The Institutional Causes of China's Great Famine, 1959-1961*

Xin Meng Nancy Qian Pierre Yared

November 22, 2011

Abstract

This paper studies the causes of the largest famine in history, where approximately 30 million individuals died in rural China. We are motivated by the observation that average rural food retention during the famine seems too high to generate a famine without rural inequality in food availability. We document two novel facts. First, there is significant variance in famine mortality rates across rural regions. Second, these rural mortality rates are *positively* correlated with per capita food production, a surprising pattern that is unique to the famine years. This suggests that government redistributive policy contributed to the spatial variation in famine. To explain these results, we document that the historical grain procurement policy was inflexible – i.e., Chinese central planners had difficulty aggregating and responding to new information. We then argue that the inflexibility of the grain procurement policy together with the drop in production in 1959 can explain the observed variation in famine severity across rural areas.

Keywords: Famines, Modern Chinese History, Institutions, Central Planning

JEL Classification: P2, O43, N45

*We are indebted to Francesco Caselli, an anonymous co-editor and three anonymous referees for invaluable suggestions. We also thank Alberto Alesina, Philippe Aghion, Abhijit Banerjee, Daron Acemoglu, Robin Burgess, Andrew Foster, Claudia Goldin, Mikhail Golosov, Avner Greif, Rick Hornbeck, Chang-tai Hsieh, Dean Karlan, Michael Kremer, James Kung, Christopher Leighton, Cormac O'Grada, Naomi Lamoureaux, Emi Nakamura, Suresh Naidu, Nathan Nunn, Gerard Padro-i-Miquel, Chris Udry, Dennis Yang and Fabrizio Zillibotti for their comments; the participants at the Berkeley Development Seminar, UCLA Applied Economics Seminar, Stanford Economic History Seminar, University of Texas at Austin Applied Micro Seminar, University of Toronto Applied Micro Seminar, Tsinghua University Economics Seminar, the Applied Workshop at CCER PKU, the Economics Workshop at Hong Kong University, the Applied Micro Seminar at the Chinese University of Hong Kong, Yale University Macro Lunch and Harvard History Tea, and the participants at BREAD-CIPREE, CEPR-DE, the NBER Summer Institute for Economic Growth, the University of Houston Health and Development Conference, and the Conference on Fetal Origins and Famines at Princeton University for useful comments; and Louis Gilbert, Sara Lowes, Ang Sun, David Liu, Jaya Wen and Kai Yan for excellent research assistance. We acknowledge the Harvard Academy Scholars program for financial support. Please send comments to any of the authors: xin.meng@anu.edu.au, nancy.qian@yale.edu, pyared@columbia.edu.

1 Introduction

During the twentieth century, approximately seventy million people perished from famine.[1] This study focuses on understanding the causes of the Chinese Great Famine, which began in the winter of 1959-60 and killed more than any other famine in history. Approximately thirty million individuals, most of whom were living in rural areas, perished in less than a year. A consensus has formed in recent years that a fall in aggregate production in 1959 followed by high government procurement from rural areas were key contributors to the famine.[2] However, existing estimates of average per capita food availability for rural workers after the aggregate procurement is deducted from aggregate production seem much too high to cause such massive famine mortality.[3] This suggests that there must be significant variation in famine severity within the rural population, since a famine occurred despite the reasonably high levels of average rural food availability. To the best of our knowledge, the importance and causes of the within-rural variation in the famine severity has received little attention from existing scholars.

Our study attempts to fill this gap. We document the presence of variation in famine severity across rural regions and examine its relationship with food production. Then, based on the descriptive patterns we uncover in the data and the qualitative historical evidence, we propose an explanation for the within-rural variation in famine severity.

The first empirical exercise investigates whether average rural food availability in 1959 was sufficient to avoid an increase in mortality. Given that the entire rural population relied on rural food stores, we compare the food retained by rural regions post-procurement to the per capita food requirements. Using historical data on aggregate food production, government procurement, population, and demographic breakdown, we find that the average rural food availability for the entire rural population was approximately three times as much as the level necessary to prevent famine mortality. We reach these conclusions even after constructing the estimates to bias against finding sufficient rural food availability. Our findings are consistent with existing estimates of high rural food availability for rural workers and imply that the high level of famine mortality was accompanied by significant variation in famine severity within the rural population.

The second empirical exercise investigates the variation in famine severity across rural regions. We find that mortality rates across provinces varied much more during the famine than in other years. To investigate whether this pattern remains true at a more disaggregated level, we also use the birth-cohort sizes of survivors observed in 1990 to proxy for famine severity.[4] This is based on the logic that famine increases infant and early childhood mortality rates and lowers fertility rates such that a more severe famine results in smaller cohort sizes for those born during

[1] See Sen (1981) and Ravallion (1997) for estimates of total famine casualties.

