CEPR DEVELOPMENT ECONOMICS SYMPOSIUM

Held jointly with Actors, Markets, and Institutions in Developing Countries:
A micro-empirical approach (AMID) Marie Curie Initial Training Network and
Swedish Development Economics Network

Stockholm,
2-3 June 2010

The Institutional Causes of China's Great Famine, 1959-61

Xin Meng, Nancy Qian and Pierre Yared

The Institutional Causes of China's Great Famine, 1959-61*

Xin Meng† Nancy Qian‡ Pierre Yared§

February 22, 2010

Abstract

This study investigates the causes of China's Great Famine. We present two empirical findings: 1) food production in 1959, which was 13% below that of the previous year, was still almost three times as much as what was needed to avert famine-induced mortality; and 2) rural regions that produced more food per capita in 1959 suffered *higher* mortality during the famine, a *reversal* of the negative correlation between food production and mortality during normal years. These findings imply that the centrally-planned food procurement system was likely to be a major contributor to the famine. Historical evidence suggests that the government could not easily aggregate and respond to information such that a central feature of the procurement system was inflexibility. We develop a model which shows that our empirical findings are consistent with optimal policy subject to inflexibility. The model also allows us to compare the Chinese procurement policy of fixing quantities to an alternative policy of fixing prices.

Keywords: Famines, Institutions, History, Socialist Planning
JEL Classification: O43, N3, O1, P21

---

*We thank Daron Acemoglu, Robin Burgess, Sylvain Chassang, Claudia Goldin, Dean Karlan, Michael Kremer, Roger Myerson, Emi Nakamura, Nathan Nunn, Gerard Padro-i-Miquel, Torsten Persson, Canice Prendergast, Andrei Shleifer, Chris Udry and Shang-Jin Wei for their comments; we are especially gratefull to Abhijit Banerjee and Mikhail Golosov for their many thoughtful insights; the partcipants at the Berkeley Development Seminar, UCLA Applied Economics Seminar, Stanford Economic History Seminar, Tsinghua University Economics Seminar, the Applied Workshop at CCER PKU, Yale University Macro Lunch and Harvard History Tea for useful comments; and Sara Lowes, Ang Sun, David Liu and Katherine Wilson for excellent research assistance.

†Australian National University, RSSS. email: xin.meng@anu.edu.au
‡Yale University, NBER, CEPR, BREAD. email: nancy.qian@yale.edu.
§Columbia University. email: pyared@columbia.edu.

1 Introduction

In the twentieth century, over 100 million people have perished from famines, more than from both World Wars combined.[1] Famines do not only kill, but they reduce the quality of life of survivors for decades afterwards.[2] In this paper, we study the causes of China's Great Famine, which began in the winter of 1959-60 and lasted until 1961 and claimed the lives of between seventeen and thirty million people.[3] We present novel empirical evidence together with a theoretical model to argue that the centrally-planned procurement system transformed an otherwise moderate fall in production into the largest famine in history.

The first fact we establish is that aggregate production of grain, the main component of the Chinese diet, was well above subsistence needs in 1959 even though it had fallen by 13% from 1958.[4] We compute aggregate caloric needs and food production in 1959 using aggregate population data on the sex and age distribution from the 1954 *Population Census* and data on total population over time to calculate two benchmarks for total caloric needs: 1) the amount of calories required for agricultural labor and healthy child development (e.g. 1,871 calories on average per capita per day); and 2) the amount of calories required to stay alive (e.g. 804 calories on average per capita per day). To address the concern that the government may have overstated production in 1959 for political reasons, we use the most recently corrected historical series on grain production which is also the most conservative estimate of production ever used in an academic study.[5] Our estimates show that food production in 1959 was 16% above the first benchmark and 192% above the second benchmark. The finding that food production was not particularly low when the famine began is not surprising since production was similar to levels in 1949-51 from which there are no accounts of famine. Moreover, when we repeat the exercise for each province, we find that all provinces produced more than what was needed to avoid mortality. These numbers show that there was enough food to prevent the famine.

The second fact we establish is that regions that produced more grain per capita in 1959 experienced more severe famine; this was a *reversal* of the negative correlation between per capita production and mortality we observe during non-famine years. We use retrospectively corrected data on historical province-level mortality rates and per capita grain production. To address potential issues from measurement error in the data, we repeat the exercise with alternative proxies for famine severity and grain production: birth cohort size from the 1990 *Population Census* and suitability for grain cultivation predicted by natural conditions. These measures are not vulnerable to politically-motivated

[1]See Sen (1981) and Ravallion (1997).

[2]In a companion paper on the long run consequences of China's Great Famine on survivors, Meng and Qian (2009) provides a thorough literature review on the effects of famine.

[3]See Coale (1981), Yao (1999), Peng (1987), Ashton et al. (1984) and Banister (1987).

[4]We use the terms grain and food interchangeably since grain makes up over 95% of diets. See Walker (1984) for evidence on the rural population. Urban workers in China during this period also consumed a grain heavy diet (as they do today). For example, in 1957, an average urban worker in Shanghai, one of the richest cities at the time, consumed approximate 270 kg of grains and 15 kg of meat in one year (Reynolds, 1981).

[5]We also intentionally construct our measures of subsistence needs to over-state true caloric requirements. We assume that the entire adult population participates in heavy physical labor (e.g. agricultural labor). In reality, approximately 80% of the population live in rural areas.

government reporting bias. The results support the main findings. Moreover, we find that the positive correlation between famine severity and local grain production is mainly driven by agricultural households.

These empirical results point to grain procurement policy as a main driving force of the famine. The first finding that food production in 1959 was su□cient for subsistence implies that the famine could not have been solely caused by the drop in food production. This is perhaps not surprinsing and is consistent with Sen's (1981) thesis that historically, famines have not been caused by aggregate food shortages, but instead are caused by the unequal distribution of food consumption.[6] According to this theory, income is negatively correlated with famine severity, implying that more productive farmers should experience lower famine mortality relative to less productive farmers. However, the second finding that regional famine severity was increasing with per capita production in 1959 is inconsistent with this prediction. A likely explanation for the di□erence is that China was a centrally-planned economy in which many of the market mechanisms studied by Sen (1981) are not in operation; China's food procurement system determined procurement and transfers of food for every region. Therefore, the empirical evidence suggests that certain features of the procurement system must have caused the famine and its surprising spatial patterns.

Historical evidence suggests that a key feature of the centrally planned procurement system was inflexibility. It was di□cult for the Chinese government to aggregate information from a large and heterogenous country and to respond quickly to new information.[7] The inherent inflexibility in centrally planned economies is not unique to China. It has been discussed in the historic works of Von Mises (1921) and Hayek (1946), and in the theoretical work of Weitzman (1974).[8] A natural question is whether the inflexibility of central planning could have, by itself, generated a famine with spatial patterns consistent with China's Great Famine.

To answer this question, we develop a model of optimal procurement policy in which the government is constrained by inflexibility. We consider an environment in which food production varies across regions. The government can redistribute food across regions through procurement and subsidies. For simplicity, we assume that mortality is a continuous function of food consumption and that the government is utilitarian such that it assigns equal weight to all individuals in the social welfare criterion. To understand the e□ect of a fall in aggregate production, we assume that all regions are subject to a stochastic aggregate production shock. The key constraint faced by the government is that procurement policy cannot respond to this shock. This captures the notion that the government is either unaware of the shock or cannot be responsive to the shock, two factors which contribute to the inflexibility of procurement policy. As such, the government assigns an inflexible region-specific level of procurement based on its expectations of

[6] Historically, scholars have held the view that famine is caused by aggregate food shortages dates. This argument dates back to Malthus (1798).

[7] See Section 5 for a detailed discussion of the procurement system.

[8] During the *Socialist Calculation Debate*, the Austrian economists argued that from the perspective of efficiency, it was, in practice, impossible for central planners to aggregate the information necessary in a timely fashion.

regional production.[9] The model predicts that the procurement policy amplifies the mortality which results from a reduction in food production with spatial patterns consistent with our empirical findings. These results hold generally under very mild assumptions regarding the spatial patterns of the aggregate shock which we are able to verify with the data.

The stylized example in Table 1 illustrates the mechanics of the model. There are three regions: two rural regions A and B and a city, where these regions have similar population and subsistence needs, which we assume to be 100 tons of food for simplicity. Under normal conditions which occur with probability 80%, rural region A produces 225 tons of food and rural region B produces 150 tons of food. If there is an aggregate shock, an event which occurs with probability 20%, production in regions A and B reduces to 180 and 120 tons. The city never produces any food. The government recognizes the probability of an aggregate shock and is fully aware of the relative productivity of each region. Given that the policy is inflexible, the government procures a fixed amount of food from regions A and B which it then redistributes to the city. For simplicity, imagine that the government's objective is to equalize the expected food consumption of all of the citizens in the economy. In this scenario, the government procures 96 and 24 tons of food from regions A and B, which is given to the city as a subsidy. In rural areas, this leaves each region with an expected food consumption of 120 tons, but with actual consumptions of only 84 and 96 tons of food for regions A and B during the shock. The result is that famine occurs in the rural regions during the food production shock since they retain less food after procurement than what is needed for subsistence even though aggregate production is sufficient for subsistence needs. Moreover, there is a negative (positive) correlation between food production and food consumption during the shock (in normal times).

In addition to providing an explanation of the famine that is consistent with the empirical facts, the model allows us to assess the merits of the Chinese procurement policy of fixing quantities relative to an alternative policy of fixing prices. The efficiency of central planning and the tradeoff between quantity and price controls are questions of long-standing interest to economists.[10] In an exercise that is similar in spirit to the study by Weitzman (1974), we show that quantity controls dominate price controls in our context if the rural population is sufficiently large in size relative to the urban population, and if there is little heterogeneity in the magnitude of productivity shocks across rural regions.[11]

[9] In principle, expectations can be formed from observations of factors of production (e.g. climate, terrain) and historical production. The historical evidence in section 5 suggests that, in practice, the government bases expected production on past production.

[10] For example, see Arrow (1964), Dales (1968), Hayek (1945), Heal (1969), Malinvaud (1967), Manove (1973), Samuelson (1970), Weitzman (1970), and Whinston (1962). Also see Browning (1985), Chen (1990), Freixias (1980), Ireland (1977) and Laffont (1977).

[11] Our theoretical model is an extension of his framework in which the government fixes quantities via procurement and the government cannot easily change these quantities in response to shocks. Our re-evaluation of the Chinese government's policy of fixing procurement versus an alternative policy of fixing food prices builds on similar insights as in this earlier work. Our result that fixing quantities dominates fixing prices if the rural population exceeds the urban population is a direct application of the more

Note that the insights provided by this paper are specific to centrally planned economies where government policies such as grain procurement may not necessarily respond flexibly to aggregate shocks. For studies of famines, this is an extremely relevant context since three of the most devastating and controversial famines in history, China's Great Famine (1959-61), the Ukrainian Famine (1932-33) and more recently, the North Korean Famine (1992-95) occurred in such non-market economies.[12]

This paper makes several contributions. First, we build on the work of Sen (1981) in showing that inequality in food consumption can generate a famine even when aggregate food production levels are sufficient for subsistence.[13] Several recent studies such as Shuie (2004, 2005) and Burgess and Donaldson (2009) have continued the exploration of factors beyond aggregate food supply that contribute to famine.[14] Our study differs by focusing on a *non-market* economy, and by illustrating a precise mechanisms through which government policy can generate a famine. Second, we add to studies on the causes of China's Great Famine. These studies have typically focused on the drivers behind the fall in aggregate food production in China.[15] In contrast, we take the fall in production as given and provide a theory of the procurement system which is consistent with the empirical findings. Moreover, this study is the first to point out the surprising spatial patterns of famine.[16] Third, we contribute to studies on central planning such as Weitzman (1974).[17] Fourth, our analysis is related to the growing number of works on institutional capacity

general results in his framework. Our result that this is also true if the productivity shock heterogeneity in the rural population is low is not a direct application of his framework since he assumes only one producer for each good.

[12]Demographers estimate that approximately 3.2 million died during the Ukrainian famine. The causes of this famine is a subject of intense scholarly and political debate. Explanations range from production falls due to misguided policies during the Soviet Industrialization process to politically-motivated deliberate attack on the potentially rebellious regions in the Ukraine by the Stalinist Soviet government. (See Vallin (2002) for an overview). In North Korea, it is commonly believed that 2-3 million individuals, approximately 10% of the total population, died during this famine (Haggard and Noland, 2006; Demick, 2009). However, there are very few academic studies or reliable accounts of details related to this famine.

[13]Most studies focus on the reduction in food supply as the primary driver of famine and many have argued that famine was worsened by institutional factors. O'Grada (2007a) and Dreze (1999) provide overviews of recent economic studies on famines. More specifically, see studies such as Hickson and Turner (2008), McGreggor (1989), O'Boyle (2006), O'Grada et al. (2006), and O'Rourke, (1902) on the Great Irish Potato Famine; Webb (1994) on the Ethiopia Famine; Ellman (2002) and Vallin (2002) on the Soviet Famine; and de Waal (1989) on the recent Sudanese Famine in Darfur.

[14]Shiue (2004, 2005) explores the role of government policy in determining famine relief during the famines in Nineteenth Century China. Burgess and Donaldson (2009) study the role of trade and market institutions in mitigating famines in India.

[15]For example, see studies by Chang and Wen (1997), Kueh (1994), Li and Yang (2005), Lin (1990), Peng (1987), Perkins and Yusuf (1984) and Yao (1999). Yang (2008) provides a review of the studies on the causes of China's famine.

[16]The positive correlation between famine severity and grain production has been mentioned in the companion paper by Meng and Qian (2009). Among non-academic sources, the correlation is described informally in Becker's (1996) book on China's famine.

[17]Weitzman's framework has been used by many studies of regulatory economics in market economies, especially in application to environmental regulation. For example, see Brown (2000), Copper and Oats (1992), Eskeland and Jimenez (1992), Fraja and Iossa (1998), Joskow, Bohi and Gollop (1989), Koenig (1985), McKibbin and Wilcoxen (2002) and Montero (2005).

such as those by Besley and Persson (2009) and Greif (2008).[18] As a study of the role of state capacity in responding to aggregate shocks, our work is also related to that of Cohen and Werker (2008), Kahn (2005), and Zeckhauser (1996).

The paper is organized as follows. Section 2 describes the historical background for the famine. Section 3 describes the data. Section 4 presents the empirical evidence. Section 5 interprets the empirical evidence as pointing to an institutional cause. Section 6 describes a model of procurement policy which is consistent with the evidence. Section 7 concludes.

2 Historical Background

This section briefly discusses the reforms leading up the famine and the timeline of the famine. Our purpose is to provide the relevant context for interpreting the empirical evidence. Because the policies of the early years of the New China government (1949-1959) have been a subject of many scholarly works, and it is beyond the scope of this paper to fully describe this interesting period of history, our discussion here only covers issues directly related to our study.[19] We do not discuss the Chinese procurement policy in detail in this section, since it is described in Section 5 before we introduce the model.

2.1 New China Reforms 1949-59

The New Communist government of China led by, amongst others, Party Chairman Mao Zedong (in power 1949-1976) designed a centrally-planned economy similar to that of the Soviets. Some of the goals of the new government were to equalize land access between tenant farmers and landlords, rapidly industrialize, and improve military defense in case of a foreign invasion. Historians today have not formed a consensus on why the Chinese government chose to model its economy based from the Soviets. As such, for our study, and particularly for our theoretical model in Section 6, we take the central planning environment of China as given and consider the policy in such a setting.

In this economy, where approximately 80% of the population worked in agriculture, grain procurement was seen by the government as key for development. Most of the grain was used to fund industrialization, which accounted for 43% of government investment during the 1950s (Eckstein, 1977: pp. 186). This included providing grain to urban populations that worked in industry and exporting grain (mostly to the USSR) in exchange for equipment and expertise. In 1959, approximately 4.3 million tons was exported to the U.S.S.R, which was approximately 2.3% of total production. To a much smaller extent, grain was also stored in government reserves as insurance for disaster relief.

[18] Besley and Persson (2009) analyzes the implications of administrative capacity on public policy and Greif (2008) examines government's dependence on administrators to implement policy choices in a historical context.

[19] For more detailed historical accounts of the political organization of China, please refer to the scholarly works of Fairbanks (1985) and Spence (1991). Becker (1996) in his book about the famine provides detailed descriptions and a rich collection of anecdotal accounts of the famine from survivors. Finally, a two-volume Chinese publication commissioned by the Ministry of Agriculture entitled *Villages for Thirty Years* (Wang, 1989) documents the details of the social and economic histories of Chinese villages during the famine era.

Land reforms, which ultimately led to full collectivization by the late 1950s, was a means through which the government could control and improve agricultural production and distribution (Twitchett and Fairbank, 1986 Spence, 1991: pp. 544). They occurred in three phases. The first, which began in 1952, encouraged farmers to form mutual aid teams that were 6-9 households in size. The households pooled their assets and land. The second phase, which began around 1954, was later called "low collectivization". This often required all households within a village to pool together their land and assets. However, the return that each household was entitled to depended on the amount of land and assets it contributed to the pool as well the amount of labor contribution. During this time, agricultural production increased due to the usage of land strips that were formerly used to separate private plots and to increased mechanization, which became more productive due to the pooling of land. During low collectivization, peasants were forced to sell a quota amount of grain to the government at a set low price and allowed to sell their production that was surplus of the state grain quota in markets. Approximately 5% of land was left to peasants as private plots for which they retained all of the production. Therefore, the farmers had much more incentive to work on these private plots. A disproportionately large amount of agricultural production came from these plots. For example, in 1957, these private plots produced 83% of China's pig and poultry.

Full collectivization, the third phase which is often also referred to as "high level" collectivization was phased in after low level collectivization. The main change was that although the farmers in each village had contributed land and capital assets for production, the amount they now received in return only depended on their labor input. This effectively erased private property rights to land and assets. Private plots were abolished. By 1959, 93% of agricultural land was under high level collectivization (Spence, 1991: pp. 549-50). At this time, mutual aid teams had ceased to exist. Markets for private transactions were also banned (Fairbanks, 1985: pp. 281-85).

In this regime, the central government faced two main problems. The first problem was that farmers were not incentivized to produce more than what was needed for their own consumption, which was guaranteed by the New Communist government. The collective system addressed this by forcing farmers to work with threats of severe punishment, constant monitoring, and peer pressure. The second problem was that farmers were incentivized to under-report true production or to hide production. The government attempted to address this by collectivizing the harvest and storage of grains so that harvest went directly from the field to communal storage depots. Communal kitchens were established so that the collective also controlled food preparation and consumption. (Collectivizing food preparation was also meant to free female labor from household production so that it could be shifted into agricultural production). It then attempted to collect the little grain that farmers could take in their pockets with virulent anti-hiding campaigns, where fields and even the floors of homes were dug up to expose hidden grain, and where the culprit would be publicly humiliated and punished (Becker, 1996: pp. 109).

Chinese peasants, like those in the USSR before full collectivization, slaughtered and ate enormous quantities of meat in anticipation of losing the property rights to their animals, reducing China's livestock by half between 1957 and 1958.[20] In response to this,

[20] See Becker (1996) for comparisons of historical accounts. See Yang (2008) for an economic comparison

the Chinese government declared that slaughtering animals without permission would be considered a crime against the state and severely punished offenders. By 1959, the remaining livestock and drought animals were typically under-nourished and badly tended as peasants no longer had much interest in caring for them.

