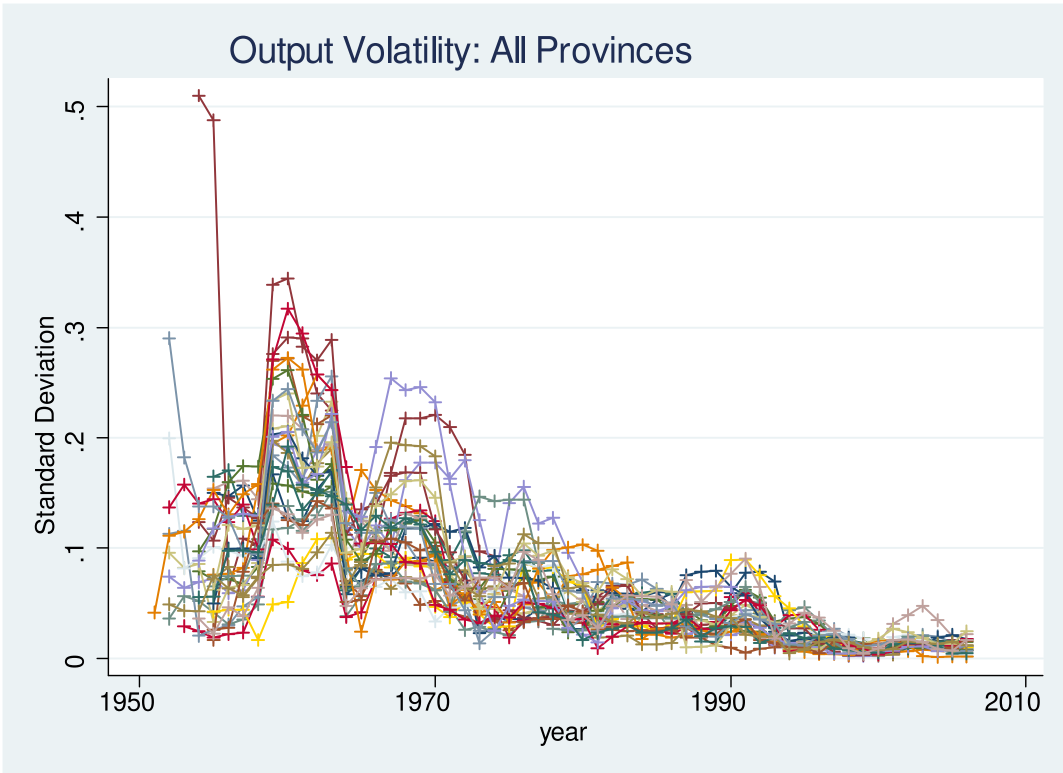

Figure 5: Output Volatility: All Provinces

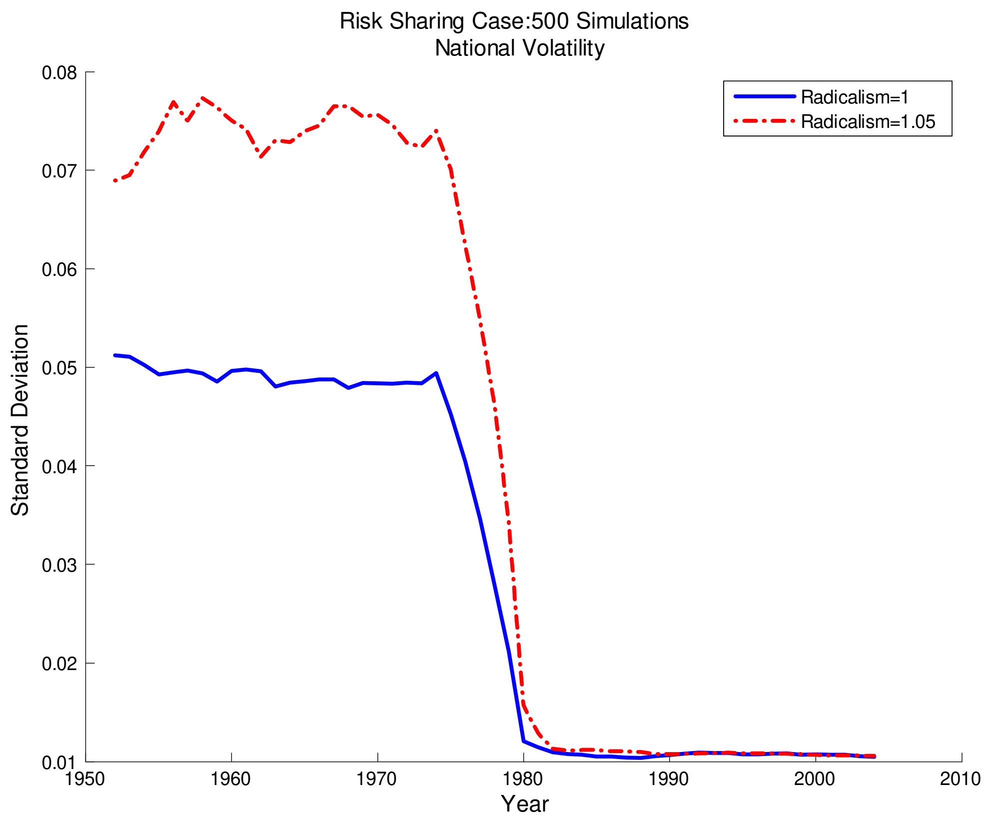