[2] For a detailed discussion, see the Section 2 on Background.

[3] Li and Yang (2005) report average per capita rural food consumption for laborers that is roughly equivalent to 2,063 calories per worker per day using the conversion scale that is provided by the Chinese Ministry of Health and Hygiene's (MHH) for the estimate of calories contained in the typical mix of grains consumed by an average Chinese worker.

[4] There is no county-level historical data on mortality rates.

the famine. The data show that there is much more variation in cross-county birth-cohort sizes for famine birth-cohorts relative to non-famine birth-cohorts. This is true both across and within provinces.

The third empirical exercise examines the within-rural cross-sectional correlation between food productivity and famine severity. We find that this correlation is *positive.* This positive correlation is unique to the year of the famine. This surprising correlation is true both at the province-level, where we use mortality rates to proxy for famine severity and per capita grain production data to measure productivity; and at the county-level (within provinces), where we use the birth-cohort size of famine survivors to proxy for famine severity, along with historical data on weather conditions and the geo-climatic suitability for grain production to proxy for productivity.[5] We also document that the fall in production was roughly proportional across regions such that the rank ordering of per capita production in 1959 was similar to previous years.

Finally, we use the spatial patterns in famine severity and food production to develop an explanation for the variation in famine severity across rural areas. We document that the historical grain procurement policy was inflexible such that the Chinese central planners had difficulty in aggregating and responding to new information. We then argue that the inflexibility of the grain procurement policy can explain the variation in famine severity across rural areas that we observe in the data. Specifically, in the late 1950s, the central government procured as much grain as it could from rural areas while leaving rural workers with enough food to be productive laborers. It set each region's procurement level in advance, and the level of the procurement could not be easily adjusted. As a consequence, the level of procurement from a given rural region was inflexible such that it did not respond to the actual amount produced, but, was instead, based on an estimated production target established months earlier. Since these targets were themselves based on past production, this meant that in the event of an unexpected proportional production drop across regions, such as the one that took place in 1959, more productive regions experience larger gaps between realized and targeted production, subjecting them to potential over-procurement and famine. Therefore, the inflexible procurement policy caused more over-procurement, lower food retention, and thus higher mortality in more productive regions.

There are two caveats to consider for our interpretation. First, there are some concerns with the accuracy of the historical production and mortality data. Historically, the Mao government understated famine severity and may have over-stated famine food production. We believe that this is unlikely to be a major problem in our data, as they have been corrected and reported by the post-Mao government and carefully examined by many academic studies in recent years.[6] Moreover, the results themselves suggest that government misreporting is unlikely to be their main driver. Our conservative estimates of rural food availability are so much higher than the level needed to avoid mortality that it is highly unlikely that misreporting would undermine our

[5] There is no county-level historical grain production data.

[6] See the Data Appendix for details on the data and Section 2 for studies of the Chinese Famine.

motivating point that there was probably a high variation in famine severity within-rural areas. More importantly, our main results on the spatial patterns of production and famine severity are similar when using data on survivor birth-cohort size and historical natural conditions, neither of which are subject to Mao-era government manipulation.

Second, our interpretation that inflexible grain procurement is the key contributing factor to the within-rural inequality in famine severity presumes that regional grain productivity and famine severity are not joint outcomes of other factors. We do not take this as given, and carefully consider alternative explanations. We provide a detailed review of potentially relevant historical factors and show that the positive correlation between famine severity and productivity is very robust to controlling for these factors. These results also show that the spatial patterns we uncover in the data cannot be easily explained by existing explanations of the Chinese famine.

This study contributes to the understanding of the causes of the most fatal famine in history. It is the first to examine the variation in famine severity across rural areas and to investigate the contribution of policy *inflexibility*–an inherent feature of China's centrally planned economy–to the famine. Our results are consistent with the theory that the famine was largely due to government policy. Specifically, previous studies have provided important evidence that the fall in aggregate production in 1959 and the subsequent aggregate over-procurement of grain from the countryside can partly be explained by the Great Leap Forward's (GLF, 1958-61) misguided economic policies, political zealousness and favoritism towards urban regions (e.g., Yang, 1996; Lin and Yang, 2000; Li and Yang, 2005; Kung and Chen, 2011). Our study departs from previous works by showing that focusing on the causes the production fall and high aggregate procurement may not be sufficient for explaining the entire famine. It is equally important to understand the substantial inequality in food distribution across rural areas since rural food retention in the aggregate was sufficiently high to avert famine. We document a novel and striking spatial pattern – that regional food production was *positively* correlated with famine mortality across rural areas, a fact that cannot be easily explained by existing explanations of the famine. We demonstrate that the inflexible historical grain procurement policy was a necessary ingredient for causing the observed inequality in famine severity across rural areas. Thus, the inflexible procurement policy is a key contributor to the famine.