For the purposes of our study, these phenomena are important because they mean that in 1959, the state had effectively procured or destroyed private savings and effectively became the only provider of insurance against shocks. Moreover, the collectivization of food preparation and consumption meant that peasants could not smooth their consumption by decreasing their food intake and therefore making their supplies last longer.

In 1958, there were accounts of starvation. However, these were isolated accounts. Widespread starvation did not occur until 1959. Grain production had grown almost monotonically between 1949 and 1958 (Li and Yang, 2005). This was partly due to the recovery and political stability after decades of conflict and to efficiency gains from early phases of collectivization. It may also have been due to new farming methods that were introduced during the collectivization period. Some of these methods, such as multiple cropping, may not have been sustainable in the long run and arguably contributed to the fall in grain output in 1959. It is believed by historians and individuals who can remember the period that there was much general optimism at the time that production will continue to grow (Spence, 1991: pp. 183).[21]

2.2 The Famine 1959-61

In 1959, grain production fell for the first time in the ten year history of the new government. It fell by approximately 30 million tons (13% from 1958). After harvest, in mid-October and November, approximately 52 million tons, 36% of total production, was procured by the central government. Had production in 1959 grown at the same 4% per annum rate as the previous years (on average), the procurement would have been 30% of production, a moderate increase from the 26% in 1958, and the same as procurement in 1954. The majority of famine deaths occurred in January and February of 1960, two to three months after the grain was procured (Becker, 1996:pp. 94).

The Chinese government has alleged that the fall in grain output was due to bad weather in 1959 and that this caused an aggregate food shortage which resulted in the famine (Coale, 1981; Yao, 1999; Peng, 1987; Ashton et al., 1984; and Banister, 1987). However, over time, scholars have revised the contribution of weather downwards to approximately 50% (Kueh, 1994) and 14% (Li and Yang, 2005). The Central Meteorological Office, which by all accounts functioned accurately as a scientific monitoring station, reported that there were no abnormalities in the weather during 1959-61 and that it was actually rather good.

Li and Yang (2005) compile province-level panel data on imputed grain consumption,

---

of the famines in China and the USSR.

[21] There was a general belief that China was awash with food. In the fall of 1958, villagers were explicitly encouraged to eat as much as they wanted from communal kitchens (Becker, 1996, pp. 80). Pressure to not publicize shortfalls and the strict control on information flows would prevent collectives from knowing about the general decrease in production in 1959.

grain production, and potential factors that contributed to the decline in production as hypothesized by existing studies to quantify the impact of each factor.[22] They find that in addition to weather, the relevant factors were diversion of labor away from agriculture for projects such as rural industrialization during the Great Leap Forward (GLF, 1958-60) and over-procurement. Diversion of labor together with weather which was not as favorable for grain cultivation as in previous years caused production to fall in 1959. However, because the government did not accordingly revise procurement downwards, retention in the country side was too low for the workers to be productive in 1960, which caused further declines in production. Our study takes their findings and the fall in grain production in 1959 as given and instead investigate the reasons that this was transformed into a famine that winter.

Survivors recall eating plentiful meals from communal kitchens during the following months, after what is typically remembered as a good harvest (e.g., Yang, 1996; Chang and Wen, 1997). Food stores ran out in the winter of 1959, when people began to die of starvation in large numbers across the country.

A critical fact to keep in mind for our study is that the highest level of mortality occurred in January and February of 1960, two to three months after the grain was procured.[23] Half of the deaths are believed to have been of children under ten years of age (Spence, 1991: pp. 583).[24] The number of deaths is staggering, particularly when one considers that relatively little food is needed to stay alive in the absence of disease and the presence of clean water, which characterized rural China after drastic public health measures undertaken during the 1950s (Fairbanks, 1985: pp. 279).[25] Hence, the deficit

[22]Studies have found that weather can only explain 30-50% of the fall (Kueh, 1994; Li and Yang, 2005). Past works have hypothesized that the fall in production was associated with Great Leap Forward (GLF) era policies such as labor and acreage reductions in grain production (e.g., Peng, 1987; Yao, 1999), implementation of radical programs such as communal dining (e.g., Yang, 1996; Chang and Wen, 1997), reduced work incentives due to the formation of the people's communes (Perkins and Yusuf, 1984), and the denial of peasants' rights to exit from the commune (Lin, 1990). Li and Yang (2005) found that amongst these hypotheses, grain procurement and labor diversion away from agriculture for GLF projects were the most important contributors to the fall in production in 1959.

Our study is most closely related to Li and Yang (2005) which uses a dynamic model to argue that erroneous expectations of production caused over-procurement in 1959, which in turn reduced inputs for agricultural production (e.g. labor was weakened, and seeds were consumed by hungry peasants) in 1960, leading to a further decline in production. They calculate grain retention after procurement in 1959 to be 223kg per person and in 1960 to be 212 kg per person, which we argue is not low enough to cause 17-30 million to die absent distributional problems. Importantly, and in contrast to our work, they do not describe or discuss the positive correlation between grain productivity and famine severity which is a large focus of our study. See Yang (2008) for a recent review of the studies on the causes of China's famine.

[23]Mortality data from the famine is not available at the monthly frequency. Historians and survivors provide consistent accounts that almost all of the mortality happened during the first winter. For a detailed description see Becker (1996) and Fairbanks (1985).

[24]Younger children may have been more vulnerable to famine for biological or food allocation reasons. They have been physically more vulnerable to nutritional deprivation, which for infants could reflect a decrease in the supply or quality of breastmilk from mothers. Alternatively, households may decide to allocate more food towards adult members who can convert these calories into income or food for the household. For similar reasons, the elderly are considered to be more vulnerable in times of shocks.

[25]The Chinese Famine is similar to the Leningrad and Dutch famines where mortality is mostly due to

of food supply relative to subsistence needs in rural areas, where most of the mortality occurred, must have been enormous.

It seems that the government began to respond to the famine as early as the spring of 1960. The government acknowledged the famine (although it did not publicly admit the magnitude of the devastation) and reduced food rations for urban areas. Urban areas, which lived on food subsidies, never experienced extreme famine or mass starvation. The government also returned rural workers that had been transferred to cities to assist in industrialization back to agriculture in order to supplement the greatly weakened rural labor supply and prevent further falls in production. However, the number of returned workers was small relative to the demands of the agriculture sector and organic inputs to production such as seeds and organic fertilizer had been consumed. Therefore, production in 1960 declined dramatically from 1959. After this bad harvest, the People's Liberation Army (PLA) delivered grain to famine stricken areas and mortality rates declined by 30% in 1961 and returned to normal in 1962. There is no detailed historical account of where exactly the grain replenishment came from. By observing the decreases in investment in industry, which had peaked at 43% of government revenues in 1959 and in military expenditure which decreased by 30% from 1959 to 1960 (Gittings, 1967: p. 309), we can speculate that these grains came from what was otherwise designated for military uses and industrial purposes. Production slowly recovered in the subsequent years.

3 Data

This study uses historical province-level data on production and mortality and retrospectively constructed county-level data of proxies for production and famine severity.

3.1 Historic Measures of Famine and Production

The annual province-level historical data on grain production are from on the *Comprehensive Statistical Data and Materials on 50 years of New China* (CSDM50) published by the China Statistical Press in 1999. In our study, we use data from all provinces for the years 1949-1998.

There are two main issues to keep in mind in our analysis of this province-level series. The first issue regards accuracy. For political reasons, the government has historically over-stated production. The 1999 series have been corrected retrospectively to account for contemporaneous reporting errors. For our study, the main concern is that the o□cial national figures overstate actual production. This would lead us to incorrectly overestimate available food per capita in 1959. In principle, this should not be the case since these data were reconstructed precisely to address issues related to historical misreporting.[26] A comparison of contemporaneous reports of grain production and the reconstructed data

starvation rather than succumbing to infectious disease (O'Grada, 2007b).

[26] To the extent that the current government which reports these statics is biased, it would likely be biased in the direction of under-reporting production and over-reporting population so as to preserve the 1959 government's claim of the existence of an aggregate food shortage below per capita subsistence needs.

suggests that the production numbers have been drastically revised downwards. For example, the *People's Daily* in August 1, 1958, claimed that"Rice production exceeded 7500 kg per mu (0.067 hectare)" for a county in Hubei province. The revised statistics report that actual grain output in that province was closer to being 120 kg per mu. If we aggregate production across provinces, our production data for all thirty provinces is approximately 10% lower than the aggregated production from 21 provinces in the 1989 Ministry of Agriculture series used by Li and Yang (2005). This is consistent with the notion that during the ten years between when these two series were published, the National Bureau of Statistics (NBS) made a sincere effort to revise past production numbers.[27] To the best of our knowledge, this is the most conservative historical production data that has ever been used in a scholarly study of the famine or the GLF era.

The second issue regards the completeness of the province-level data. Provinces for which production could not be accurately revised such as Sichuan in 1959 have been dropped from the sample. In non-famine years, Sichuan produces approximately 16% more grain per capita than the average province. This means that our calculation of aggregate production per capita in 1959 is much lower than true production per capita. The series also does not report production or mortality rates for Tibet in 1959.

The national historical data on population are based on a series recently released by the *China Population Information and Research Center* (CPIRC) in 2000. The main concern with government reported data on population is that it understates population losses. For political reasons, government officials may have wished to understate the famine severity. The CPIRC series takes into account the retrospectively corrected mortality data (see below) and fertility changes that can be observed in famine year birth cohort sizes from later population censuses. We believe that the population data is reasonably accurate. Our estimates for food need in 1959 should not be affected even if these data still understate population losses from the famine because famine deaths mostly occurred in 1960.[28]

The CPIRC series only report aggregate population. To calculate caloric needs, we use the sex and age distribution from Coale (1981) which is based off of the *1954 Population Census*. We assume that the population had the same sex and age distribution as in 1954 for all years in our sample. See Coale (1981) for details on the quality, collection, and subsequent corrections of this data. This should be a reasonable estimate for the years close before and after 1954. But for years after the famine began, 1960 onwards, this becomes increasingly inaccurate, especially since the famine killed disproportionately more young children and elderly. However, this is not crucial for our study, which focuses on whether production before the famine began in 1959 was sufficient for aggregate population needs.

Historical data on mortality rates (deaths per 1,000) are also published by the CSDM50

[27]Much of the recent revisions have been made possible by the uncovering of contemporaneous reports of production that were not exaggerated and not published in the past. Many of these re-discovered collective reports can be found in the multi-volume government publication *Villages for Thirty Years* (Wang et al, 1989). The NBS uses these to estimate the amount of exaggeration and to make projections across similar regions. The details of the method of revision is not made public.

[28]For the years 1960 and 1961, such understatement would cause us to overestimate population food need and overestimate any aggregate food shortages. Therefore, it would bias against our finding that there was no shortage.

series. The main concern here is that the government understated mortality. Famine induced mortality numbers vary between 16.5 million (Coale, 1981) to 30 million (Banister, 1987) due to different estimation methods (e.g. 18.5 million in Yao, 1999, 23 million in Arid, 1982 and Peng, 1987 and 29 million in Ashton et al., 1984). Our mortality data, which does not report mortality rates in 1959 for Tibet, Sichuan and Hainan due to the NBS's inability to provide accurately corrected mortality rates, show that mortality for the remaining regions during the years 1959-1961 sum to approximately 21.5 million individuals. Since most scholars of the famine believe that Tibet and Sichuan experienced very high famine mortality, an estimate of 21.5 million when these provinces are excluded suggests that our mortality data is very similar to the higher estimates by famine scholars

We plot the average mortality rates over time in Figure 1. It shows that over the fifty years of the New Communist regime, there was a strong secular trend such that average mortality rates declined from approximately 15 per 1,000 to approximately a third of that, five per 1,000. The data show that this decline was not strictly monotonic and that there were occasional increases of up to 10% relative to the previous year's mortality rates (e.g. in 1958, 1964, 1972, 1990). However, none of these increases are close in magnitude to what occurred in 1960, when mortality rates almost doubled from approximately 11 per 1,000 in 1958 to peak in 1960 at approximately 22 per 1,000. This is consistent with historical accounts which place the time of the most severe mortality rates during January and February of 1960. Mortality rates return to trend in 1962.

Table 2 Panel A describes the province-level data. It shows that on average, a province has a population of approximately 29 million. The mortality rate in 1960 was more than double the sample average. Excluding Sichuan and Tibet, an average province produced 5.3 million tons of grain in 1959. Per capita production in 1959 was approximately 252 kg per person.

3.2 Retrospectively Constructed Measures of Famine and Production

Since we cannot observe production and mortality rates during the famine years at the county-level, we supplement the province-level historical data with proxies of famine severity and grain production using retrospectively measured and imputed data.

We proxy for historical production at the county-level with data on suitability for grain cultivation as predicted by natural conditions from the FAO.[29] This measure of suitability is based purely on the biophysical environment of a region and it is not influenced by which crops were actually adopted in an area. Factors that are easily affected by human actions, such as soil pH, are not parameters in this model.[30] The data on suitability is available at a 50 km×50 km grid cell level, where one can choose the level of agricultural inputs on which to base the calculation. Our chosen level of inputs allows for rain-fed irrigation but no heavy machinery or chemical fertilizers since GLF policies forbade chemical fertilizers

[29]The data are the result of over twenty years of research and are the product of a joint collaboration between the FAO and the International Institute for Applied Systems Analysis (IIASA).

[30]Nunn and Qian (2009) provide a detailed description of the construction of this data and how to calculate suitability measures at the regional level from this data. We follow their method.

and since the use of heavy machinery such as tractors would have been unlikely in this era. We aggregate grid-level data to the county data as follows. The grid-level data reports the predicted amount of output of rice and wheat. If a grid can produce 40% or more of the maximum possible output for any grid, then we code it as "suitable". The suitability measure at the county-level is the fraction of grids within a county that is suitable. We use this measure for the sake of computational ease.[31] Since procurement targets treated rice and wheat similarly, our measure of suitability is the union of land that is suitable for either rice or wheat within each county. To get a sense of the county-level agricultural suitability data, Appendix Figures A2A and A2B present maps that overlay county-level boundaries with the grid level suitability measures for rice and wheat, respectively. Table 2 Panel B describes the county-level data. It shows that on average, 14-15% of land is suitable for cultivating rice or wheat.

For famine severity, we use birth cohort size as measured in the *1990 Population Census*. A smaller birth cohort size during famine years reflect a more intense famine. This data has the advantage that it allows us to disaggregate down to the county-level and therefore capture much more of the variation in famine. We can also split the data into agricultural and non-agricultural households. Non-agricultural households live in small cities and towns, often in the same county as agricultural populations, who live in villages surrounding the towns. Important for our study is the fact that only agricultural households face grain procurement. Non-agricultural households receive grain subsidies from the government. These categories were first assigned during the 1950s. It is very di□cult for households to transition from agriculture to non-agriculture. One caveat to using birth cohort size to measure famine severity is cross-region migration. The Census does not report region of birth. We restrict the sample to households who report as living in the place they are reporting from for at least five years. This excludes approximately 5% of the sample, most of which are amongst non-agricultural households. Note that because strict migration policies made it extremely di□cult for rural individuals to move, we interpret our sample as people who are living in their county of birth (West and Zhao, 2000).[32] The majority of the little migration that did occur was mostly for non-agricultural households. Therefore, the empirical analysis focuses on agricultural households and the results for non-agricultural households should be interpreted cautiously.

The county-level sample we construct is a balanced panel of birth cohorts of 1,454 counties and 36 birth years (1930-66) for agricultural households, and 1,414 counties

[31] Moderately changing the threshold does not affect the estimates. Using county-level production data from the 1997 Agricultural Census shows that our measures of suitability are highly correlated with actual production. The correlation across counties is approximately 0.7 and statistically significant at the 1% level. To assess whether our suitability data are good proxies for historical production, we can aggregate the measures to the province-level to show that suitability is also a good predictor of production at that more aggregate level. These estimates are omitted for brevity. They are available upon request.

[32] West and Zhao (2000) survey studies on migration in China. There is broad consensus that migration was largely controlled until very recently, and most of the migration that did occur were across urban areas, which would not affect this study. In principle, it is possible that some rural regions at the time of the 1990 Census Renumeration may have contained urban youths were moved from cities to rural areas during the Cultural Revolution (1966-76). However, there have been no accounts to suggest that such movement correlated with famine intensity.

and 36 birth years for non-agricultural households. The latter is smaller because not all counties have non-agricultural populations. Note that unlike the province-level analysis on mortality which spans the years 1949-98, we end the sample for the county-level analysis on cohort size in 1966 when the cultural revolution began. This is to avoid confounding factors that could have influenced fertility but are unlikely to influence mortality (e.g. family planning policies). Similarly, the sample on county-level birth cohort extend back to 1943 whereas the province-level data only begins in 1949. Table 2 Panel B shows that agricultural households have approximately 3,714 individuals per cohort on average in each county. Famine cohorts are smaller on average, comprising of approximately 3,301 individuals. This is approximately 28% smaller than the cohorts born prior to the famine (1954-57), which contain approximately 4,968 individuals per county. The ratio of the famine cohort relative to the pre-famine cohort is approximately 0.72. If we use this ratio being below one to indicate whether there was a famine, then 85% of the counties in our sample experienced the famine to some extent. The table also shows that famine was more severe for agricultural households than non-agricultural households living in the same county. The ratio of famine cohort to pre-famine cohort is larger in non-agricultural households (0.85) than agricultural households (0.72). Moreover, by this metric, 85% of counties with agricultural households experienced some famine. In comparison, only 65% of counties with non-agricultural households experienced some famine. As we discussed before, if some agricultural households successfully obtain non-agricultural households status, then this observed difference would understate the difference in famine severity between agricultural and non-agricultural households.

To observe aggregate cohort size over time, we aggregate the county-level data to the national level and plot the number of people living from each birth year for agricultural and non-agricultural households in Figure 2. It shows that both agricultural and non-agricultural households experienced a decrease in cohort size close to the famine years, though the drop is much more dramatic for the agricultural population. The drop in cohort size for those born close before the famine reflect the mortality of young children during the famine. The more severe drop for the famine birth cohort (1959-61) reflects infant mortality and more importantly, a dramatic decrease in fertility. In the figure, we plot a projected linear trend for the agricultural households and show that there is a positive linear trend in cohort sizes from 1942 to approximately 1955. Cohort sizes are well below trend for individuals born right before and during the famine as indicated by the vertical lines, though they return to trend after 1961 when the famine is over. Figure 2 shows that the cohort size is smallest for individuals born during the famine (1959-61). To observe the cross-sectional variation in famine intensity, we plot a histogram of the ratio of famine cohort size to pre-famine cohort size for agricultural populations in Figure 3. These show that there is substantial cross-sectional variation in famine intensity.