Figure 6: National Volatility

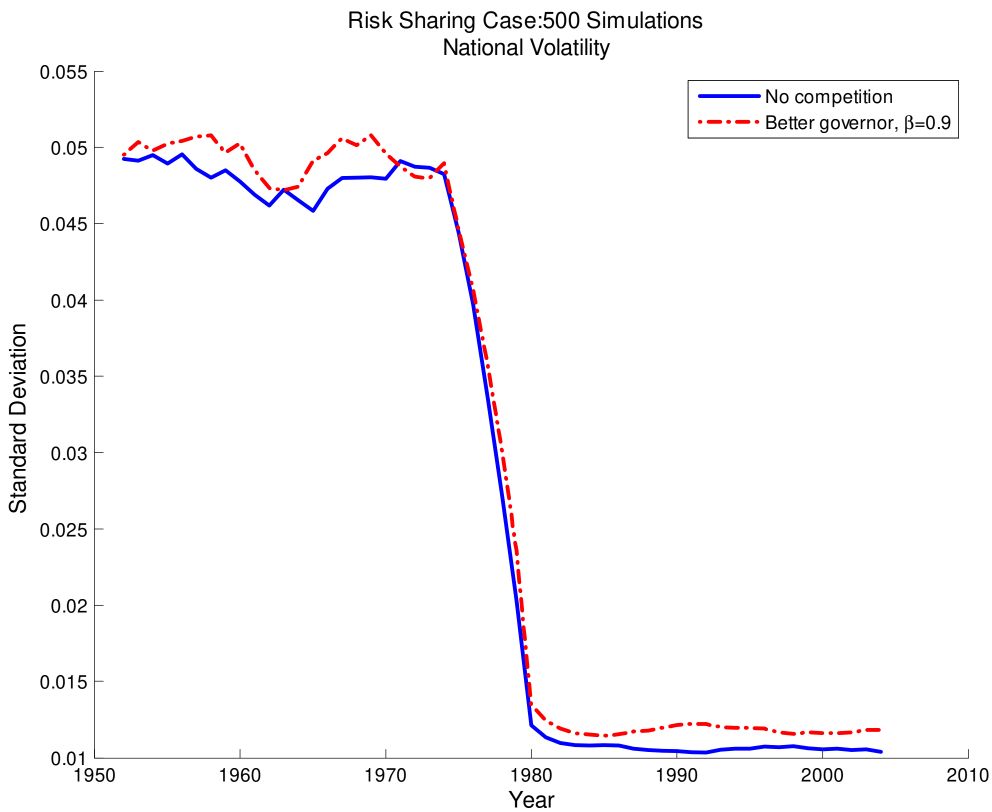

Figure 7: Local competition: better governor