We also contribute to studies of the Chinese famine by bringing previously unused data (e.g., birth-cohort size, historical weather conditions, suitability for cultivation) into the analysis. These data allow empirical analysis at a much finer geographic level than the province-level, which has been the norm for existing studies of the Chinese Famine. The data also have the major advantage of avoiding misreporting by the famine-era government.

More generally, our finding that food distribution is key for causing China's Great Famine supports Sen's (1981) famous argument that famines are mainly due to food distribution rather than aggregate food deficits. We expand on his seminal work by studying the detailed mechanisms of famine in a non-market context.[7] For studies of famine, this is especially important since

[7]For recent studies on the causes of famines in market economies, see studies such as Burgess and Donaldson

some of the most devastating famines and approximately sixty percent of all famine deaths in the twentieth century have taken place in non-market economies (e.g., China's Great Famine in 1959-61, the Soviet Ukrainian Famine in 1932-33, and the North Korean Famine in 1992-95).[8] Interestingly, there are striking similarities between the Chinese Famine and the Soviet Famine, which suggest that our insights may be useful for understanding this other historical catastrophe. We return to this discussion when we offer concluding remarks.

This paper is organized as follows. Section 2 provides a brief historical background. Section 3 provides suggestive evidence that after procurement, there was enough food in rural areas as a whole to prevent famine at the end of 1959. Section 4 uses the historical data on famine severity to establish that there was significant variation in famine severity across rural regions. Section 5 establishes the positive correlation between famine severity and productivity across rural regions. Section 6 relates the empirical patterns to the inflexibility of the Chinese grain procurement system. Section 7 offers concluding remarks.

2 Historical Background

2.1 Collective Agriculture

The production, distribution and consumption of food in China on the eve of the famine were entirely controlled by the central government. This meant that the government was the sole insurer of food consumption in the event of a drop in production.[9] At the time, approximately 80% of the population worked in agriculture.[10] Land reforms that began in 1952 had resulted in full collectivization by the late 1950s. Private property rights to land and assets were erased, and markets for private transactions were banned (Fairbank, 1986: pp. 281-5). Agricultural workers were forced to work under constant monitoring and were no longer rewarded for their marginal input into production (Johnson, 1998). By the end of the 1950s, there were no wages or cash rewards for effort.[11]

Grain production was harvested and stored communally. Private stores of grain were banned. This ban was sometimes enforced with virulent anti-hiding campaigns (Becker, 1996: pp. 109). Grain was procured by the central government from communal depots after the fall harvest around November. Procured grain was fed to urban workers, exported to other countries in exchange for industrial equipment and expertise, and stored in reserves as insurance against

(2010), Shiue (2002, 2004, 2005) and O'Grada (2008). Also, Dreze (1999) and O'Grada (2007) provide overviews of this literature.

[8]Davies and Wheatcroft (2004) estimate that up to 6.5 million died across the Soviet Union during the 1932 famine. In North Korea, it is commonly believed that 2-3 million individuals, approximately 10% of the total population, died during this famine (e.g., see Haggard and Noland, 2005; and Demick, 2009). There are very few academic studies or reliable accounts of details related to this famine.

[9]See the previous version of this paper, Meng, Qian and Yared (2010) for a detailed discussion on how agricultural collectivization during the 1950s reduced rural households' ability to smooth consumption.

[10]We calculate this from data reported by the National Bureau of Statistics (NBS).

[11]See Walker (1967, p. 16-7) for a detailed chronological description of collectivization.

natural disaster.[12]

The grain retained by rural regions was fed to peasants in communal kitchens, which were established so that the collective controlled food preparation and consumption. The government prevented peasants from migrating, and thus, they were mostly bound to consume the amount distributed in their collective (Thaxton, 2008: pp. 166). When that was insufficient, then famine occurred.