To assess whether birth cohort size from 1959-61 is a good proxy for famine severity, we compare their trends over time and across provinces to those of the mortality data. For this, we aggregate the Census data to calculate cohort size by birth year and province. The correlation between the percent drop in cohort size and the percent increase in mortality during 1959-61 is approximately -0.65 and is statistically significant at the 1% level. This can be illustrated visually by plotting mortality rates and cohort sizes over time for each

province. Figures 3A and 3B show clearly that for every province that exhibits a spike in mortality rate during the famine in Figure 3A, there is corresponding drop in famine birth cohort size in Figure 3B. However, there are several provinces that exhibit a drop in birth cohort size in Figure 3B for which there is no corresponding spike in mortality rate in Figure 3A (e.g. Guangdong, Henan, Jiangxi, Shandong). Moreover, using the survival measure, we are able to measure famine intensity for the three provinces for which there is no famine era mortality data (e.g. Sichuan, Henan, and Tibet).

These figures suggest that survival in 1990 is a reasonable measure of famine intensity and because it does not suffer from government reporting bias, it is likely to be a more accurate measure. Survival is also likely to be a more sensitive measure of famine as a moderate famine will typically cause affected individuals to delay fertility before it induces mortality.[33] Note that these figures also show that there was substantial variation in famine intensity across provinces.

As we described above, there are several caveats to interpreting the county-level proxies for production and famine severity. However, these data have three key advantages over the province-level historic data. First and most important, they are not subject of systematic government reporting bias. Second, the disaggregated nature of the data allows us to have a larger sample size, capture more of the variation in famine, and therefore obtain more precise estimates. Finally, in the county-level data, we have data on all thirty provinces whereas in the province-level data, we lack mortality data in 1959 for three provinces.[34]

In summary, the empirical analysis will use two data samples. This section has described in detail the advantages and disadvantages of each. The key point is that both

4.1 National Grain Production and Subsistence in 1959

In this section, we discuss our first finding that food production in 1959 exceeded per capita subsistence needs. We compare the historical estimates of national food production to two benchmarks for caloric needs in 1959. The two benchmarks distinguish between the caloric needs for preventing *a decrease in labor productivity* from the needs for preventing *mortality*. Because the majority of famine mortality occurred during the winter following the harvest in the fall of 1959, we focus on the level of production in 1959 only, and we do not consider the additional fall in production in 1960 which occurred after a large proportion of the rural workers had already died or were starving. Note that, a priori, it would not be surprising to find that production in 1959 did not fall below the needs for preventing mortality since aggregate production per capita in 1959 only dropped to the same level as in 1950, a year in which there was no famine.

Table 3 Columns (1) and (2) show the population age and sex distribution in 1954 as reported by Coale (1981). Caloric requirements in Column (3) for working and healthy child development are calculated based on a model published by the United States Department of Agriculture. In Panel A, for adults, we assume that females age 21-50 weigh 120 lbs., females age 51-100 weigh 100lbs. Males age 21-50 weigh 140 lbs., and age 51-100 weigh 120 lbs..[35] We assume that all adults age 21-50 perform a high level of physical activity, and those age 51-100 perform a medium level of physical activity. Caloric needs for staying alive are estimated to be 43% of those in Panel A. This is projected from the assumption that an adult male laborer needs approximately 900 calories to stay alive, which is approximately 43% of the requirement for heavy physical labor.[36] In Panel A, Column (5) shows that the average population caloric need for productive agricultural laborers (or for normal child development) was 1,870.7 calories per day. Panel B Column (5) shows that average need to stay alive is approximately 804.4 calories per day.

Note that this calculation overstates average caloric needs for two reasons. First, we have assumed that the entire adult population works as laborers in agriculture whereas in reality, approximately 20% of the population in 1959 worked in non-agricultural jobs which are less intensive. Second, post-World War II fertility rates were very high. Therefore, relative to 1954, a larger percentage of the population was made up of very young children in 1959, and children need fewer calories than the adults.

Table 4 Column (1) shows that production had increased almost monotonically by approximately 70% from 102 million tons in 1949 to almost 170 million tons in 1958. In 1959, production fell by approximately 13% to 148 million tons. Column (2) shows that population was also increasing during this period. We use the data on population and average population caloric needs from Table 3 to compute population food needs in terms of grain. For this, we follow the Ministry of Health and Hygiene of China in assuming that 1 kg of grain (in the form consumed by the average Chinese worker) provides 3,587 calories. We assume that individuals subsist solely on grain and that each individual consumes the same amount every day of the year. Therefore, a diet of 1,870 calories per

[35] Weights are computed using data from physical examinations from the *China Health and Nutritional Survey* 1989.

[36] See Dasgupta and Ray (1986) for a discussion of caloric needs.

day translates into per capita grain needs of 190kg per year. In column (3), we aggregate the needs for the entire population and report them in units of millions of tons. The estimates show that aggregate food needs had increased by approximately 20% between 1949 and 1959. In Column (4), we calculate the deficit in production as the difference between production as stated in Column (1) and need as stated in Column (3). The estimate show that in 1959, there was no deficit. In fact, there was a 21 million ton surplus. Interestingly, according to our estimated needs, there was a small shortage in 1949, a year from which there were no accounts of famine. This is consistent with the fact that we are most likely overstating caloric needs.

In Columns (5) and (6) of Table 4, we repeat the exercise for the lower benchmark of caloric needs for preventing mortality. These estimates highlight a stark fact: in 1959, production was almost three times as what was needed to avoid mortality in the following year. In other words, there was 98 million tons in surplus of subsistence needs, which was 51 million tons. These patterns are illustrated in Figure 4.

The enormous gap between production and need in 1959 is important when considering the data concerns we described in the previous section. The main point conveyed here–that the fall in production by itself could not have caused the famine absent distribution problems–must be true unless if our data on production in 1959, the most conservative that has been used in any study of the famine, still overstates true production by 200%. This seems highly unlikely.

In conclusion, these results provide evidence against the aggregate supply view of famine and imply that some additional mechanism must have amplified the effect of the reduction in aggregate food production in order to cause a famine that killed 17 to 30 million individuals.

4.2 Regional Grain Production and Famine in 1959

The fact that there should be some significant variation in famine intensity across households naturally follows from our previous section which shows that the total level of food production exceeded per capita subsistence needs, implying that significant inequality in food consumption must have caused the famine. This level of inequality does not only exist between rural and urban households. In particular, rural households retained enough food in the aggregate to prevent mortality even after one accounts for the aggregate level of procurement. Average per capita retention in 1959-60 was almost 195 kg per capita (Li and Yang, 2005; see Appendix Table A1B), more than the 190 kg needed for workers to stay productive and more than twice as the 75 kg needed to stay alive. This suggests that we should find significant variation in famine severity within rural households.

Using regional data on mortality rates and production, we systematically examine the spatial patterns of famine. Table 5 lists the provinces in ascending order of mortality rate in 1960 (which captures deaths in the 1960 winter following procurement in the fall of 1959). Columns (1) and (2) show mortality rates in 1960 and production in 1959. In Columns (3) and (4), we calculate grain production that was in surplus of the two benchmarks used in the previous section. They illustrate two stark facts. First, three of the four regions that produced less than what was needed for laborers to be productive

(the three municipalities) also experienced three of the lowest mortality rates (see Column (3)). A striking fact is shown in Column 4. Local production did not fall below the level needed to avoid starvation in *any* province in 1959. This reinforces the finding in the previous section that aggregate production did not fall below subsistence needs.

To investigate the cross-sectional relationship between per capita production and mortality rates more systematically, we estimate the correlation between the natural logarithm of per capita production in province p and year t and the natural logarithm of the mortality rate in that province the following year.

$$LnMortality_{p,t+1} = \beta lnGrainpc_{p,t} + \varepsilon_{pt} \quad (1)$$

We separately estimate this relationship for the famine years (1959-61) and the non-famine years (1949-58, 62-98). The estimate is shown in Table 6 Columns (1) and (2). They show that during the famine years, per capita grain production was positively correlated with mortality rates. The estimate implies an elasticity of 0.2. It is statistically significant at the 5% level. Importantly, this is a reversal from the correlation in normal years, when higher per capita production is correlated with lower mortality rates. The estimate implies an elasticity of -0.18 and is statistically significant at the 1% level.

To assess whether these two estimates are statistically different from each other we pool the data.

$$LnMortality_{p,t+1} = \beta(\ln Grainpc_{p,t} \times FamineDummy_t) + Faminedummy_t + \varepsilon_{pt} \quad (2)$$

Mortality rates in province p and year t+1 is a function of: the interaction term between the natural logarithm of per capita grain that is produced in that province, $\ln(grainpc)$, and a dummy variable for the famine years of 1959-61, $Faminedummy_t$; and the famine years dummy main effect.

Column (3) of Table 6 estimates this relationship and shows that the estimate of the interaction effect is statistically significant at the 1% level so that the difference in the coefficients estimated in columns (1) and (2) is significant. In Column (4), we control for government expenditures on health and education, which we interpret as a proxy for public goods.[37] The estimates show that this is negatively correlated with mortality. Adding this control reduces the magnitude and significance of the coefficient on per capita grain production, since regions with higher average per capita production also have better public goods provision. However, the estimated interaction effect of per capita grain production and famine years dummy is unchanged in magnitude and still significant at the 1% level. In both columns (3) and (4), the sum of the main effect of per capita production and the interaction effect of per capita production and a dummy for famine years is positive, approximatley 0.22, and statistically signficant at the 5% level. Therefore, the reversal in the correlation between per capita production and mortality rates during the famine years is statistically signficant.

As we described in Section 3, there are many concerns over the quality of the province-level historic data. To address this issue, we conduct a supplementary analysis at the

[37]This data is reported in the CSDM50.

county-level using survival data as measured by birth cohort size from the *1990 Population Census* and using a proxy for grain production measured as the suitability for cultivating rice or wheat as predicted by time-invariant natural conditions. This supplementary analysis has three major advantages over the province-level analysis. First, the disaggregated nature of the data allows us to capture much more of the variation in famine. Second, the survival data from the *1990 Population Census* can be divided into agricultural households who were subject to grain procurement by the central government, and non-agricultural households who were not taxed and in contrast received grain subsidies. Finally, and most importantly, the data is not subject to concerns of systematic government misreporting. Therefore, the supplementary analysis can be viewed as a robustness check for the provincial historic analysis.

The main estimating equation where we examine the cross-sectional relationship between the natural logarithm of birth cohort size and a county's suitability for grain production is the same as equation (1), except now we use an unnormalized measure of birth cohort size as the dependent variable and we control for the natural logarithm of each county's average cohort size (over time) on the right hand side. This additional covariate allows us to control for a proxy for the population of each county on the right hand side in order to scale each observation by its relevant population. This is important since we are interested in comparing these results to the province-level correlations which document the structural relationship between mortality *rate* and production *per capita*. Given the absence of these exact measures at the county level, it is important to control for a county's average population which can be proxied by average cohort size on the right hand side.[38]

Table 7 Columns (1) and (2) show the estimates for famine birth cohorts (born 1959-61). Like the provincial level results, they show that the correlation is reversed. For these cohorts, grain suitability is negatively correlated with cohort size. Taken literally, these estimates imply that increasing suitability by one standard deviation (0.26) is associated with a 2% smaller cohort size on average across China. In column (2), we address the possibility that political economic factors which may vary across provinces can affect cohort sizes by adding controls for province fixed effects. The estimate shows that within provinces, a one standard deviation increase is on average correlated with a 6% reduction in cohort size. All of these estimates are statistically significant at the 1% level. Column (3) repeats the estimates for the non-famine birth cohorts (born 1943-58 and 1962-66). It shows that grain suitability is positively correlated with cohort size. Increasing suitability by one standard deviation is on average associated with a 2.4% increase in cohort size. In column (4), we address the possibility that political economic factors which may vary across provinces can affect cohort sizes by adding controls for province fixed effects. As with the famine cohorts, the estimate shows that the relationship is more stark within provinces.

These estimates support the province-level estimates. As with those estimates, we can assess the statistical significance of the difference between the famine and non-famine years as well as improve the precision of the estimates by pooling the data and estimating

[38]For our panel estimates, we can allow average cohort size to have time varying effects by interacting it with time dummies. This does not change the estimates. Therefore, they are excluded for brevity.

the interaction effect of grain suitability and a dummy variable for being born during the famine. For interest, we divide the sample into agricultural and non-agricultural households. For brevity and to control for differences in regional political economic factors, we focus on the results with province fixed effects.[39] For comparison with the province-level estimates in Table 6, we first show the estimate when controlling for a dummy variable indicating that a cohort is born during the famine (Table 7 Column 5). In column (6), we control for birth year fixed effects. The two sets of estimates are very similar. They show that controlling for province-level fixed effects, grain suitability is on average positively correlated with birth cohort size for agricultural households. However, for famine birth cohorts, the correlation reverses and is negative. The estimates are statistically significant at the 1% level.

To further isolate the effect of grain suitability from other factors that could vary across regions, Column (7) controls for county fixed effects. This addresses the possibility that there is variation in factors that could affect cohort size at the county-level which is uncorrelated with grain production (e.g. the number of party leaders, availability of public goods), and it is mechanically equivalent to the estimation of Columns (5) and (6) if one constrains the coefficient on average county cohort size to be equal to one.[40] The estimated interaction effect is smaller in magnitude those in Columns (5) and (6), which is consistent with the belief that there was much local variation in factors that could affect cohort size (or famine intensity). However, it is still negative and statistically significant a the 1% level. The estimate shows that for famine years, increasing suitability by one standard deviation was associated with a 5% reduction in cohort size relative to normal years.

Columns (7)-(9) repeat the estimation for non-agricultural households who were not subject to agricultural procurement. They show that the reduction in cohort size during famine years is much smaller than for agricultural households when we control for province fixed effects. However, when county fixed effects are introduced, there is no correlation between cohort size and local grain suitability. Note that because of migration amongst urban populations, these results should be interpreted very cautiously.

The estimates in Table 7 provide a broad sense of how much of the variation in famine intensity can be explained by differences in production. The R-squared for the regressions Column (1) is 0.81 and suggests that approximately 81% of the variation can be explained by differences in production. This means that regional differences in productivity in 1959 are important for explaining the geographic variation in famine severity.

The large sample size provided by the disaggregated county-level data allows us to examine the correlation between grain suitability and cohort size in more detail. Specifically, we can examine whether the reversal in the positive correlation between grain suitability and cohort size coincides with the timing of the famine. We estimate the relationship between cohort size and grain suitability for each birth year separately as in the following equation. For this exercise, cohorts born before 1943 are collapsed into one reference group.

[39] The estimated interaction effects with no province or county fixed effects are nearly identical to those with province fixed effects. They are available upon request.

[40] Since average cohort size is time invariant, it is omitted from this specification.

$$\ln(cohortsize_{it}) = \sum_{s=1943}^{1966} \beta_s(grain\_suit_i \times 1 \bullet (biryr_t = s) + \gamma_i + \delta_t + \varepsilon_{it}, \quad (3)$$

The natural logarithm of the cohort size of individuals born in year t in county i, $\ln(cohortsize_{it})$, is a function of the following variables: the interaction terms between the fraction of land that is suitable for rice or wheat production in county i, $grain\_suit_i$ and dummy variables $biryr_{st}$ which equals 1 if $s = t$ and equals 0 otherwise; county fixed e□ects, γ_i; and birth year fixed e□ects, δ_t. The reference group is comprised of individuals born during 1930-1942. This group has all of its interaction terms dropped. All standard errors are clustered at the county level. The inclusion of year fixed e□ects controls for secular changes in fertility and mortality that may a□ect cohort sizes. The inclusion of county fixed e□ects controls for time-invariant di□erences between counties. For example, counties that are more suitable for grain cultivation are also typically richer and provide better health care, and this may cause these counties to have larger cohorts or to be more resilient to negative shocks. Note that because the coe□cient on grain suitability is interacted with a year dummy, even with the addition of county fixed e□ects, these regressions continue to exploit the cross-regional variation in log cohort size as our previous regressions. As the descriptive statistics suggest, most of the reduction in cohort size occurs for individuals born close before and during 1959-1961 (see Figure 2). Our analysis thus predicts that β_t should be negative for those years so that the cross-regional reduction in cohort size is negatively correlated with grain suitability in these years.

The coe□cients and their 95% confidence intervals are plotted in Figure 5A. (They are reported in Appendix Table A2). It shows that for those born many years before the famine, cohort size is positively correlated with grain suitability. It is only for those born close before or during the famine that cohort size is negatively correlated with grain suitability. For interest, we estimate the same equation for the sample of non-agricultural households. The coe□cients and their standard errors are shown in Appendix Table A2 Column (2). The coe□cients are plotted in Figure 5B together with the estimated coe□cients for agricultural households. The figure shows that for cohorts born many years before the famine and after the famine, the correlation between cohort size and local grain production is positive and similar between the two types of households. However, for cohorts born close before and during the famine, the correlations diverge, and it becomes negative for agricultural households. These results highlight the fact that the reversal in the correlation between grain suitability and mortality is primarily driven by agricultural populations who were subject to procurement, and this is a key factor for understanding the geographic patterns of the famine.[41]

[41] The weak positive correlation between suitability and cohort size for non-agricultural households suggests that non-agricultural households to some extent benefit from being geographically close to suitable agricultural areas from where the grain is procured.

5 The Grain Procurement System

The previous section provides evidence for two findings that point to grain procurement policy as a main driving force of the famine. The first finding that food production in 1959 was sufficient for subsistence implies that the famine could not have been solely caused by the drop in food production, a traditional explanation for why famines occur.[42] It is consistent with Sen's (1981) thesis that historically, famines have not been caused by aggregate food shortages, but instead are caused by the unequal distribution of food consumption. According to this theory, income is negatively correlated with famine severity, implying that more productive farmers should experience lower famine mortality relative to less productive farmers. However, the second finding that regional famine severity was increasing with per capita production in 1959 is inconsistent with this prediction. A likely explanation for the difference is that China was a centrally-planned economy in which many of the market mechanisms studied by Sen (1981) are not in operation; China's food procurement system determined procurement and transfers of food for every region. Therefore, the empirical evidence suggests that certain features of the procurement system must have caused the famine and its surprising spatial patterns.

Historical evidence suggests that a key feature of the centrally planned procurement system was inflexibility due to difficulties in aggregating and responding to information. In this section, we describe the procurement system and document potential structural causes for its inflexibility. Specifically, we argue that inflexibility was a result of the lack of local incentives to truthfully report production, the political pressures to follow rules, and the limited bureaucratic capacity of the central government.

Grain procurement was planned centrally. The central government decided on the production targets each year. These made their way down to regional government officials, who traveled to collectives each spring to announce the expected production (e.g. production targets) for that collective. In the fall, around mid-October and November, procurement would take place. The government's formula for procurement can be seen in policies such as the "Three Fix Policy". In 1956, it stipulated that to "fix" procurement levels for each collective, expected local production levels in 1956 should be based on production in 1955, and subsistence levels of consumption and seed retention should be based on population and production needs.[43]

The main reasons for setting procurement based on expected production is that peasants and local officials were not incentivized to report actual production truthfully. Discussions amongst the top party leadership shows that they were well aware that peasants had a clear incentive to under-report production in order to retain a larger amount of

[42] The view that famine is caused by aggregate food shortages dates back to Malthus (1798).