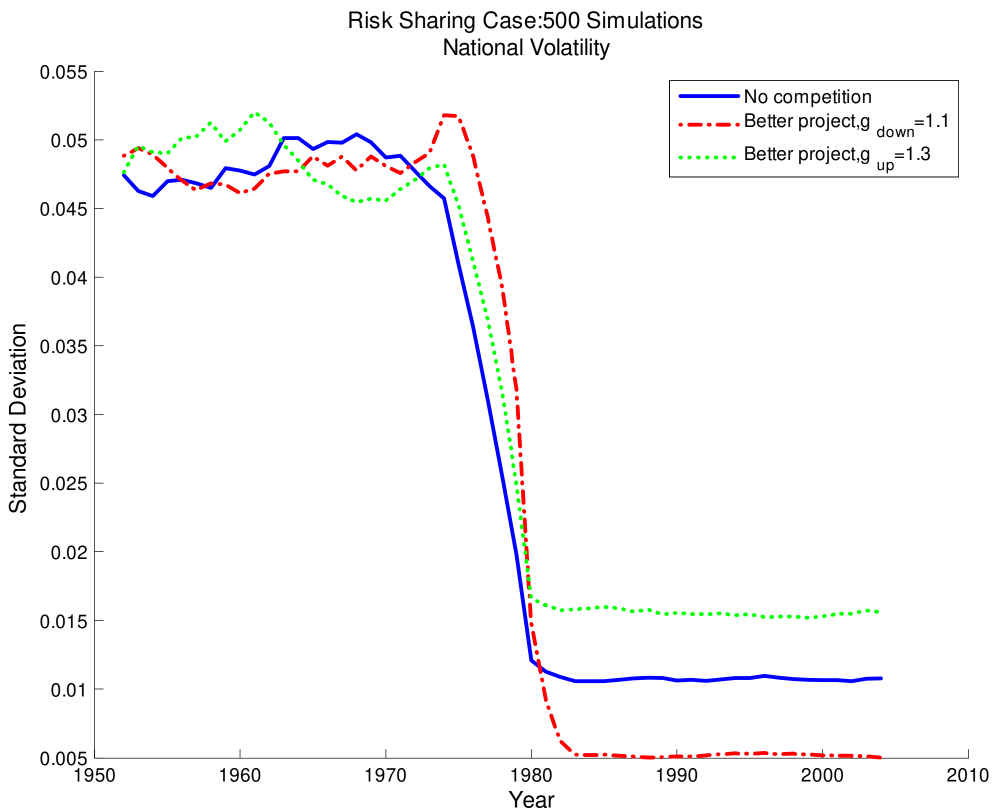

Figure 8: Local competition: better project

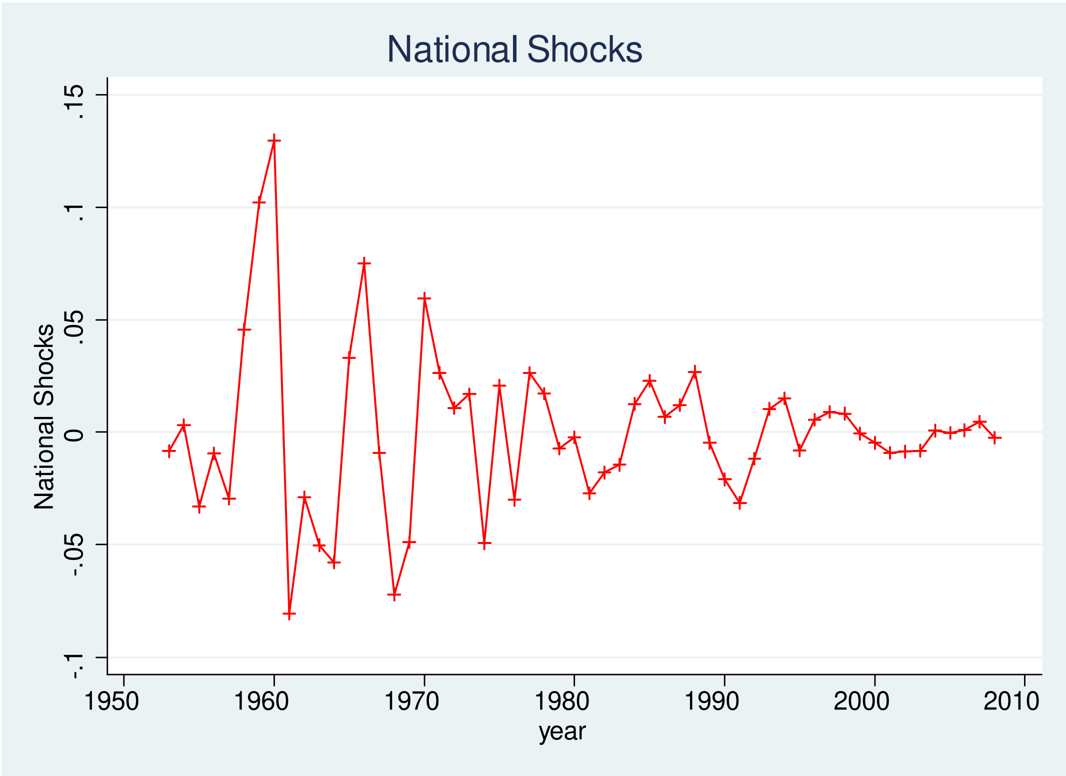