[43] See Johnson (1998) for a description of the procurement system. Historical grain policies are outlined in public government archives. See http://2006.panjin.gov.cn/site/gb/pj/pjjz/pjjz_detail.php?column_id=2382. The fact that procurement was set based on past production is consistent with the available data on procurement targets and production from the 1980s. They show that procurement targets are predicted by past production and not by current production. To the best of our knowledge historical data on procurement targets from the famine era do not exist and the procurement system in the 1980s used similar rules as the 1950s and 60s.

grain. In addition, they would have wanted to under-report to prevent the government from demanding greater production in the future. Local leaders could share the incentives of the peasants, or could be incentivized by potential political reasons to over-report production (Fairbank, 1985: pp. 305-8). Given that reported information could have been very unreliable, it made sense for the government to condition procurement on historic information.

To a large extent, bureaucrats seemed to have followed the prescribed procurement rules. This was especially true in 1958 and 1959, when political tensions were intensified between Mao and members of the Politburo who did not support his GLF policies. At the height of tensions, Mao purged all moderate political leaders from the upper and middle levels of government, creating an environment where few were willing to report that production in 1959 was lower than expected before the production numbers could be aggregated and presented to Mao in an impersonal manner.[44] In other words, the rules, together with the political pressure to follow them created led to a very inflexible policy.[45]

[44]The political climate in 1959 was extremely tense and most likely caused leaders to follow rules, even those that were likely to prove problematic later. The GLF had been received with cynicism from the very beginning, and its failures and successes were crucial to Mao's political leadership. In December 1958, at a meeting of the Central Committee of the CCP in Wuhan, party leaders refused to fully endorse GLF policies. Following this meeting, Liu Shaoqi replaced Mao, who remained Party Chairman, as the Head of State in early Spring of 1959 (Spence, 1991: pp. 581). Many historians view this as an unwilling back step by Mao. It is therefore predictable that further challenges of the GLF resulted in a strong response from Mao. In July 1959, Mao famously purged Peng Dehuai, a field marshal of extremely high political standing, for criticizing collectivization and other GLF policies and expressing forebodings of famine. These problems of the collective system mandated by the GLF were a source of contention between communist party moderates and hard-liners who backed Mao. However, with the exception of Peng Dehuai, a field marshal who did a tour of the countryside during the spring of 1959, there is no evidence that any top leader ever obtained an accurate picture of the problems of collectivization and the danger of famine. Peng discretely reported these problems to Communist Party Chairman Mao Zedong in a personal letter. The problems he mentioned included reduced incentives to work, a diversion of labor away from agriculture, and over-procurement of grain by mid-level party leaders who were under-pressure to fulfill grain target quotas that had been set too high. Fearing a political revolt against his leadership based on perceived failures of the GLF, Mao used the contents of this letter to purge Peng as a rightist at the historic Lushan conference in July of 1959. Peng was put under house arrest and later executed during the Cultural Revolution. At this conference, the top party leaders made clear that the first year of the GLF was a success and that collectivization was increasing grain harvest more than ever (Becker, 1996, pp. 87-92).) The Lushan conference had important consequences. The removal of Peng was accompanied by a violent purge of all of his supporters amongst top party members as well as any moderate mid-level party leaders who had expressed concerns about collectivization and the dangers of famine (Fairbank, 1985: pp. 303-335; Becker, 1996, pp. 93). It put remaining leaders under enormous pressure to deliver the high targets for grain quotas for the harvest of 1959 in order to not be grouped with the critics of Mao (Spence, 1991: pp. 574-583).

[45]One obvious question of the local leadership during China's Great Famine is why local leaders allowed grain to be procured in 1959 when they knew that this would leave them with less than subsistence needs. One explanation is that political pressure from the central government caused local leaders to be willing to risk falling below subsistence later over being immediately punished for failing to produce enough grain. A complimentary explanation comes from the fact that the New Communist government came to power partly because of their promise of "no more famines". Therefore, in these early years of the new government, local leaders may have naively believed that once people began to starve, they will be given grain replenishments by the central government. We can speculate that a reasonable response for local leaders is to give the government the planned amount of procurement and postpone their plea for grain

An alternative source of inflexibility that is entirely independent of incentive issues is limited bureaucratic capacity together with the centralization of political power. The Standing Committee of around seven Politburo members was the only government organ with the power of making major policy decisions.[46] Policies were decided from the top and implemented by lower level governments. Information on the effectiveness of policies was collected locally, aggregated by the regional government, and then eventually reported upwards to the Standing Committee (Fairbank, 1985: pp. 297-341; Spence, 1991: pp. 542).

Part of the difficulty for a centrally planned regime to govern a country like China was its size. China is the third or fourth largest country in terms of geographic size.[47] Therefore, conditions which determine agricultural production, amongst other concerns of the central government, were very heterogeneous across regions. The poor conditions of China's transportation and communications infrastructure at this time greatly added to the central government's difficulties in obtaining and aggregating information.[48]

In the late 1950s, three factors significantly exacerbated these structural difficulties in administration. First, in order to reduce the budget deficit, the government severely cut expenditure on administration, which declined from 19.3% of total government budget expenditure in 1950 to only 7.8% in 1957 (Eckstein, 1977: pp. 186). Since both China's

---

(and potential punishment) from the central government. This is consistent with accounts of collective kitchens providing large quantities of food even after the smaller fall harvests were realized (e.g., Yang, 1996; Chang and Wen, 1997).

The rigidity of rules and how it caused officials to sacrifice efficiency can be observed in food delivery. Oi (1999) documents that local leaders punctually put harvests by the roadside for pick up even in bad weather causing huge losses sometimes. Presumably, these leaders knew that they would be punished for the lack of punctual delivery but not for bad weather induced losses. Local leaders may have had an additional sense of false security from believing that the decrease in production was not shared by other regions. During the late 1950s, there was a general belief that China was awash with food. This belief came from government propaganda and the high yields in the years before the famine.

See Section 6.2 for a discussion of the implications of politically motivated regional variation under our model.

[46]It controlled 21 provinces, five autonomous regions, and two municipalities, which in turn governed approximately 2,300 county-level governments that supervised over one million branch offices of the Chinese Communist Party (CCP) in towns, villages, army units, factories, mines and schools.

[47]The precise ranking depends on boundary definitions for certain territories of China and the U.S.

[48]Thousands of officials were sent from urban areas to collectives for procurement and information gathering. When they returned to cities, information from each was collected and cumulatively reported to the provincial capital, which aggregated information from across the province and then, in turn, reported it upwards to Beijing. Only then could Beijing have information for the entire country.

Traveling between cities, where information was accumulated and policies made, and rural areas, where the food was produced, was very time consuming. Transportation networks were almost completely destroyed by decades of civil unrest (e.g. the civil war between the Sun-Yat Sen led Guomingtang (KMT) and warlords, 1911-1935; the war with Japan, 1936-1945; the civil war between Communist CCP and Chang Kai-Shek led KMT, 1945-49) and reparations had just begun (Fairbanks, 1987: pp. 278). The most common method of transportation for officials who traveled to rural areas was a combination of riding on government conveyance vehicles, bicycles, and mules. In a country as geographically vast as China, where urban centers were relatively few and geographically concentrated, it could take many weeks to reach an outlying collective. Moreover, rural areas were typically not connected by telecommunications infrastructure. This meant that the central government learned about production figures from rural areas rather slowly.

economy and government expenditures were increasing during this period, these figures suggest that government administration did not grow even though the economy and the scope of central planning had increased substantially. Second, the government lost much of its able personnel from the bureaucracy. Approximately 700,000 of its most educated bureaucrats were purged in 1957 after the Hundred Flowers Movement.[49] Moreover, in 1958, Mao actually abolished the State Statistical Bureau, which meant that there were no statisticians or demographers in 1959 to project national production figures before all of the harvests were procured and aggregated across regions (Fairbank, 1985: pp. 300; Spence, 1991: pp. 580).[50] Third, for political reasons, Mao implemented measures which further decreased the structural flexibility of the system. For example, after the Lushan meeting in 1959, in order to solidify his power, Mao banned the twice-weekly meetings of the Standing Committee and further removed decision-making powers from regional governments, two institutions which helped the leadership to address unexpected shocks. By the end of 1959, the Standing Committee met only once every two months, and the regional leadership had little power for independent decision making (Fairbank, 1985: pp. 303).

To summarize, many factors hampered the Chinese government's ability to aggregate information and respond to new information. The inflexibility of the Chinese government is similar to the inherent inflexibility in centrally planned economies discussed in the historic works of Von Mises (1921) and Hayek (1946), and in the theoretical work of Weitzman (1974).

6 Model of Procurement

This section presents a simple model to determine whether the inflexibility of central planning as we have described in the previous section, could have, by itself, generated a famine with spatial patterns consistent with China's Great Famine. The model is also useful for understanding the contribution of additional factors (i.e., misreporting of production, miscalculation of production, preferential treatment of certain regions) to the famine. Moreover, it allows us to interpret the merits of the Chinese procurement policy relative to the alternative central planning policy of fixing prices.

6.1 Model

We consider procurement policy in an environment in which different regions produce different quantities of food. A key feature of our environment is that all regions are subject

[49] In 1957, in order to fight off criticism from intellectuals during the *Hundred Flowers Movement*, the leadership promoted the anti-rightist campaign, where as many as 700,000 intellectuals (e.g. high school graduates and above) were removed from government positions, and where some were sent to labor camps. This did not directly affect agricultural production, which did not involve the labor intellectuals, but it crippled the bureaucracy.

[50] Being branded as a rightist effectively ended the career of the individual. Many were demoted to manual labor jobs for re-education. In extreme cases, individuals were sent to labor camps. Since most intellectuals lived in urban areas, this did not have a direct affect on agriculture.

to an aggregate production shock that reduces food production. The government can procure food from some regions and subsidize other regions with food. Given our discussion in Section 5, the government's procurement policy is constrained by inflexibility. In other words, the government's redistributive policy must be chosen prior to the aggregate shock and it cannot adjust to the aggregate shock. This constraint on policy captures the fact that the Chinese government could not easily aggregate and respond to new information because of institutional frictions. Given this constraint on policy, our model is therefore in the spirit of Weitzman (1974) who studies the optimal choice of quantities in a centrally planned economy in which quantities cannot respond to aggregate shocks.

More formally, the economy consists of M rural regions labeled by $i = \{1, ..., M\}$ and N urban regions labeled by $i = \{M + 1, ..., M + N\}$. Every region is populated by a mass p_i of identical households which have a stochastic per-capita agricultural endowment $e_i(s) \geq 0$ which depends on the aggregate shock $s = \{H, L\}$ which can be low or high. Let $\Pr\{s = H\} = 1 - \Pr\{s = L\} = 1 - \mu \in (0, 1)$, the probability that a food reducing aggregate shock is avoided. Let $e_i(H) = \widehat{e}_i$ and $e_i(L) = \widehat{e}_i - \sigma_i$. $\widehat{e}_i$ parameterizes the productivity of a region since a higher $\widehat{e}_i$ corresponds to a higher level of food production per capita. σ_i captures the volatility of production in region i. Urban regions do not produce any food so that $e_i(s) = 0$ for $s = \{H, L\}$ if $i \in \{M + 1, N\}$. We consider the economies subject to the following two assumptions regarding the production process:

Assumption 1 $e_i(L)$ is strictly increasing in $\widehat{e}_i$.

Assumption 2 σ_i is strictly increasing in $\widehat{e}_i$.

Assumption 1 states that more productive regions produce more food per capita during both the high and the low shock. Assumption 2 states that more productive regions experience a higher variance in production (i.e., a sharper drop during the aggregate food downturn). One can easily verify that the historical evidence on production supports the validity of these two conditions. The correlation between per capita production in 1959 and the average per capita production from the previous four years is 0.85. The correlation between the rank of per capita between 1959 and the previous four year average is 0.75. Both are statistically significant at the 1% level. These correlations are consistent with Assumption 1. Similarly, the correlation between the absolute vale of the magnitude of the per capita drop in food production in 1959 and the average production from the previous four years is 0.14 and statistically significant at the 1% level. This positive relationship indicates that the drop in production per capita was sharper for more productive regions, which is consistent with Assumption 2.

Every household in region i produces food $e_i(s)$ and is subject to a level of food procurement τ_i, where a negative value of τ_i corresponds to a food subsidy. A household's level of food consumption $c_i(s)$ therefore satisfies

$$c_i(s) = e_i(s) - \tau_i \text{ for } s = H, L. \tag{4}$$

Note that while food consumption and production depend on the aggregate shock s, the level of procurement τ_i *does not depend on the aggregate shock*. This assumption

is motivated by our discussion in Section 5 where we argue that a central feature of the Chinese procurement is its inflexibility. The government could not easily aggregate and respond to information, making it di□cult for levels of procurement to respond to new information. [51] Note that since the shock σ_i equals 0 for urban regions, the level of consumption $c_i(s)$ is independent of the aggregate shock for these households. The government runs a balanced budget and does not engage in any public spending so that its budget constraint is

$$\sum_{i=1}^{M+N} p_i \tau_i = 0. \tag{5}$$

from the right hand side of equation (4) where $\delta_i \geq 0$ is a region-specific transport cost.[52]

The government is utilitarian. Therefore, the government chooses a set of taxes and transfers to maximize the following object:

$$\sum_{i=1}^{M+N} p_i \left((1-\mu) \pi (c_i(H)) \chi + \mu \pi (c_i(L)) \chi \right) \ . \tag{6}$$

$\pi(c_i(s))$ corresponds to the probability of survival as a function of consumption $c_i(s)$ and χ corresponds to the value of life. We assume that $\pi(\cdot)$ is continuously di□erentiable, strictly increasing, and strictly concave, so that the probability of survival rises with food consumption, but this is subject to diminishing returns.[53]

The government knows the productivity $\widehat{e_i}$ and the volatility σ_i of each region and the probability of the aggregate shocks. It is clear in this environment that if the government could condition procurement τ_i on the shock s, then it would provide all households with the same level of food consumption conditional on the shock. In such an environment, there would be no cross-regional variation in mortality in response to an agricultural shock.[54]

In our environment, such a redistributive policy is not possible because procurement cannot respond to the shock. More specifically, consider a hypothetical procurement policy $\tau = \{\tau_i\}_{i2f1,M+Ng}$. Given Assumption 2 and equation (4), it is clear that the variance in

[51] We do not distinguish between the different factors which could underlie this inflexibility. Our model takes the extreme view that the policy does not respond to the shock. Nonetheless, our main results hold more generally in a setting in which the government can respond to a noisy signal about the state of the economy. Details available upon request.

[52] One can easily incorporate transport costs in our framework without changing our results. For instance, one can subtract $\delta_i \tau_i^2/2$.

[53] One can easily incorporate in our framework a motive for the government to save or deplete its current stock of food by ignoring the food portion of (6.1) and adding an additional term in the government objectives:

$$\mu V \left(\sum_{i=1}^{M+N} p_i \left(e_i(H) - c_i(H) \right) \right) + (1-\mu) V \left(\sum_{i=1}^{M+N} p_i \left(e_i(L) - c_i(L) \right) \right)$$

for $V(\cdot)$ which is increasing and concave. This refinement does not affect any of our results.

[54] Note that one could easily incorporate the government's potential bias towards the urban elite without changing any of our results since this would correspond to assigning a higher weight to urban regions in the social objective.

consumption for a given region is increasing in $\widehat{e}_i$ (i.e. more productive regions experience a higher variance in production). Thus, under an inflexible procurement policy, it is not possible for the government to equalize consumption across regions in all states of the world. More specifically, the government in choosing the optimal policy solves the following program:

$$\max_{\tau} (6) \text{ s.t. } (4) \text{ and } (6.1).$$

Letting ψ correspond to the Lagrange multiplier on constraint (6.1), the first order conditions to the government's program yield:

$$(1-\mu)\,\pi^{0}\left(c_i\left(H\right)\right) + \mu\pi^{0}\left(c_i\left(L\right)\right) \;= \psi \;\forall i. \quad (7)$$

Therefore, the government equates the expected marginal utility of food consumption of all households, taking into account that more productive households will inevitably experience a higher variance in food consumption. Equation (7) has some important implications which are summarized in the below proposition. All of the proofs are in the Appendix.

Proposition 1 *(predictions) The optimal policy of the government has the following features:*

1. *Aggregate survival $\sum_{i=1}^{M+N} p_i \pi\left(c_i\left(s\right)\right)$ conditional on $s = \{H, L\}$ is below that implied by an equal distribution of consumption,*

2. *Procurement τ_i is increasing in productivity $\widehat{e}_i$, and*

3. *Regional survival $\pi\left(c_i\left(s\right)\right)$ is decreasing in productivity $\widehat{e}_i$ if $s = H$, and regional survival $\pi\left(c_i\left(s\right)\right)$ is increasing in productivity $\widehat{e}_i$ if $s = L$.*

Corollary 1 *The variance of mortality $Var\left(\pi\left(c_i\left(s\right)\right)\right)$ is rising in productivity $\widehat{e}_i$.*

The first part of Proposition 1 states that the intensity of famine is higher under optimal government policy relative to that implied under the equal distribution of food, which clearly minimizes mortality. This result follows from Assumption 2 which implies that an equal distribution of food consumption is impossible under all shocks and an inflexible procurement policy.[55] This result suggests that even under the optimal procurement policy, it is possible that some individuals may die of famine as a consequence of the inflexibility of such a policy.

The second part of Proposition 1 states that procurement is increasing in productivity $\widehat{e}_i$, so that more productive regions experience a higher procurement tax relative to less productive regions. This follows from the fact that by Assumption 1, more productive regions produce more in all states of the world, so that a government wishing to redistribute towards the less productive regions should procure more food from these more productive regions.[56]

[55] While we discuss our result in terms of aggregate mortality, one can easily discuss this result in terms of the fraction of the population below some arbitrarily chosen per-capita famine threshold c^*.

[56] See Footnote ?? for empirical evidence supporting this result.

This third part of Proposition 1 states that during a food production boom, mortality and productivity are negatively correlated across regions. In contrast, during a food production downturn, mortality and productivity are positively correlated across regions. This prediction is consistent with our empirical findings regarding the spatial distribution of famine intensity. Intuitively, recall that more productive regions have more volatile production (Assumption 2) though all regions are subject to an inflexible and non-volatile procurement policy. Thus, more productive regions experience more volatile consumption, a result which is stated formally in Corollary 1. Since the government cares about all households equally, it follows that households subject to more volatile consumption experience relatively higher consumption during the food production boom and relatively less consumption during the food production downturn, leading to the spatial patterns of mortality.[57] For an illustration of the mechanics of this model, recall the simple stylized example presented in the Introduction and Table 1.

Note that the model has several implications that we can verify with the data. First, the model predicts that controlling for region fixed effects, higher production implies lower mortality, even during the famine years. The intuition is simple. Taken literally, our model argues that food consumption is the difference between expected production and procurement, two factors which are largely fixed over time. The positive correlation between production and mortality during the famine years is caused by the fact that regions that typicaly produce more produced less relative to their average production during the shock. Therefore, conditional on region-specific average production and procurement (e.g. controlling for region fixed effects), it must still be the case that higher production is correlated with lower mortality. In other words, if we re-estimate equation (2) with province fixed effects, then the sum of the main effect on per capita grain production and the interaction effect of per capita grain production and a dummy for the famine years should become negative. Indeed this is the case, the joint statistic changes from 0.22 (Table 6 Column 3) to -0.12 when province fixed effects are added. However, the latter is not statistically significant. Second, the model suggests that regions that have more volatility in grain production will also have more volatility in food consumption. To test this, we collect historic data on weather conditions from scientific weather stations. We estimate the standard deviation in average monthly rainfall, a key determinants of grain production, and the average standard deviaton in the natural logarithm of cohort size for each county. We find that the standard deviation of precipitation and cohort size are postively correlated across counties and statistically significant. It is consistent with the model.

6.2 Additional Institutional Mechanisms

Our model shows that even in the absence of additional institutional factors which may have contributed to the famine, the optimal procurement policy which cannot adjust to aggregate shocks can both amplify the mortality increase from a food production downturn and can lead to the spatial pattern of mortality which are observed in the data. In this

[57]If the government is biased towards the urban elite, this prediction will hold for the sample of rural regions but not for the comparison of urban versus rural regions.

section, we discuss how additional institutional factors may have contributed to the famine in the context of our model.[58]

First, we explore whether misreporting could have contributed to the famine beyond the mechanisms illustrated in the model (i.e. cause the government to condition procurement on expected rather than actual production). In a dynamic extension of our environment, one can imagine that the government estimates the productivity $\widehat{e_i}$ of each region based on the history of reports of production. In such an environment it is clear that a tendency by officials to over-report in previous years may cause the government to over-procure from certain regions in the current year, and this can amplify the rise in deaths due to an aggregate food production downturn. More generally, one can imagine that incompetence on the part of the government could cause it to miscalculate many of the parameters of the model. For instance, if the government underestimates region-specific food production volatility, σ_i, or the probability of a food production downturn, μ, then one can show that that these types of systematic biases by the government could serve to reinforce our conclusions since they could result in over-procurement. However, in the absence of the constraint of an inflexible procurement policy, such biases on their own would not generate the empirical spatial distribution of mortality.[59]

A second issue to consider is the possibility that the government was too committed to high levels of grain procurement and this caused the aggregate procurement level to be very high during the famine. This could have been the case historically for two reasons. First, it is possible that the government wished to send the grain abroad in order to use the revenue to invest in industry. Second, the government may have wished to procure more and more grain from rural regions as a means of providing incentives for farmers to raise production levels and productivity.[60]In the context of our model, the motive to procure grain would amplify even further the mortality consequences of the reduction in food production, since this is equivalent to increasing the Lagrange multiplier ψ in (7) which represents the shadow value of food consumption.[61] However, a commitment to high levels of procurement alone would lead to a uniform distribution of mortality, and not to the spatial inequality that we observe in the data.[62]

[58]In particular we consider the effects of misreporting of production, government incompetence, government commitment to high procurement levels, and political favoritism towards particular regions.

[59]A natural question is whether misreporting alone with a hypothetically fully flexible procurement policy could account for the spatial distribution of famine. For this to be true, one would have to assume that for some behavioral reasons, region leaders who over-report during the food production downturn also under-report during the food production boom and additionally that the government is unaware of this misreporting bias.

[60]For example, the government may have been trying to learn to aggregate capabilities of each rural region by procuring more and more over time. In addition to potentially causing the downturn in production, the theory proposed by Li and Yang (2005), high levels of procurement could have exacerbated the impact of the downturn by creating large inequalities in food consumption.

[61]In fact, the government may have recognized that the high procurement levels may have contributed to the famine since the procurement rate declined significantly following the famine (see Appendix Table A1) though the system itself remained inflexible throughout the next three decades.

[62]Empirically, our discussion in Section 4.2 also suggests that even after one takes into account aggregate procurement levels, there was enough food in the aggregate to prevent famine, which suggests that aggregate procurement levels alone cannot explain the famine.

A third issue to consider is the possibility that the government favored certain regions over others and that this may have contributed to the famine. More specifically, one could interpret the self-interest or malevolence of politicians as manifesting itself in favoritism of some regions over others so that some regions would receive more weight in the social welfare function. For the famine, this means that the government favored urban areas over rural areas.[63] In the context of our model, this could lead to further inequality in food consumption and a higher famine intensity, particularly if this favoritism is towards cities over rural regions.[64] It is important to note that favoritism on its own would cause some regions to consistently experience higher mortality both during a food production boom and during a downturn. It cannot explain the reversal in the correlation between food production and mortality between good and bad years that we find in the data.[65]

The final issue to consider is the extent to which transport costs contributed to the famine. Theoretically, if transport costs are high, then they could generate a famine by making it very di□cult for the government to transfer food from high food productivity regions to low food productivity regions. In the context of our model, the addition of transport costs can be easily introduced as an extension. What the extension implies is that if the government faces transport costs alone, then regions with the higher levels of production would consume more food and hence experience lower famine intensity than the regions with lower levels of production. This is because the presence of transport costs makes it di□cult to equalize food consumption across regions so that the government cannot transfer as much food to the low productivity region as it would like. The implied patterns of transport cost frictions are therefore inconsistent with the patterns in the data. Therefore, while transport costs may have amplified the extent of the famine, they must have done so in conjunction with the inflexibility of government policy.

6.3 Counterfactual Exercise: Fixing Quantities vs. Prices

A natural question given our interpretation of this historical episode is the extent to which the Chinese government could have chosen a better policy. More specifically, in the

[63] It is important to recognize that the communist party rose to power with a promise of ending famines in China and that the power base for Mao and the party as a whole was in the rural areas. Too see this, note that the Chinese CCP membership of approximately 5.2 million in 1957 was approximately 70% rural. This is a sharp contrast to the USSR, where CCP membership was approximately 70% urban. Throughout this period, the party leadership in China were aware that no policy which caused the peasants misery would be popular and that China could not politically afford to implement a procurement policy that will cause a famine such as what occurred in the USSR (Spence, 1991; pp. 575-576). Therefore, while one may criticize the government for being callous, it is difficult to believe that the government wanted the famine to occur. The government should have wanted to avoid famine even if simply from the selfish desire of remaining in power.

[64] If the government is very biased towards urban households then it is thus very likely to provide rural households with very low food consumption so that famine is even more severe for these households during the aggregate food shortage.

[65] In principle, one could imagine an environment in which the social welfare function is state dependent, so that during a food production boom, the social planner assigns more weight to the more productive regions, whereas during a food production downturn, the social planner assigns more weight to the less productive regions. Such a setting would generate the empirical spatial patterns of famine even without an inflexible procurement policy.

context of an inflexible central planning environment, the government could have chosen to have redistributed food from farms to cities by paying a fixed price to farmers for this food.[66] This style of policy was used under central planning regimes such as the Soviet Union during the New Economic Policy. In China, it was used in the early 1950s and again from the mid 1990s to today.

In this section, we use the model developed in Section 6.1 in order to discuss the trade-offs a government faces in deciding to use quantity versus price controls since these policies have different implications for which segment of the population bears the burden of the aggregate shocks to food production. In highlighting these trade-offs, we show that a government is better off pursuing quantity controls in the same fashion as the Chinese government if a large fraction of the population is rural and if the heterogeneity in the magnitude of productivity shocks across the rural populations is low.

For this exercise, we introduce a second consumption good to the model to serve as the numeraire for the price of food P. Our exercise is in the spirit of that of Weitzman (1974) who studies the use of price and quantity controls in an inflexible policy setting. As in this work, one can gain some insight into the answer to this question by assuming linear preferences over the non-food good and assuming that the function $\pi(\cdot)$ is quadratic. More specifically, letting $x_i(s)$ represents household i's non-food consumption as a function of the state s, then the social welfare function is

$$\sum_{i=1}^{M+N} p_i \chi \left((1-\mu) \left(\pi(c_i(H)) \chi + x_i(H) \right) + \mu \left(\pi(c_i(L)) \chi + x_i(L) \right) \right)$$

$$\text{for } \pi(c_i(s)) = \begin{cases} 1 - \alpha \left(\overline{c} - c_i(s) \right)^2 & \text{if } c_i(s) \leq \overline{c} \\ 1 & \text{if } c_i(s) > \overline{c} \end{cases}$$

for some parameter $\alpha > 0$.

The government fixes the price of food as follows. It commits to purchasing any quantity of food from rural households at a price P and it redistributes this food to urban households. To finance these purchases, the government taxes the non-food endowment of households. Note that because preferences over non-food consumption are linear, the government does not care about the inequality in non-food consumption from this taxation, so that we can effectively ignore non-food consumption in the government's optimization program. For simplicity, imagine that the government chooses an interior price $P \geq \max_{i \in \{1,M\}} \pi'(e_i(L))$ so that it is sufficiently high that all rural households would choose to sell food to the government in all states of the world.[67] Moreover, to facilitate interpretation, suppose that the implied level of consumption under the optimal policy always satisfies $\overline{c} \geq c_i(s) \geq \overline{c} - \alpha^{-1/2}$ so that the value of $\pi(\cdot)$ is always between 0 and 1. In this circumstance, the first order conditions for rural households would imply

[66] If we allow for two goods and quasi-linear preferences in our model, the utilitarian optimum could be achieved with perfectly competitive markets. For this exercise, we rule out this possibility to examine the less dramatic measure of fixed supplier prices which the Chinese government may have been able to pursue during this time period.

[67] If the government could choose a region specific price, it would choose the same price for all regions since it is utilitarian.

that

$$\pi^0\left(c_i\left(s\right)\right) = P \text{ for } s = \{H, L\} \tag{8}$$

so that all rural households have a level of food consumption that is independent of the aggregate shock and which sets the marginal utility of food consumption equal to the price of food. This means that during the food production boom, they would sell more food to the government, and during the food production downturn, they would sell less food to the government. Consequently, urban households would all have a volatile consumption and would endure the entire risk associated with the aggregate production shock. Interestingly, this is the exact *opposite* situation as in an environment with fixed quantities in which the entire burden of the aggregate production shock is borne by rural households.

By analogous reasoning as in the environment with fixed quantities, optimal policy implies that the first order condition in equation (7) (where ψ must be interpreted as the Lagrange multiplier for the resource constraint of the entire economy). More specifically, the government equates the expected marginal utility of food consumption across households, taking into account that this level of consumption is deterministic for rural households and stochastic for urban households. In addition to treating all rural households symmetrically, the government treats urban households symmetrically, so that they all equally bear the burden of the aggregate shocks.

Proposition 2 *(quantities dominate prices) Expected mortality is lower under fixed quantities relative to fixed prices if and only if the following condition holds:*

$$\left[\sum_{i=1}^{M} p_i / \sum_{i=M+1}^{M+N} p_i\right]\left[\left(\sum_{i=1}^{M}\frac{p_i}{\sum_{i=1}^{M} p_i}\sigma_i\right)^2 / \sum_{i=1}^{M}\frac{p_i}{\sum_{i=1}^{M} p_i}\sigma_i^2\right] > 1 \tag{9}$$

Proposition 2 states that a policy of controlling quantities dominates a policy of controlling prices if the size of the rural population is significantly higher than the size of the urban population (i.e., $\sum_{i=1}^{M} p_i$ is significantly higher than $\sum_{i=M+1}^{M+N} p_i$) and if the cross-sectional variance in the magnitude of shocks σ_i across rural regions is sufficiently low (i.e., $\sum_{i=1}^{M} p_i\sigma_i^2 / \sum_{i=1}^{M} p_i$ is sufficiently low relative to $\left(\sum_{i=1}^{M} p_i\sigma_i \sum_{i=1}^{M} p_i\right)^2$).

The intuition for this proposition is as follows. Imagine for simplicity if all rural regions are identical so that condition (9) collapses to $\sum_{i=1}^{M} p_i > \sum_{i=M+1}^{M+N} p_i$. This means that quantity controls dominate price controls if the urban population is in the minority. To understand this result, note that if the rural households are a majority, then the government faces a choice between having a majority of the population experiencing small consumption fluctuations under fixed quantities versus having a minority of the population facing large consumption fluctuations under fixed prices. The government prefers to let a majority experience the shock because because large volatilities in consumption are extremely costly to the government from a welfare perspective and it is better to pool this risk across rural households.[68]

[68] This insight is related to Weitzman's (1974) result that quantity controls dominate price controls if

To understand why quantity controls dominate price controls only if the cross-sectional variance in the magnitude of shocks is low, imagine for simplicity that rural and urban regions have the same population size so that (9) collapses to $0 > Var(\sigma_i)$. Thus, if rural households are homogeneous, then quantity and price controls are equivalent from a welfare perspective for reasons previously discussed. However, if there is any heterogeneity in the productivity shocks across rural households, then price controls dominate quantity controls. The reason is because price controls make it possible for the urban population to pool all of the differential risk faced by the rural population. For example, if there were two rural regions of equal size, one with a higher value of the shock, σ_i, than the other, then the government would prefer to let half of the population (the urban population) experience an intermediate level of consumption volatility under price controls versus having one quarter experiencing very high volatility and one quarter experiencing very low volatility under quantity controls.[69]

In conclusion, a retrospective evaluation of the merits of the Chinese procurement policy of fixing quantities versus fixing prices relies on two factors. On the one hand, it is clear that the urban population represented a small minority of the population, and this fact provides support for the relative benefit of the procurement policy. On the other hand, the Chinese rural regions were not identical, as is evidenced by the fact that more productive regions experience a larger reduction in total production during the famine. The government could have in principle been able to pool the risk associated with this heterogeneity by fixing a price at which farmers would sell their food to the cities, though this would have come at a cost of volatile mortality outcomes in cities. The extent to which the procurement policy dominated price controls is an important quantitative question for future research.

7 Conclusion

This paper provides an analysis of the institutional causes of China's Great Famine. We provide two pieces of empirical evidence on China's Great Famine: the perhaps unsurprising but important fact that production fall in 1959 by itself could not have caused the famine; and the novel fact that the more productive regions experienced higher mortality, a *reversal* of the negative correlation between mortality rates and food production in non-famine years. We interpret this evidence in the context of a model which shows how a famine can be caused by constrained procurement policy in a non-market economy. Moreover, this model allows us to evaluate the merits of the Chinese procurement policy relative to an alternative central planning policy of fixing prices.

the absolute value of the second derivative of the benefit function with respect to quantity exceeds the second derivative of the cost function with respect to quantity. This is also true in our setting if one interprets the benefit function as the portion of social welfare attributable to the urban population and the cost function as the negative of the portion of social welfare attributable to the rural population. In this light, the relative curvature of each function depends on the relative size of the urban and rural population.

[69]Note that this second effect regarding the distribution of productivity is not present in Weitzman (1974) since he assumes only one producer for each good.

Our analysis leaves open several interesting directions for future research. A natural future direction is to study the geographic patterns of other famines that have occurred in history and to use these patterns to understand the role of policy failures in causing the famine. It would be interesting to understand whether similar mechanisms contributed to the Ukrainian Famine (1932-33) and the North Korean Famine (1992-95). Furthermore, our model leaves open several interesting theoretical questions. Specifically, our model of inflexible government policy, which is inspired by historical evidence and which builds on the model of Weitzman (1974), assumes that government procurement policy cannot adjust to aggregate shocks. An interesting question for future research is to understand why some government policies are more flexible than others and whether concrete policy recommendations can be made during food production declines to avoid famine, both in market and non-market economies.

8 Appendix

Proof of Proposition 1 and Corollary 1

An equal distribution of consumption maximizes (6) but cannot be achieved given constraint (4) and (6.1) by Assumption 2 which proves the first part of the proposition. Consider two regions k and l with $\widehat{e}_k > \widehat{e}_l$. If $\tau_k \leq \tau_l$, then $c_k(s) > c_l(s)$ for $s = \{H, L\}$ by Assumption 1, but given the concavity of $\pi(\cdot)$, this violates (7), which proves the second part of the proposition. If $c_k(L) > c_l(L)$, then by (4) and Assumption 2, this implies that $c_k(H) > c_l(H)$ which violates (7). Therefore, $c_k(L) < c_l(L)$ and satisfaction of (7) implies that $c_k(H) > c_l(H)$, and this proves the third part of the proposition. To prove the corollary, note that $Var(\pi(c_i(s))) = \mu(1-\mu)[\pi(c_i(H)) - \pi(c_i(L))]^2$. Since $c_i(H)$ is rising in $\widehat{e}_i$ and $c_i(L)$ is declining in $\widehat{e}_i$, $\pi(c_i(H)) - \pi(c_i(L))$ is rising in $\widehat{e}_i$, which implies that $Var(\pi(c_i(s)))$ is rising in $\widehat{e}_i$. **Q.E.D.**

Proof of Proposition 2

Under fixed quantities, (7) together with (4) and (6.1) imply that if $i \in \{1, M\}$, then

$$\begin{aligned} c_i(H) &= \sum_{i=1}^{M} p_i(\widehat{e}_i - \mu\sigma_i) / \sum_{i=1}^{M+N} p_i + \mu\sigma_i \text{ and} \\ c_i(H) &= \sum_{i=1}^{M} p_i\widehat{e}_i(\mu + (1-\mu)\lambda) / \sum_{i=1}^{M+N} p_i - (1-\mu)\sigma_i, \end{aligned}$$

and if $i \in \{M+1, M+N\}$, then

$$c_i(H) = c_i(L) = \sum_{i=1}^{M} p_i(\widehat{e}_i - \mu\sigma_i) / \sum_{i=1}^{M+N} p_i \tag{10}$$

This implies that government welfare (ignoring non-food consumption) is equal to

$$1 - \alpha \sum_{i=1}^{M+N} p_i \left(\overline{c} - \sum_{i=1}^{M} p_i(\widehat{e}_i - \mu\sigma_i) / \sum_{i=1}^{M+N} p_i\right)^2 - \alpha\mu(1-\mu)\sum_{i=1}^{M} p_i\sigma_i^2. \tag{11}$$

Under fixed prices, (8) and the resource constraint of the economy implied by the substitution of (4) into (6.1) imply that if $i \in \{1, M\}$, then (10) holds, and if $i \in \{M+1, M+N\}$, then

$$\begin{aligned} c_i(H) &= \sum_{i=1}^{M} p_i(\widehat{e}_i - \mu\sigma_i) / \sum_{i=1}^{M+N} p_i + \mu\sum_{i=1}^{M} p_i\sigma_i / \sum_{i=M+1}^{M+N} p_i \text{ and} \\ c_i(L) &= \sum_{i=1}^{M} p_i(\widehat{e}_i - \mu\sigma_i) / \sum_{i=1}^{M+N} p_i - (1-\mu)\sum_{i=1}^{M} p_i\sigma_i / \sum_{i=M+1}^{M+N} p_i \end{aligned}$$

This implies that government welfare (ignoring non-food consumption) is equal to:

$$1 - \alpha \sum_{i=1}^{M+N} p_i \left(\overline{c} - \sum_{i=1}^{M} p_i(\widehat{e}_i - \mu\sigma_i) / \sum_{i=1}^{M+N} p_i\right)^2 - \alpha\mu(1-\mu)\left(\sum_{i=1}^{M} p_i\sigma_i\right)^2 / \sum_{i=M+1}^{M+N} p_i. \tag{12}$$

(11) exceeds (12) if and only if condition (9) holds. **Q.E.D.**

References

[1] Aird, JS. 1982 “Population studies and population policies in China” *Population and Development Review* 8: pp. 85-97.