Figure 9: National Shocks

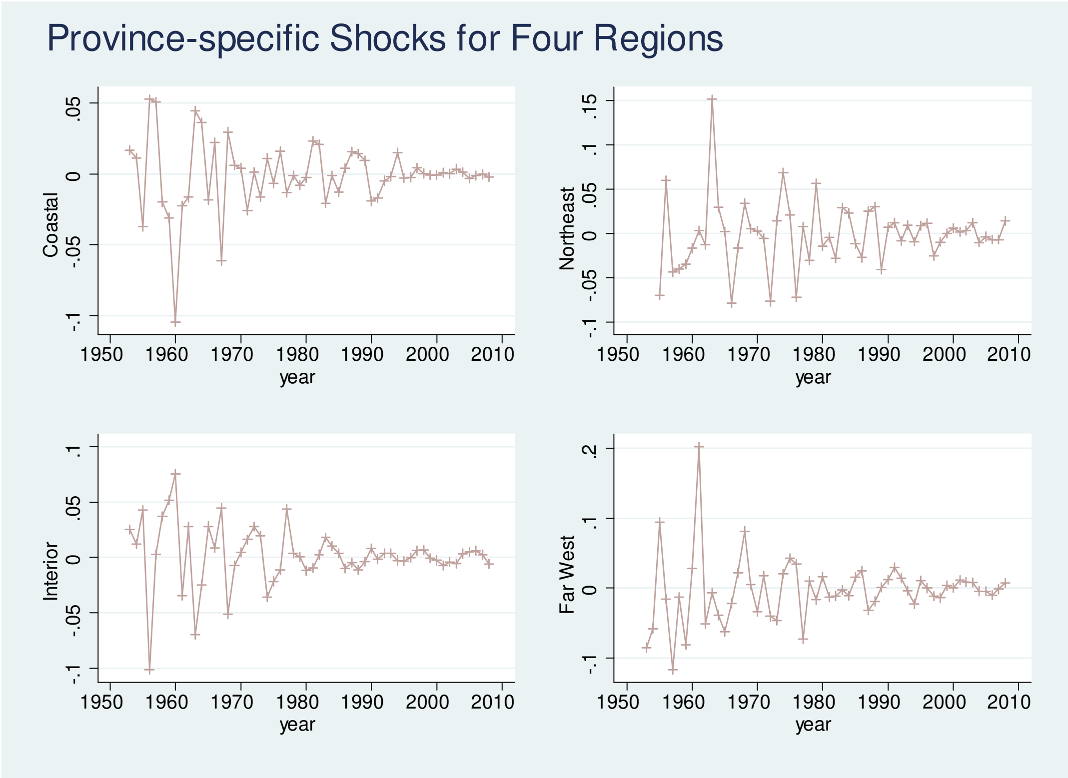

Figure 10: Province-specific Shocks

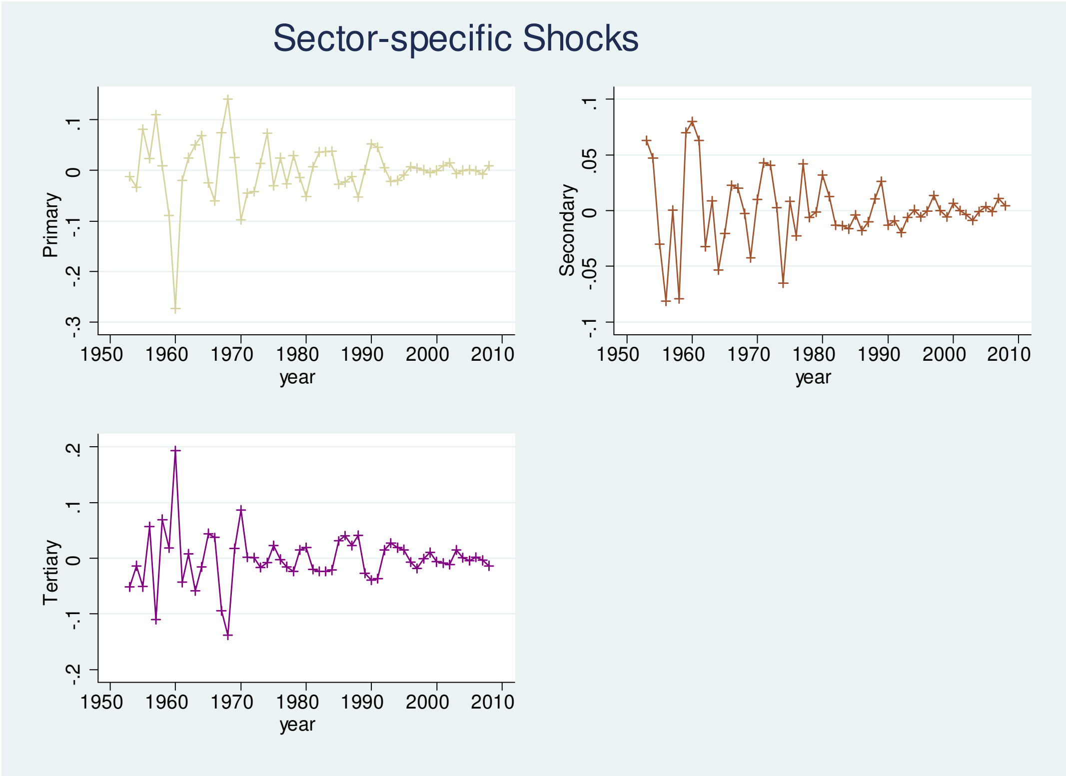

Figure 11: Sector-specific Shocks

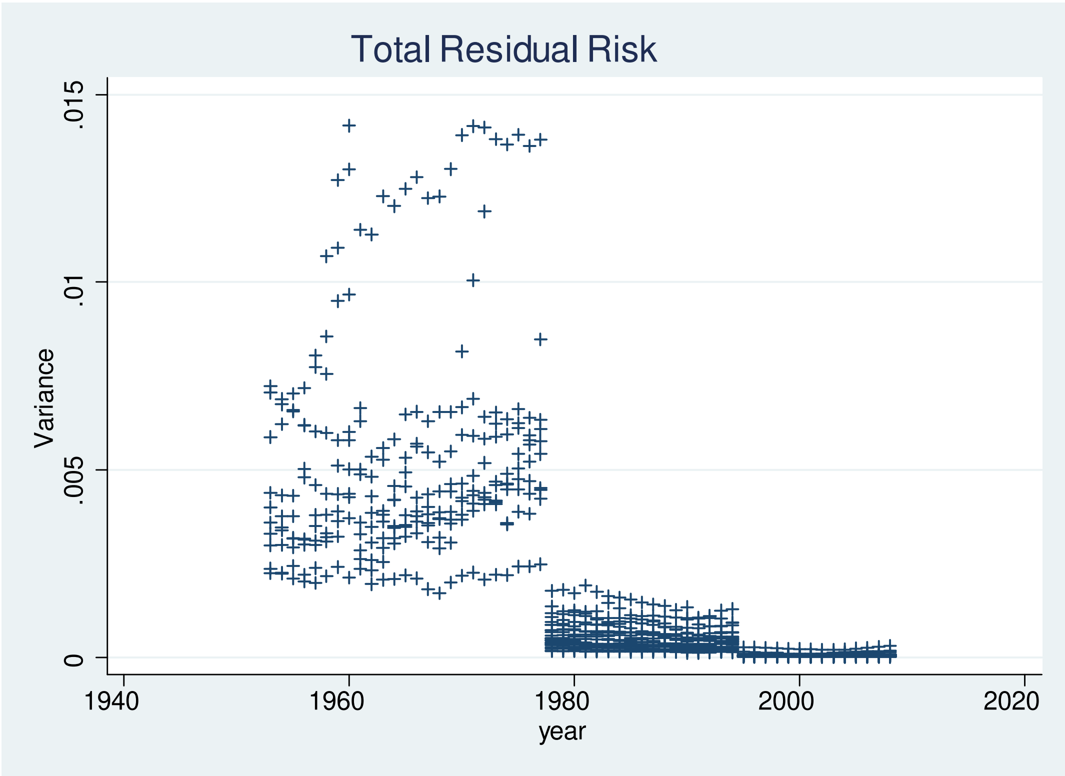