[2] Arrow, K.J. “Research in Management Controls: A Critical Synthesis", pp. 317- 327, in Bonini, Jaedicke and Wagner (eds.), Management Controls (New York: McGraw-Hill, 1964).

[3] Ashton, Basil, Kenneth Hill, Alan Piazza, and Robin Zeitz. “Famine in China, 1958-1961.” Population and Development Review 10 (1984): 613-45.

[4] Banister, Judith. China’s Changing Population. Stanford, CA: Stanford University Press, 1987.

[5] Becker, Jasper. Hungry Ghosts: China’s Secret Famine. London: John Murray Publishers, 1996.

[6] Besley, Timothy. “Property Rights and Investment Incentives: Theory and Evidence from Ghana.” Journal of Political Economy 103.5 (1995): 903-37.

[7] Besley, Timothy, and Torsten Persson. “The Origins of State Capacity: Property Rights, Taxation, and Politics.” NBER Working Papers 13028 (2007).

[8] Blayo, Y. “Political events and birth rates in China since 1950.” Population 46.6 (1991): 1589-615.

[9] Brown, Gardner “Renewable Natural Resource Management and Use without Markets” Journal of Economic Literature, Vol. 38, No. 4 (Dec., 2000), pp. 875-914

[10] Browning, Martin “Prices vs. Quantities vs. Laissez-faire” The Review of Economic Studies, Vol. 54, No. 4 (Oct., 1987), pp. 691-694

[11] Burgess, Robin and Donaldson, David (2009) “Can Trade Openness Reduce Real Income Volatility? Evidence from Colonial India’s Era of Famine” MIT Working Paper.

[12] Chang, Gene Hsin, and Guanzhong James Wen. “Communal Dining and the Chinese Famine of 1958–1961.” Economic Development and Cultural Change 46 (1997): 1-34.

[13] Chen, Y. and L-A. Zhou. “The long term health and economic consequences of 1959-1961 famine in China.” Journal of Health Economics 26 (2007): 659-681.

[14] Chen, Paul “Prices vs. Quantities and Delegating Price Authority to a Monopolist” The Review of Economic Studies, Vol. 57, No. 3 (Jul., 1990), pp. 521-529.

[15] Cheng, Pei-Kai et al. The Search for Modern China: A Documentary Collection. New York: Newton, 1999.

[16] Coale, Ansley J. 1981. “Population Trends, Population Policy and Population Studies in China.” *Population and Development Review* 7 (March): 85-97.

[17] Cohen, Charles and Eric D. Werker. “The Political Economy of Natural Disasters.”Journal of Conflict Resolution 52.6 (2008): 795-819.

[18] Cropper, Maureen and Oats, Wallace “Environmental Economics: A Survey” Journal of Economic Literature, Vol. 30, No. 2 (Jun., 1992), pp. 675-740

[19] Dales, J.H.Pollution, Property and Prices (Toronto: University of Toronto Press, 1968).

[20] Demick, Barbara Reflections, “The Good Cook,” The New Yorker, November 2, 2009, p. 58.

[21] Dreze, Jean. The Economics of Famine. Elgar Reference Collection, International Library of Critical Writings in Economics, Cheltenham, U.K. and Northampton, Mass, vol. 101, 1999.

[22] Eckstein, Alexander China’s Economic Revolution. Cambridge: Cambridge University Press, 1977: pp. 186.

[23] Easterly, W., and R. Levine. “Tropics, Germs, and Crops: How Endowments Influence Economic Development.” Journal of Monetary Economics 50 (2003): 3-40.

[24] Eskeland, Gunnar S. and Jimenez, Emmanuel “Policy Instruments for Pollution Control in Developing Countries” The World Bank Research Observer, Vol. 7, No. 2 (Jul., 1992), pp. 145-169

[25] Ellman, Michael. “The 1947 Soviet Famine and the Entitlement Approach to Famines.” Cambridge Journal of Economics 24.5 (2000): 603-30.

[26] Fairbank, John King. The Great Chinese Revolution, 1800-1985: 1800-1985. New York: Harper & Row, 1986.

[27] de Fraja, Gianni and Iossa, Elisabetta “Price Caps and Output Floors: A Comparison of Simple Regulatory Rules The Economic Journal, Vol. 108, No. 450 (Sep., 1998), pp. 1404-1421

[28] Freixas, Xavier “Monopolistic Behaviour, Prices and Quantities” The Review of Economic Studies, Vol. 47, No. 4 (Jul., 1980), pp. 747-753

[29] Giles, John, Albert Park and Juwei Zhang. “The Great Proletarian Cultural Revolution, Disruptions to Education, and Returns to Schooling in Urban China”Michigan State University (2006).

[30] Gittings, John The Role of the Chinese Army. New York: Oxford University Press, 1967.

[31] Greif, Avner "Toward Political Economy of Implementation: The Impact of Administrative Power on Institutional and Economic Developments". In Elhanan Helpman (ed.), *Institutions and Growth*. Harvard University Press, 2008.

[32] Hall, Robert E. and Jones, Charles I. "Why Do Some Countries Produce So Much More Output Per Worker Than Others?" Quarterly Journal of Economics 114.1 (1999): 83-116.

[33] Haggard, Stephan and Noland, Marcus (2006) "Hunger and Human Rights: The Politics of Famine" U.S. Committee for Human Rights in North Korea, Washington D.C.

[34] Hayek, F.A. "The Use of Knowledge in Society" The American Economic Review, Vol. 35, No. 4 (Sep., 1945), pp. 519-530

[35] Hayek, F.A. and Friedman Milton. The Road to Freedom. 50th Anniversary Edition, University Of Chicago Press, 1994.

[36] Heal, G. M. "Planning Without Prices" The Review of Economic Studies, Vol. 36, No. 3 (Jul., 1969), pp. 347-362

[37] Hickson, Charles R. and Turner, John D. "Pre- and Post-famine Indices of Irish Equity Prices." European Review of Economic History 12.1 (2008): 3-38.

[38] Ireland, N. J. "Ideal Prices vs. Prices vs. Quantities" The Review of Economic Studies, Vol. 44, No. 1 (Feb., 1977), pp. 183-186

[39] Johnson, D. Gale. "China's Great Famine: Introductory Remarks" China Economic Review 9 (1998): 103-9.

[40] Joskow, Paul, Doughlas Bohi and Frank Gollop "Regulatory Failure, Regulatory Reform, and Structural Change in the Electrical Power Industry" Brookings Papers on Economic Activity. Microeconomics, Vol. 1989 (1989), pp. 125-20

[41] Kahn, Matthew. "The Death Toll from Natural Disasters: The Role of Income, Geography, and Institutions." Review of Economics and Statistics 87.2 (2005): 271-284.

[42] Koenig, Evan "Indirect Methods for Regulating Externalities Under Uncertainty" The Quarterly Journal of Economics, Vol. 100, No. 2 (May, 1985), pp. 479-493

[43] Kueh, Y. Agricultural Instability in China, 1931-1990: Weather, Technology and Institutions. Oxford: Clarendon, 1995.

[44] La□ont, Jean Jacques "More on Prices vs. Quantities" The Review of Economic Studies, Vol. 44, No. 1 (Feb., 1977), pp. 177-182

[45] Li, Wei and Dennis Yang. "The Great Leap Forward: Anatomy of a Central Planning Disaster." Journal of Political Economy 113.4 (2005): 840-77.

[46] Lavely, William R. “Age Pattern of Chinese Marital Fertility 1950-1980.” Demography 23.3 (1986):419-434.

[47] Lin, Justin Yifu. “Collectivization and China’s Agricultural Crisis in 1959-1961.” Journal of Political Economy 98 (1990): 1228-52.

[48] Lin, Justin Yifu and Yang, Dennis Tao. “Food Availability, Entitlements and the Chinese Famine of 1959-61” The Economic Journal 110.460 (2000): 136-158.

[49] Malinvaud, E. "Decentralized Procedures for Planning ", ch. 7 in Malinvaud (ed.), Activity Analysis in the Theory of Growth and Planning (New York: Macmillan, 1967).

[50] Malthus, Thomas (1798) An Essay on the Principle of Population. Oxford University Press, London (2008).

[51] Manove, Michael “Non-Price Rationing of Intermediate Goods in Centrally Planned Economies” Econometrica, Vol. 41, No. 5 (Sep., 1973), pp. 829-852

[52] McGregor, Patrick. “Demographic Pressure and the Irish Famine: Malthus after Mokyr.” Land Economics 65.3 (1989): 228-38.

[53] McKibbin, Warwick ad Wilcoxen, Peter “The Role of Economics in Climate Change Policy” The Journal of Economic Perspectives, Vol. 16, No. 2 (Spring, 2002), pp. 107-129

[54] Meng, Xin and Qian, Nancy. ‘The Long Run Consequences of Famine on Survivors: Evidence from China’s Great Famine 1959-61.” NBER Working Paper (2009).

[55] Mises, Ludwig Von. Economic Calculation in the Socialist Commonwealth. The Ludwig Von Mises Institute 1990 Edition, 1920.

[56] Montero, Juan Pablo “Pollution Markets with Imperfectly Observed Emissions Juan-Pablo Montero The RAND Journal of Economics, Vol. 36, No. 3 (Autumn, 2005), pp. 645-660

[57] North, Douglass C. Structure and Change in Economic History. New York: W.W. Norton & Co., 1981.

[58] Nunn, Nathan and Nancy Qian. “The Historical Impact of the Potato on World Population.” Brown University Working Paper (2008).

[59] O’Boyle, Edward J. “Classical Economics and the Great Irish Famine: A Study in Limits.” Forum for Social Economics 35.2 (2006): 21-53.

[60] O’Grada, Cormac, et al. Ireland’s Great Famine: Interdisciplinary Perspectives. Dublin: University College Dublin Press, 2006.

[61] O’Grada, Cormac “Famine and Markets” UCD Centre for Economic Research Working Paper WP07/20 (2007a).

[62] O'Grada, Cormac "Famine Demography" UCD Centre for Economic Research Working Paper WP07/21 (2007b).

[63] Oi, Jean. State and Peasant in Contemporary China: The Political Economy of Village Government. Berkeley: University of California Press, XXI, 1989.

[64] O'Rourke, John. The History of the Great Irish Famine of 1847: With Notices of Earlier Irish Famines. Dublin: BiblioBazaar, LLC, 2007.

[65] Peng, XZ. 1987 "Demographic Consequences of the Great Leap Forward in China's Provinces" *Population and Development Review* 13: pp. 639-70.

[66] Procyk, Oksana. Famine in the Soviet Ukraine, 1932-1933: A Memorial Exhibition. Cambridge: Harvard College Library, 1986.

[67] Perkins, Dwight H., and Shahid Yusuf. Rural Development in China. Baltimore: Johns Hopkins University Press (for The World Bank), 1984.

[68] Ravallion, Martin. "Famines and Economics." Journal of Economic Literature 35 (1997): 1205-42.

[69] Reynolds, Bruce, "Changes in the Standard of Living of Shanghai Industrial Workers, 1930-73," in Shanghai: Revolution and Development in an Asian Metropolis, ed. Christopher Howe (Cambridge, 1981), p. 223.

[70] Samuelson, Paul "The Fundamental Approximation Theorem of Portfolio Analysis in terms of Means, Variances and Higher Moments The Review of Economic Studies, Vol. 37, No. 4 (Oct., 1970), pp. 537-542

[71] Sen, Amartya. Poverty and Famines: An Essay on Entitlement and Deprivation. Oxford: Clarendon, 1981.

[72] Shiue, Carol."Transport Costs and the Geography of Arbitrage in Eighteenth Century China," American Economic Review, Vol. 92, No. 5, pp.1406-1419.

[73] Shiue, Carol H. "Local Granaries and Central Government Disaster Relief: Moral Hazard and Intergovernmental Finance in Eighteenth and Nineteenth Century China" Journal of Economic History 65 (2004): 100-124.

[74] Shiue, Carol H. "The Political Economy of Famine Relief in China, 1740–1820."Journal of Interdisciplinary History, xxxvi:1 (Summer, 2005), 33-55.

[75] Spence, Jonathan The Search for Modern China. New Yor: W.W. Norton & Company. 1991.

[76] Twitchett, Denis and Fairbank, John K. Cambridge History of China, 14 (1985): 378-386.

[77] Unger, Jon. Education Under Mao. New York: Columbia University Press. 82.3. 1982: 393-408.

[78] Vallin, Jacques. “A New Estimate of Ukrainian Population Losses during the Crises of the 1930s and 1940s.” Population Studies 56.3 (2002): 249-64.

[79] Walker, Kenneth R. Food Grain Procurement and Consumption in China. Cambridge: Cambridge University Press, 1984.

[80] de Waal, Alex “Famine Mortality: A Case Study of Darfur, Sudan 1984-5” Population Studies, Vol. 43, No. 1 (Mar., 1989), pp. 5-24.

[81] Wang et al. *Chinese Village for Thirty Years (Xiang Cun San Shi Nian) 1949-83*. Agriculture Press of China, Beijing. 1989.

[82] Webb, Patrick and Von Braun, Joachim Famine and Food Security in Ethiopia: Lessons for Africa. New York: John Wiley, (1994).

[83] Weitzman, Martin L. “Prices vs. Quantities,” Review of Economic Studies 41 (1974), 477-491.

[84] —— “Iterative Multilevel Planning with Production Targets” Econometrica, Vol. 38, No. 1 (Jan., 1970), pp. 50-65

[85] West, Lorraine and Zhao, Yaohui. Rural-urban migration in China: the past and present. Institute for East Asian Studies, University of California, Berkeley, 2000.

[86] Wen, Guanzhong James. “Total Factor Productivity Change in China’s Farming Sector: 1952–1989.” Economic Development and Cultural Change 42 (1993): 1-41.

[87] West, Lorraine and Zhao, Yaohui. Rural-Urban Migration in China: The Past and Present. Institute for East Asian Studies, University of California, Berkeley, 2000.

[88] Whinston, A. "Price Guides in Decentralized Institutions", Ph.D. thesis, Carnegie Institute of Technology, 1962.

[89] Yang, Dali L. Calamity and Reform in China: State, Rural Society, and Institutional Change since the Great Leap Famine. Stanford, CA: Stanford University Press, 1996.

[90] Yang, Dennis. “China’s Agricultural Crisis and Famine of 1959-61: A Survey and Comparison to Soviet Famines.” Comparative Economic Studies 50 (2008): 1-20.

[91] Yao, Shujie. “A Note on the Causal Factors of China’s Famine in 1959-1961”. Journal of Political Economy 107.6 (1999): 1365-69.

[92] Zeckhauser, Richard. “The Economics of Catastrophes.” Journal of Risk and Uncertainty 12 (1996): 113-140.

Table 1: Illustrative Example of Grain Procurement

	Collective A	Collective B	City
Subsistence Needs	100	100	100
Production under High Shock (Probability 80%)	225	150	0
Production under Low Shock (Probability 20%)	180	120	0
Expected Production (0.8 x High + 0.2 x Low)	216	144	0
Procurement/Subsidy (Expected Production - Subsistence)	116	44	-100
Consumption under High Shock (High Production - Procurement)	109	106	100
Consumption under Low Shock (Low Production - Procurement)	64	76	100

Table 2: Descriptive Statistics

	Obs	Mean	Std. Err.			
	A. Province Level 1949-98					
Population (10,000 People)	1422	2898.27	54.22			
Death Rate (per 1,000 People)	1367	8.51	0.12			
Death Rate in 1960 (per 1,000 People)	27	21.91	2.89			
Grain Production in 1959 (10,000 Tons)	28	529.10	63.91			
Annual Per Capital Grain Production (Kg Per Person)	1419	319.30	4.00			
Annual Per Capital Grain Production in 1959 (Kg Per Person)	28	252.24	17.75			
	B. County Level (1943-66)					
	Agricultural Households			Non-Agricultural Households		
	Obs	Mean	Std. Err.	Obs	Mean	Std. Err.
Average Cohort Size (1942-66)	46212	37.14	0.18			

Table 3: Population Composition and Average Caloric Needs

Age Bracket (1)	Population (100) (2)	Daily Caloric Needs (3)	Population Daily Caloric Need (4)	Average Daily Caloric Need (5)
	A. 1954 Caloric Needs for Heavy Agricultural Labor (or Healthy Child Development)			
Female				
0-5	495,641	1,300	64,433,330,000	
6-10	335,192	1,800	60,334,560,000	
11-15	294,474	2,200	64,784,280,000	
16-20	298,419	2,200	65,652,180,000	
21-50	1,055,377	1,800	189,967,860,000	
51-100	432,744	1,300	56,256,720,000	
Male				
0-5	542,455	1,300	70,519,150,000	
6-10	373,404	1,800	67,212,720,000	
11-15	347,053	2,500	86,763,250,000	
16-20	343,704	3,000	103,111,200,000	
21-50	1,165,685	2,100	244,793,850,000	
51-100	387,607	1,600	62,017,120,000	
Total	**6,071,755.00**		**1,135,846,220,000**	**1,870.70**
	B. 1954 Caloric Needs for Avoiding Mortality			
Female				
0-5	495,641	559	27,706,331,900	
6-10	335,192	774	25,943,860,800	
11-15	294,474	946	27,857,240,400	
16-20	298,419	946	28,230,437,400	
21-50	1,055,377	774	81,686,179,800	
51-100	432,744	559	24,190,389,600	
Male				
0-5	542,455	559	30,323,234,500	
6-10	373,404	774	28,901,469,600	
11-15	347,053	1,075	37,308,197,500	
16-20	343,704	1,290	44,337,816,000	
21-50	1,165,685	903	105,261,355,500	
51-100	387,607	688	26,667,361,600	
Total	**6,071,755.00**		**488,413,874,600**	**804.40**

Source: Coale (1981) and authors' computations.

Notes: Caloric requirements are calculated based on model from the USDA. In Panel A., for adults, we assume females 21-50 weigh 120 lbs, females 51-100 weigh 100lbs. Males 21-50 weigh 140 lbs, and 51-100 weigh 120 lbs. We assume that all adults 21-50 perform a high level of physical activity. And those 51-100 performs a medium level of physical activity. Caloric needs for staying alive are estimated to be 43% of those in Panel A. This is projected from the observation that an adult male labor need approximately 900 calories to stay alive, which is approximately 43% of the requirement for heavy physical labor.

Table 4: National Grain Production and Population Needs 1949-76

	National Production and Retention Over Time					
			190 kg/person, 1870 Calories		75.25 kg/person,804 Calories	
	Grain Prod	Population	Needed	Grain Surplus	Needed	Grain Surplus
	(Millions Tons)	(10000)	(Million Tons)	(Million Tons)	(Million Tons)	(Million Tons)
Year	(1)	(2)	(3)	(4)	(5)	(6)
1949	101.59	54167	103	-1	41	61
1950	119.88	55196	105	15	42	78
1951	128.12	56300	107	21	42	86
1952	157.42	57482	109	48	43	114
1953	148.56	58796	112	37	44	104
1954	149.44	60266	115	35	45	104
1955	163.97	61456	117	47	46	118
1956	165.84	62828	119	46	47	119
1957	174.37	64563	123	52	49	126
1958	169.82	65994	125	44	50	120
1959	**148.33**	**67207**	**128**	**21**	**51**	**98**
1960	127.66	66207	126	2	50	78
1961	122.98	65859	125	-2	50	73
1962	148.19	67295	128	20	51	98
1963	146.59	69172	131	15	52	95
1964	166.12	70499	134	32	53	113
1965	201.67	72538	138	64	55	147
1966	197.29	74542	142	56	56	141
1967	201.23	76368	145	56	57	144
1968	193.80	78534	149	45	59	135
1969	193.76	80671	153	40	61	133
1970	241.66	82992	158	84	62	179
1971	238.21	85229	162	76	64	174
1972	229.14	87177	166	64	66	164
1973	254.98	89211	170	85	67	188
1974	264.20	90859	173	92	68	196
1975	296.58	92420	176	121	70	227
1976	276.65	93717	178	99	71	206

Source: CDSM50 (1999), CPIRC (2000) and authors' computations.

Notes: Total production reported in column (1) is aggregate from province level production. This excludes Sichuan, a major grain producer, for which data is not available. Surplus in Columns (4) and (6) refer to production that is excess of subsistence needs. Average caloric needs in Columns (3) and (5) are computed using the national age distribution of population from the 1954 Census (see Coale, 1981). See Table 2.Based on estimates provided by the Ministry of Health and Hygiene of China, we assume that 1 kg of grain provides 3,587 calories.

Table 5: Province Level Production and Population Needs in 1959

Famine Mortality and Production by Province				
Province	1960 Death Rate	1959 Grain Prod	1959 "Surplus"	
		Kg/Person	1,870 Calories	706 Calories
	(1)	(2)	(3)	(4)
Shanghai	6.9	107.02	-82.98	36.02
Beijing	9.14	82.01	-107.99	11.01
Neimeng	9.4	412.16	222.16	341.16
Jilin	10.13	401.07	211.07	330.07
Tianjin	10.34	91.42	-98.58	20.42
Heilongjiang	10.52	505.95	315.95	434.95
Shanxi	11.21	244.48	54.48	173.48
Liaoning	11.5	235.91	45.91	164.91
Zhejiang	11.88	382.06	192.06	311.06
Shan'xi	12.27	251.99	61.99	180.99
Ningxia	13.9	303.70	113.70	232.70
Guangdong	15.24	242.70	52.70	171.70
Xinjiang	15.67	304.35	114.35	233.35
Hebei	15.8	195.12	5.12	124.12
Jiangxi	16.06	314.36	124.36	243.36
Jiangshu	18.41	231.42	41.42	160.42
Fujian	20.7	259.23	69.23	188.23
Hubei	21.21	241.07	51.07	170.07
Shandong	23.6	195.24	5.24	124.24
Yunnan	26.26	265.26	75.26	194.26
Hunan	29.42	300.32	110.32	229.32
Guangxi	29.46	246.98	56.98	175.98
Henan	39.56	195.72	5.72	124.72
Qinghai	40.73	200.49	10.49	129.49
Gansu	41.32	223.95	33.95	152.95
Guizhou	52.33	242.67	52.67	171.67
Anhui	68.58	204.55	14.55	133.55
Hainan	N/A	181.51	-8.49	110.51
Tibet	N/A	N/A	N/A	N/A
Sichuan	N/A	N/A	N/A	N/A

Source: CSDM50 (1999) and authors' computations.

Notes: "Surplus" in Columns (3) and (4) refer to production that is excess of what is needed to work (for children, this refers to normal child development), and the excess of what is needed to stay alive. Average caloric needs in Columns (3) and (4) are computed using the national age distribution of population from the 1954 Census (see Coale, 1981). See Table 2.

Table 6: Province Level Relationship between Per Capita Grain Production and Mortality Rates

	Dependent Variable: Ln Mortality Rate			
	(1)	(2)	(3)	(4)
	Famine	Non-Famine	All	All
Ln Per Capita Grain Prod	0.216	-0.182	-0.182	-0.111
	(0.120)	(0.0787)	(0.0787)	(0.0679)
Ln Per Capita Grain Prod x 1959-61 Dummy			0.398	0.326
			(0.120)	(0.116)
Dummy for 1959-61			-1.688	-1.299
			(0.627)	(0.606)
Gov Exp on Health and Edu				-0.00399
				(0.000824)
Observations	82	1259	1341	1300
R-squared	0.030	0.037	0.142	0.185
Joint: Ln PC Prod + Ln PC Grain Prod x 1969-61 Dummy			0.216	0.215
Joint p-value			0.082	0.083

Standard errors are clustered at the province level.
Famine years are 1959-61. Non-famine years are 1949-58, 1962-98.

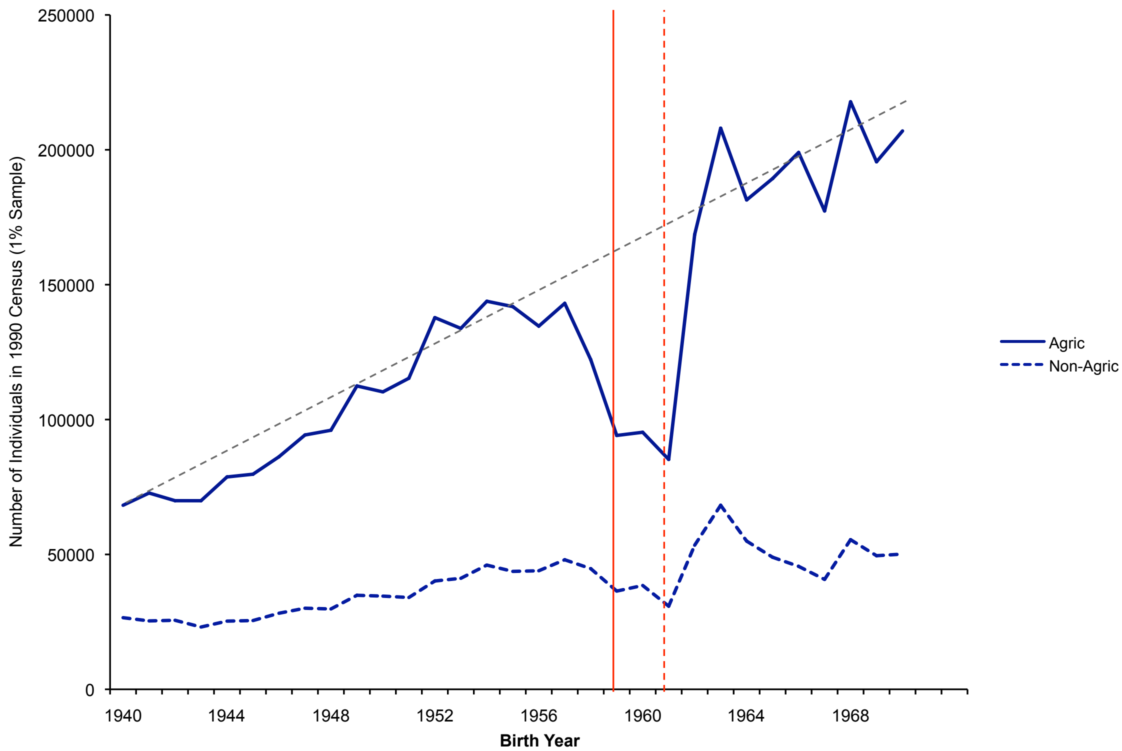
Table 7: County Level Relationship between Grain Suitability and Birth Cohort Size

	Dependent Variables: Ln Birth Cohort Size							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	All Households				Agricultural Households		Non Agricultural Households	
	Famine	Famine	Non-Famine	Non Famine	All Birth Years	All Birth Years	All Birth Years	All Birth Years
Grain Suitability	-0.0756	-0.227	0.0934	0.238	0.259		-0.288	
	(0.0416)	(0.0654)	(0.0321)	(0.0509)	(0.0949)		(0.140)	
Grain Suit x Born 1959-61					-0.321	-0.177	-0.196	0.0126
					(0.0666)	(0.0528)	(0.0812)	(0.0473)
Controls								
Average County Cohort Size	Y	Y	Y	Y	Y	N	Y	N
Birth Year FE	N	N	N	N	Y	Y	Y	Y
Prov FE	N	Y	N	Y	Y	N	Y	N
County FE	N	N	N	N	N	Y	N	Y
Observations	1478	1045	1481	1047	36748	46212	21198	35175
R-squared	0.810	0.837	0.862	0.886	0.665	0.907	0.494	0.892

Standard errors are clustered at the county level.

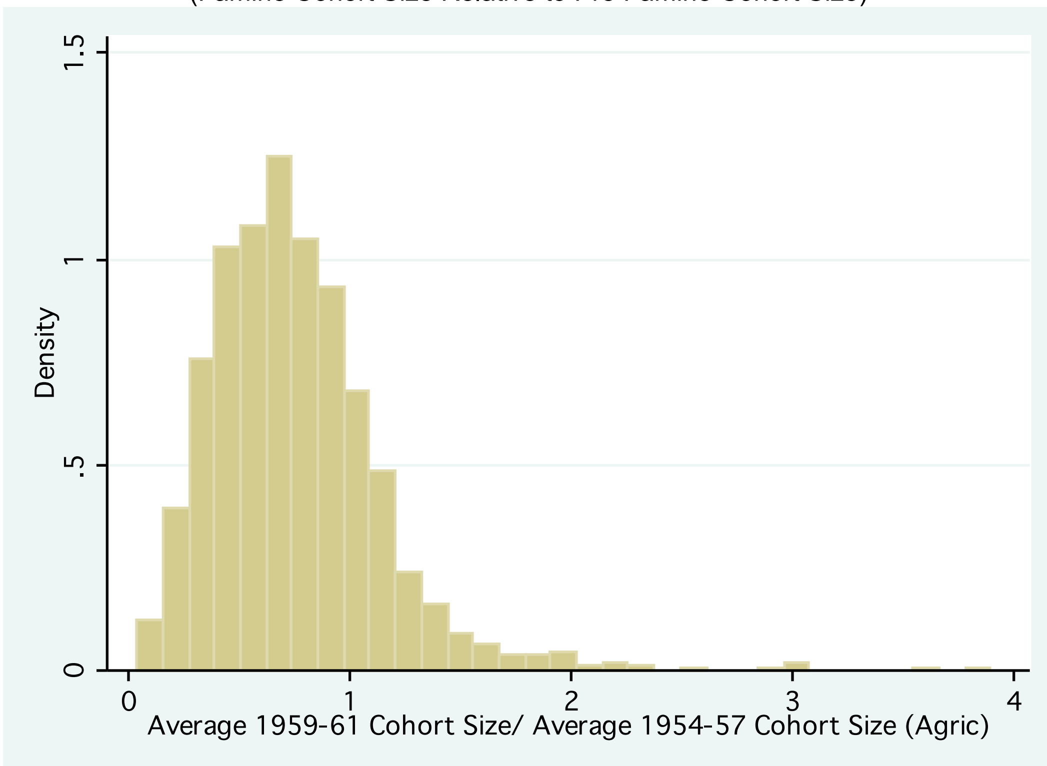
Famine birth cohorts are born during 1959-61. Non-famine birth cohorts are born during 1949-58, 62-66.

Figure 1: Birth Cohort Size over Time



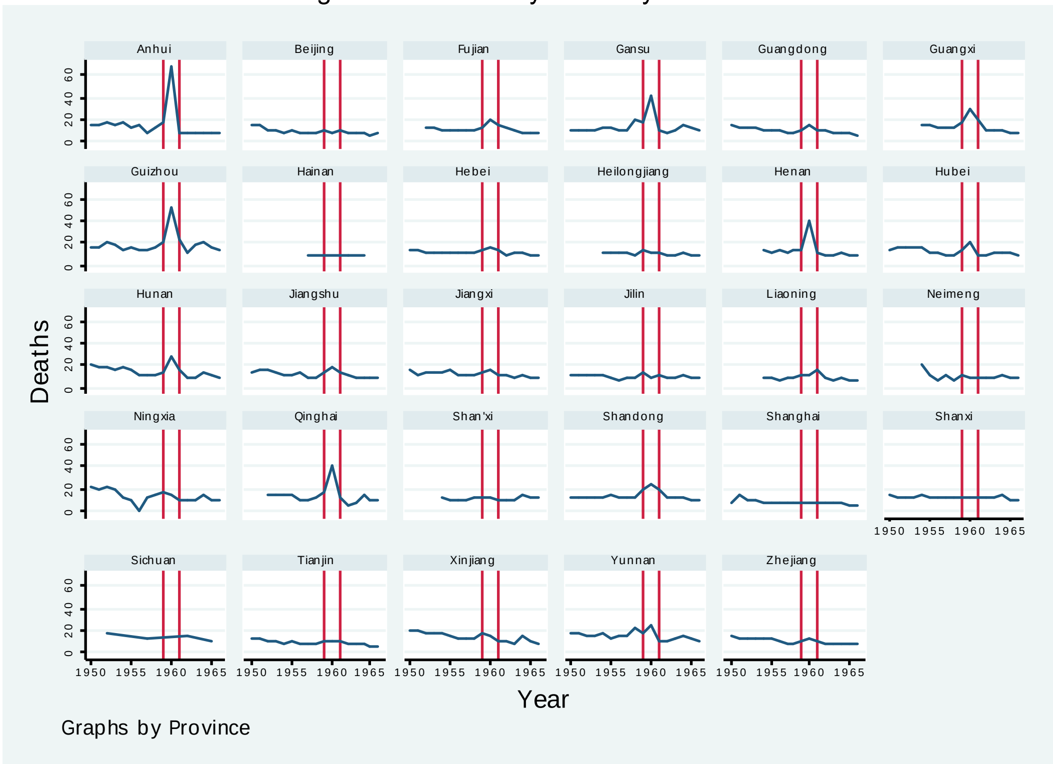
Source: 1990 Population Census

Figure 2: Histogram of Famine Intensity
(Famine Cohort Size Relative to Pre Famine Cohort Size)



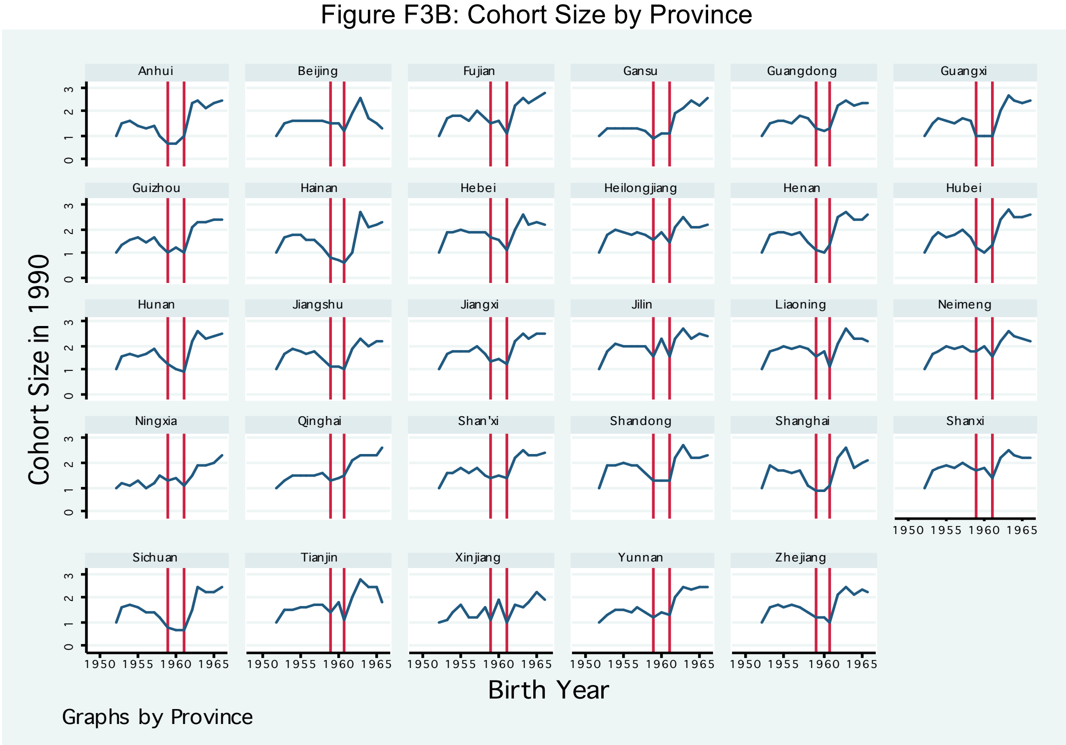
Source: Authors' computations

Figure F3A: Mortality Rates by Province



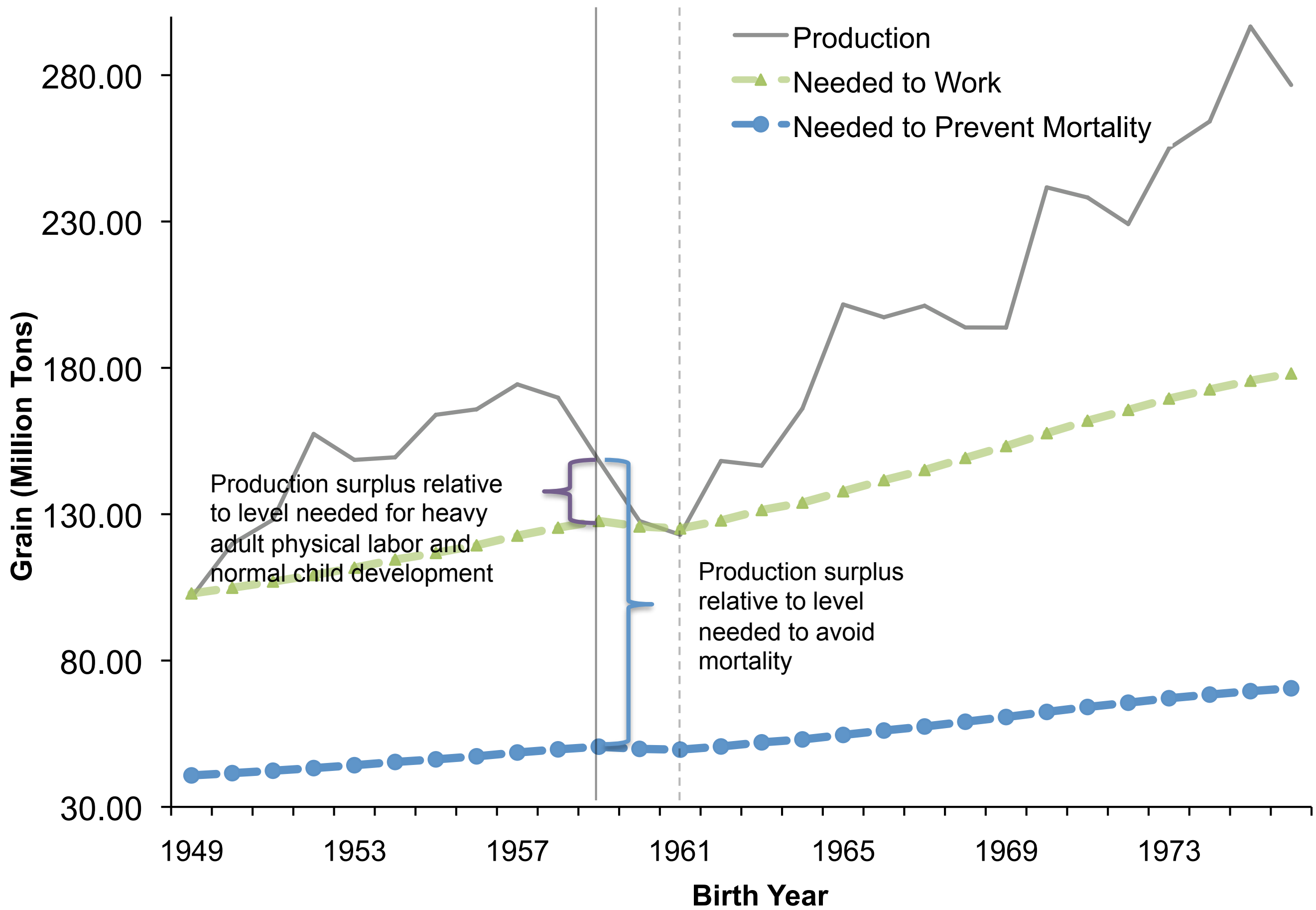
Source: CSDM50 (1999)