Figure 12: Total Residual Risk

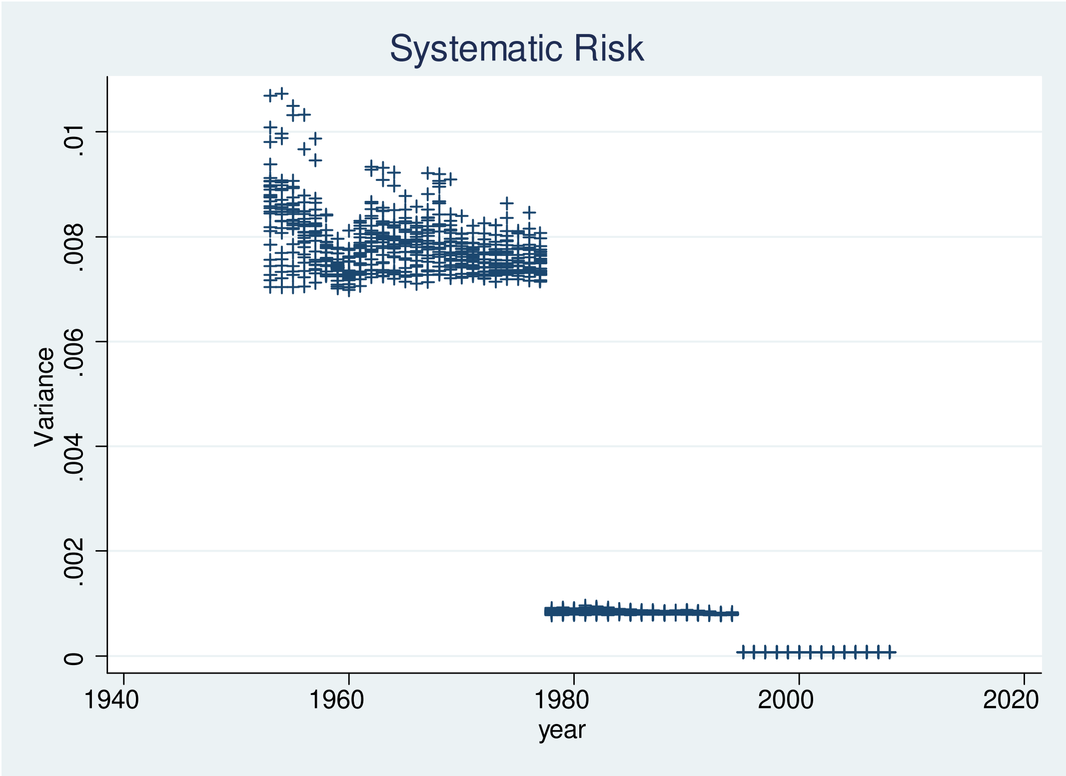

Figure 13: Systematic Risk