Figure F3B: Cohort Size by Province



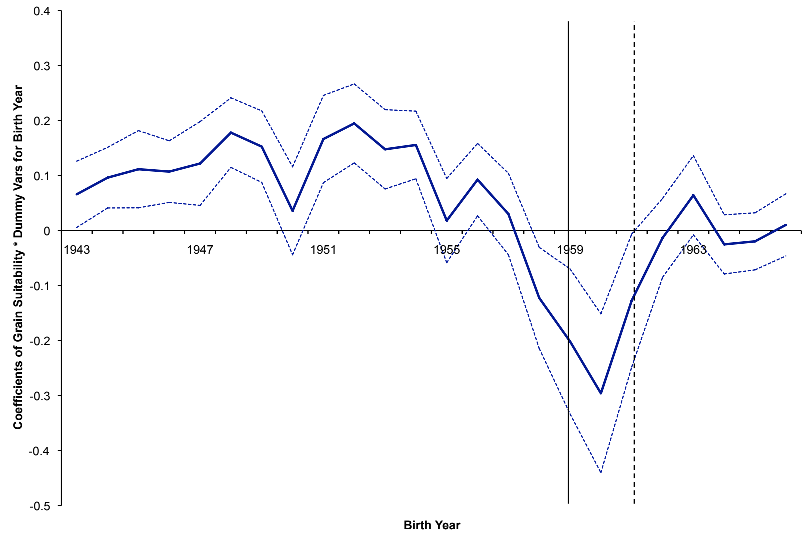
Source: 1990 Population Census

Figure 4: Grain Production and Population Needs 1949-76



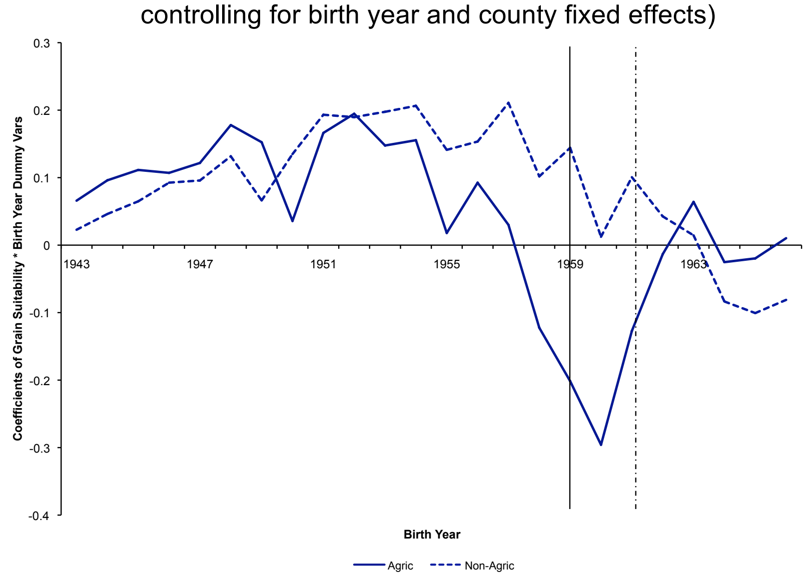
Source: CSDM50 (1999), Authors' Computations. See Table 3.

Figure 5A: The Yearly Correlations between Grain Suitability and Cohort Size and their 95% Confidence Intervals for Agricultural Households
(The coefficients of the interaction terms of grain suitability and dummy variables for birth year, controlling for birth year and county fixed effects)



Source: Authors' Computations. Appendix Table A3.

Figure 5B: The Yearly Correlations between Grain Suitability and Cohort Size for Agricultural and Non-Agricultural Households
(The coefficients of the interaction terms of grain suitability and dummy variables for birth year, controlling for birth year and county fixed effects)



Source: Authors' Computations. Appendix Table A3.

APPENDIX Table A1: National Production, Retention and Procurement (Li and Yang, 2005)

	Li and Yang (2005) 21 Provinces Published by Ministry of Agriculture in 1989					
	Grain Prod			Retained Grain	Grain Procurement	
	Production (Millions Tons)	Annual Growth Rate	Growth Rate 4MA	(kg/agric laborer)	(Millions Tons)	% of Production
Year	(1)	(2)	(3)	(4)	(5)	(6)
1952	164			260	33	20.12%
1953	167	0.02		242	47	28.14%
1954	170	0.02		228	51	30.00%
1955	184	0.08		256	48	26.09%
1956	193	0.05	0.04	284	40	20.73%
1957	195	0.01	0.04	273	46	23.59%
1958	200	0.03	0.04	268	52	26.00%
1959	**170**	**-0.15**	**-0.02**	**193**	**64**	**37.65%**
1960	143	-0.16	-0.07	182	47	32.87%
1961	148	0.03	-0.06	209	37	25.00%
1962	160	0.08	-0.05	229	32	20.00%
1963	170	0.06	0.00	231	37	21.76%
1964	188	0.11	0.07	256	40	21.28%
1965	195	0.04	0.07	261	39	20.00%
1966	214	0.10	0.08	282	41	19.16%
1967	218	0.02	0.06	281	41	18.81%
1968	209	-0.04	0.03	261	40	19.14%
1969	211	0.01	0.02	259	38	18.01%
1970	240	0.14	0.03	282	46	19.17%
1971	250	0.04	0.04	293	44	17.60%
1972	241	-0.04	0.04	298	39	16.18%
1973	265	0.10	0.06	293	48	18.11%
1974	275	0.04	0.04	303	47	17.09%
1975	285	0.04	0.03	304	53	18.60%
1976	286	0.00	0.04	306	49	17.13%

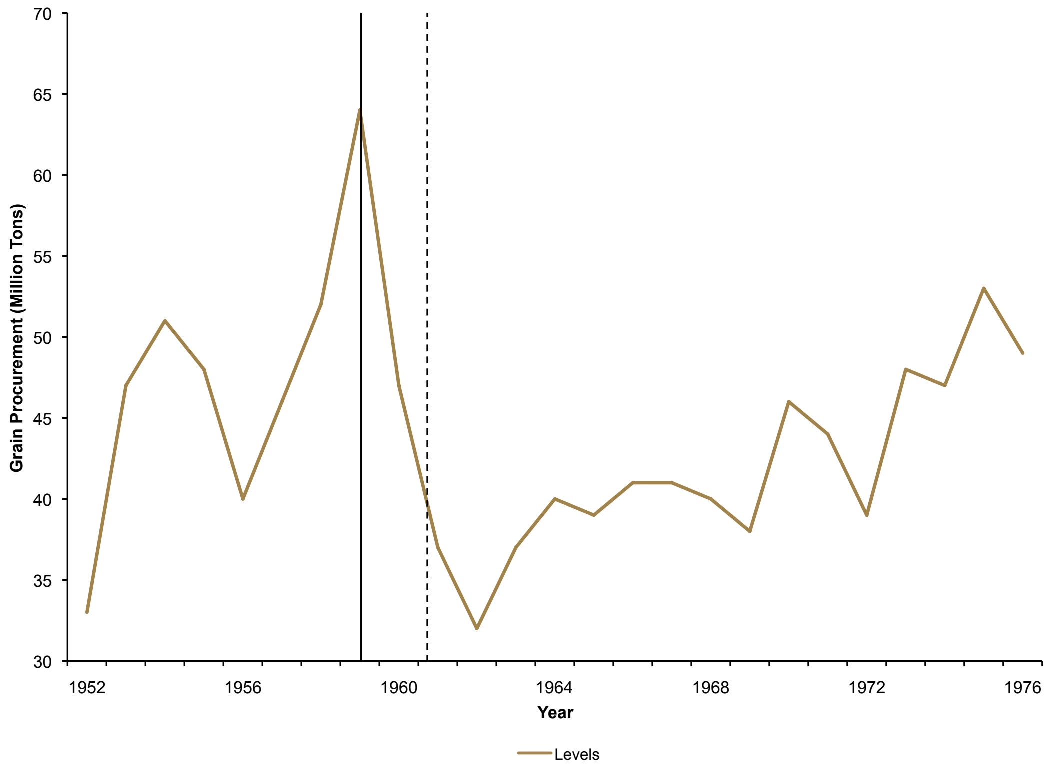
Source: Li and Yang (2005) (Original Sources: Ministry of Agriculture (1989)).

Table A2: The Correlation between Grain Suitability and Cohort Size

Dependent Variable: Ln Cohort Size	(1)	(2)
	Agric HH	Non-Agric HH
Grain Suit x Born 1943	0.0283	0.118
	(0.0410)	(0.0501)
Grain Suit x Born 1944	0.114	0.0756
	(0.0394)	(0.0519)
Grain Suit x Born 1945	0.0916	0.0512
	(0.0460)	(0.0587)
Grain Suit x Born 1946	0.130	0.167
	(0.0399)	(0.0557)
Grain Suit x Born 1947	0.129	0.136
	(0.0395)	(0.0601)
Grain Suit x Born 1948	0.252	0.149
	(0.0381)	(0.0561)
Grain Suit x Born 1949	0.206	0.157
	(0.0396)	(0.0563)
Grain Suit x Born 1950	0.110	0.225
	(0.0442)	(0.0649)
Grain Suit x Born 1951	0.343	0.264
	(0.0413)	(0.0631)
Grain Suit x Born 1952	0.292	0.304
	(0.0449)	(0.0707)
Grain Suit x Born 1953	0.291	0.334
	(0.0454)	(0.0654)
Grain Suit x Born 1954	0.251	0.308
	(0.0428)	(0.0681)
Grain Suit x Born 1955	0.143	0.288
	(0.0441)	(0.0630)
Grain Suit x Born 1956	0.251	0.307
	(0.0434)	(0.0663)
Grain Suit x Born 1957	0.180	0.379
	(0.0463)	(0.0677)
Grain Suit x Born 1958	0.0231	0.197
	(0.0583)	(0.0760)
Grain Suit x Born 1959	-0.0639	0.188
	(0.0685)	(0.0716)
Grain Suit x Born 1960	-0.169	0.0908
	(0.0806)	(0.0744)
Grain Suit x Born 1961	-0.0200	0.131
	(0.0587)	(0.0700)
Grain Suit x Born 1962	0.0530	0.200
	(0.0459)	(0.0664)
Grain Suit x Born 1963	0.140	0.319
	(0.0426)	(0.0728)
Grain Suit x Born 1964	-0.0192	0.0574
	(0.0389)	(0.0703)
Grain Suit x Born 1965	-0.0134	0.0428
	(0.0390)	(0.0707)
Grain Suit x Born 1966	-0.0260	-0.0173
	(0.0394)	(0.0749)
Observations	46212	35175
R-squared	0.907	0.893

Regressions control for county and birth year fixed effects. Standard errors are clustered at the county level.

Figure A1A: Aggregate Procurement (Li and Yang, 2005)

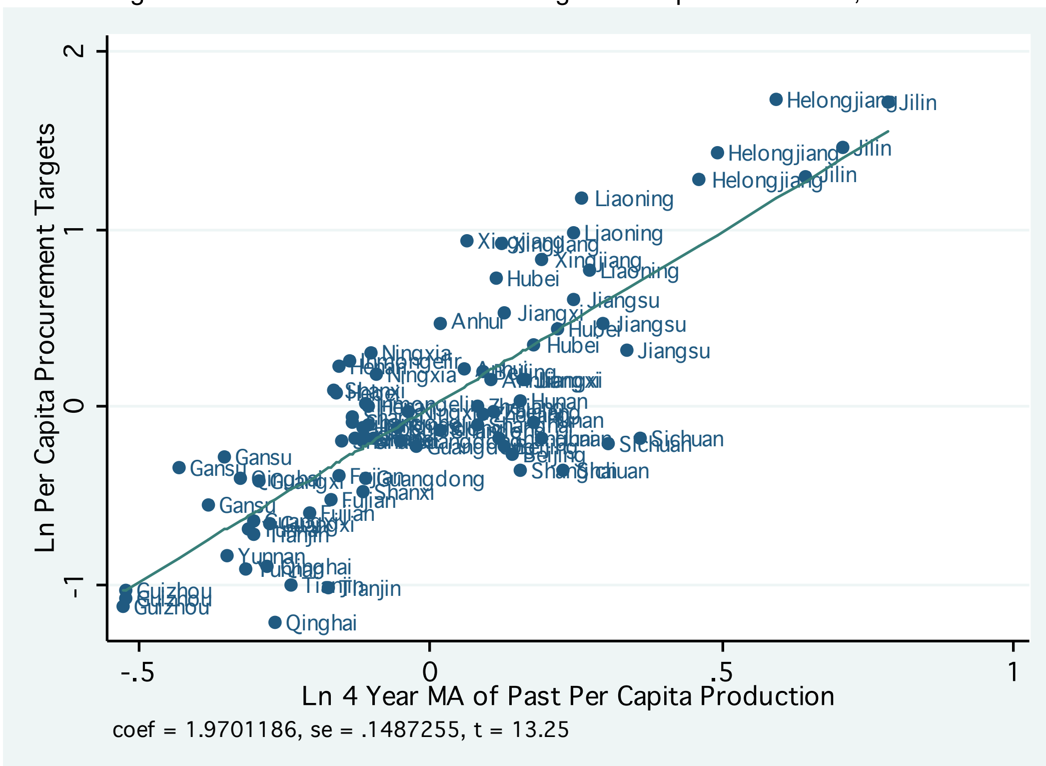


Source: Appendix Table A1

Figure A1B: Aggregate Retention (Li and Yang, 2005)

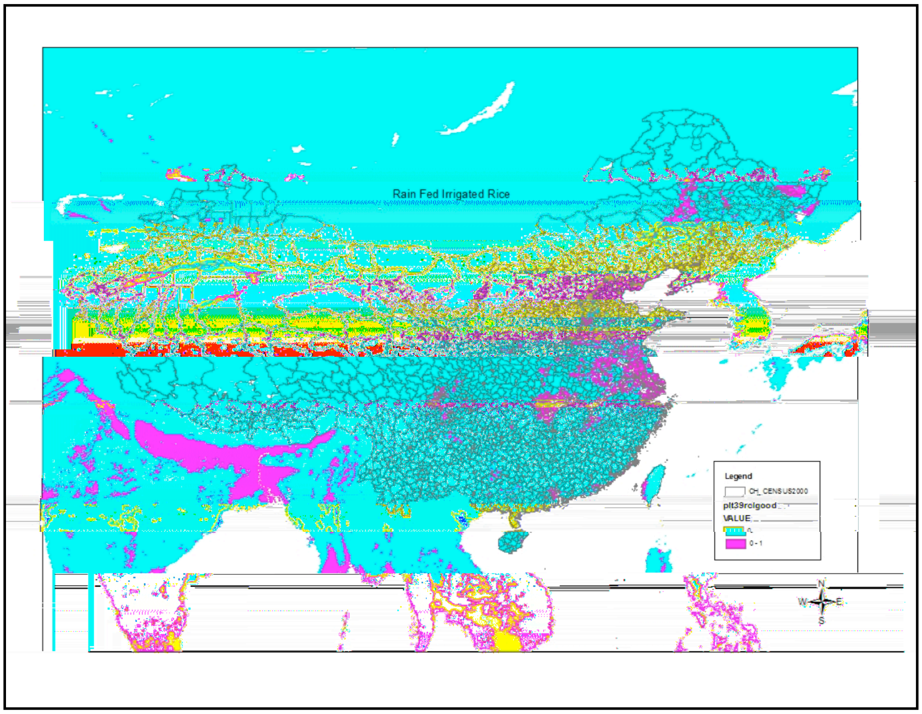
Source: Appendix Table A1

Figure A2: Residual Plot of Bivariate Correlation between Province Level Per Capita Procurement Targets and a 4 Year MA of Past Average Per Capita Production, 1980-88



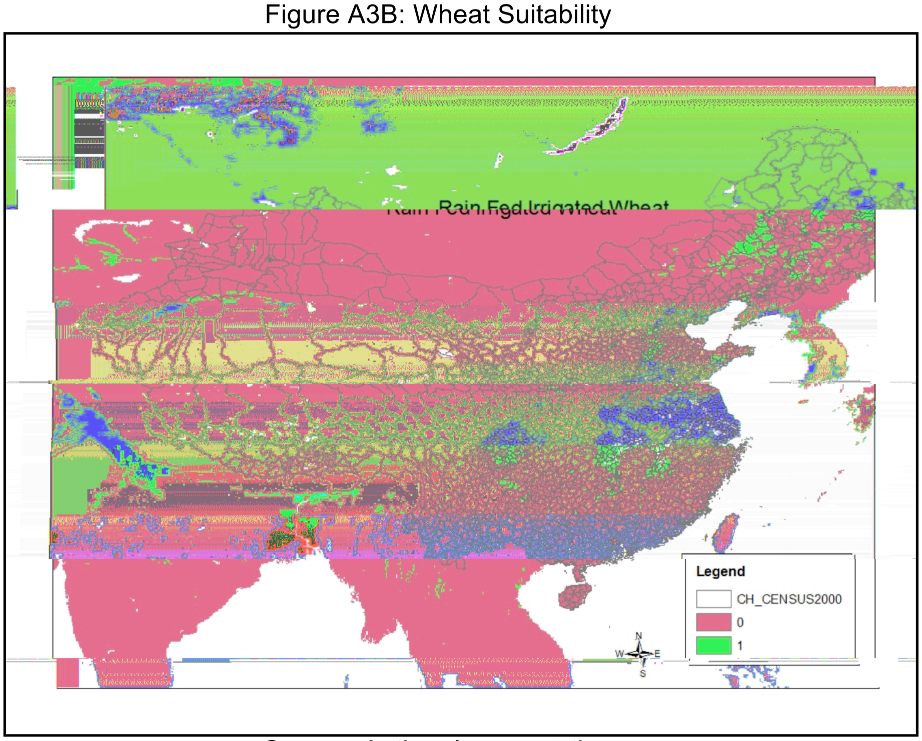
Source: Authors' Computations

Figure A3A: Rice Suitability



Source: Authors' computation

Figure A3B: Wheat Suitability



Source: Authors' computation