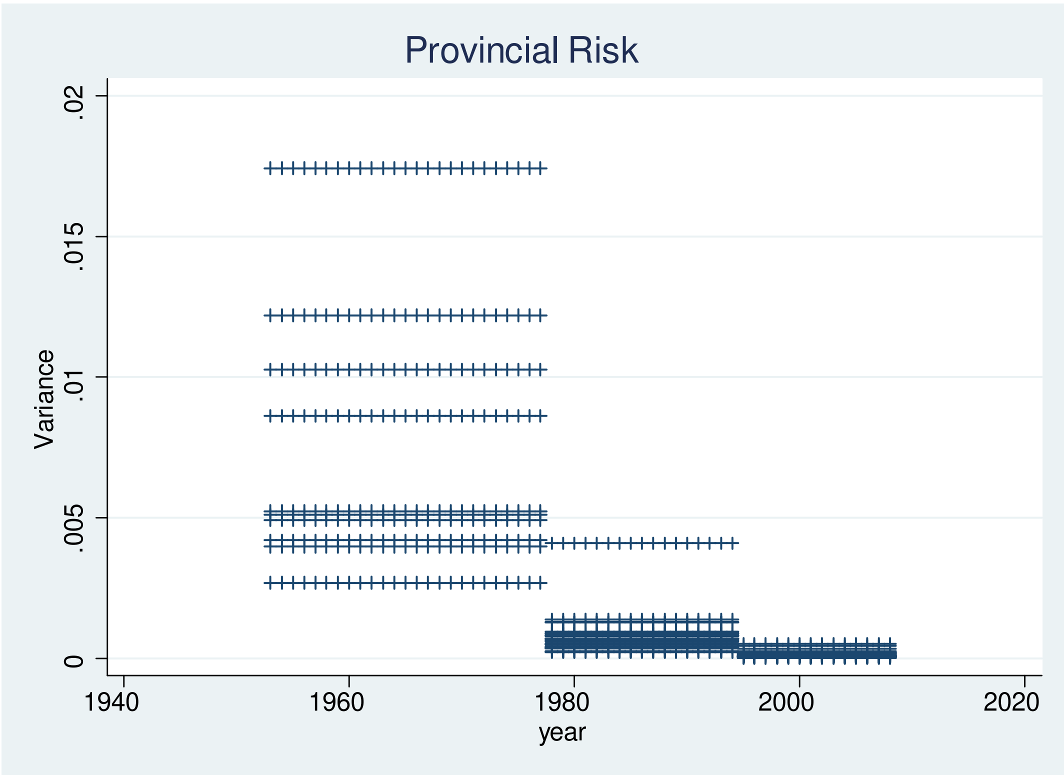

Figure 14: Province Risk

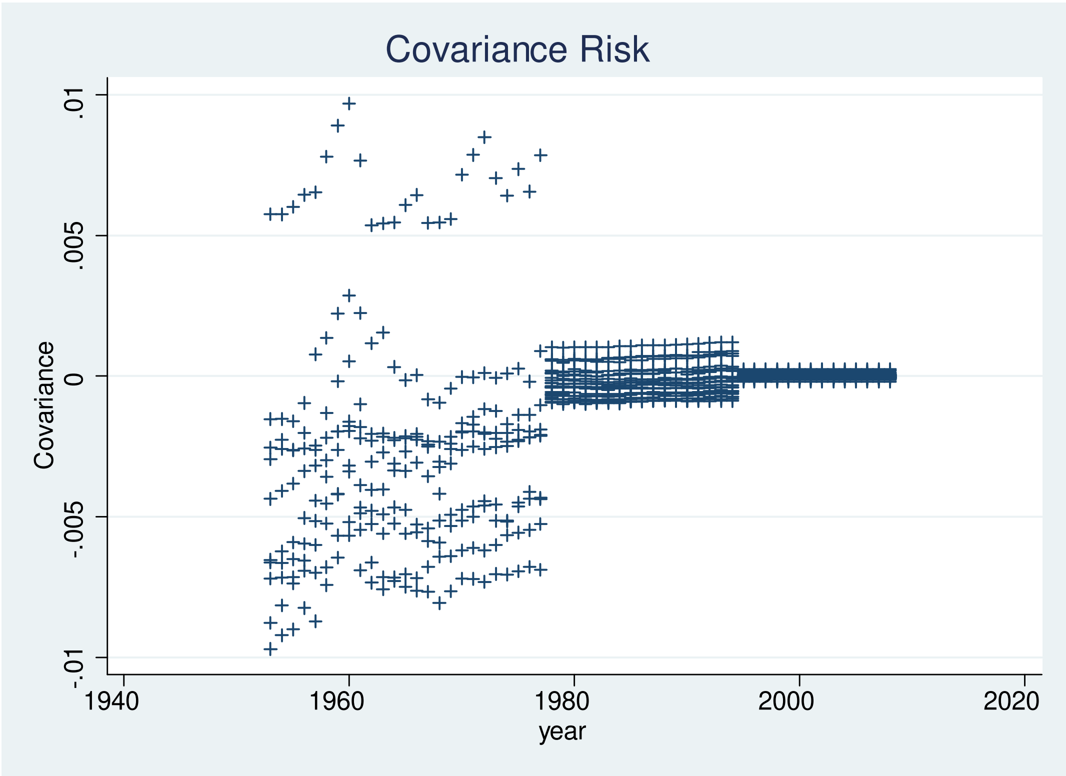

Figure 15: Covariance Risk