2.2 The Famine

In 1959, per capita grain production fell by approximately 15% from the previous year, after ten years of nearly monotonic growth. The official explanation provided by the government was bad weather. Recent studies have provided evidence that the fall in output was only partly due to bad weather; it was also due to bad government policies such as the diversion of resources away from agriculture to industrialization, and weakened worker incentives.[13]

The majority of deaths occurred when local stores of the 1959 harvest ran out during the early part of 1960 (Becker, 1996: pp. 94; Thaxton, 2008: p. 207-10). Approximately 30 million people died in the spring and summer months of 1960. Famine primarily struck the rural areas. Communal kitchens, which survivors recall as having served large quantities of food, suddenly ran out. Peasants scavenged for calories and ate green crops illegally from the field when they could (*chi qing*) (Thaxton, 2008: p. 202). Mortality rates were mostly concentrated amongst the elderly and young children, and some believe that over half of total deaths were of young children under five years of age (Ashton et al., 1984: Tables 3 and A7; Spence, 1991: pp. 583). Most of the prime-age adults survived (Thaxton, 2008: p. 202-10).

"People really did die of starvation−in contrast to many other famines where disease loomed large on the horizon of death" (Dikotter, 2010: p. 285).[14] This is an important point to keep in mind for calculating the caloric requirement for avoiding mortality in the Chinese context.

In recent years, a broad consensus has formed that the government over-procured grain from rural areas in the fall of 1959, and this exacerbated the production decline and caused the massive mortality in the spring months of 1960. There are many hypotheses for what caused the over-procurement. The central government placed the blame on local leaders, accusing them

[12]Historical central planning documents state that approximately 4-5 million tons per year were put into reserves as insurance against natural disasters (Sun, 1958). During the late 1950s, total grain exports were approximately 2% of total production (Walker, 1984: Table 52).

[13]The policies include 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) compile province-level panel data on grain production and attempt to quantify the impact of various potential factors. They find that in addition to weather, the relevant factors were over-procurement and the diversion of labor away from agriculture during the Great Leap Forward for projects such as rural industrialization.

[14]The low level of disease in rural areas during the famine has been attributed to the limited population movements, the prevalent use of DDT prior to the famine, and public health measures taken by the government during earlier years (e.g., Becker, 1996; Dikotter, 2010: ch. 32; Fairbank, 1986: p. 279).

of over-reporting production and consequently leading the central government to over-estimate true production (Thaxton, 2008: p. 293-9). Recent academic studies have found that over-procurement was driven by multiple factors, including the government's bias towards providing high levels of food to urban areas (Lin and Yang, 2000), the political zealousness and career concerns of provincial leaders (Yang, 1996 and Kung and Chen, 2011) and an over-commitment by the central government to meeting export targets (Johnson, 1998). In addition, some have argued that mortality rates were exacerbated by food wastage in communal kitchens (Chang and Wen, 1997).

2.3 Government Response and the Aftermath

The Chinese government did not begin to systematically respond to the famine until the summer of 1960, after most of the mortality had already taken place during the preceding spring. The government responded in several ways. It returned workers who had been recently moved to urban areas to assist in industrialization back to their home villages. This was intended to replenish the greatly weakened and demoralized rural labor force in order to minimize further falls in production (Li and Yang, 2005; Thaxton, 2008: pp. 169). Urban food rations were reduced, although not to the level below that needed to prevent significant urban famine mortality (Lin and Yang, 2000). The government also abandoned many of the more extreme policies of collectivization (Walker, 1967: p. 83, 86-92; Thaxton, 2008: ch. 6, pp. 215-16). For example, households again stored and prepared their own food, peasants were again allowed to plant strips of sweet potatoes for their own consumption, and the government sometimes also turned a blind eye to the black market trading of food across regions and the illegal consumption of green crops; all this helped preserve lives until the next harvest (Thaxton, 2008: ch. 4).

These measures could not prevent another decline in production in 1960, this time caused by the the diminished physical capacity of the rural labor force, the lack of organic inputs such as seeds and fertilizers which had been consumed during the months of deprivation (e.g., Li and Yang, 2005), and the consumption by starving peasants of green crops from the field (Thaxton, 2008: p. 202). Despite the further fall in production, the government continued to fulfill its commitments to grain exports, which were based on expectations of high yields formed before the production fall. Exports peaked in 1959 and 1960.[15] In 1961, the government finally ended the famine by sending large amounts of grain into rural areas. Thirty million tons of grain reserves were depleted (Walker, 1984: Ch. 5) and China switched from being a net-exporter to a net importer of grain (Walker, 1984: Table 52). Grain production recovered in subsequent years.

After the famine, procurement rates were kept at a much lower level than during the famine-era, although the procurement policy remained largely unchanged otherwise. Consistent with the low procurement levels and the government's needs to feed its growing urban population, China remained a net importer of grain for several decades. The government did not attempt to

[15]Net exports of grain declined very little, from 3.95 million tons in 1959 to 3.2 million tons in 1960 (Walker, 1984: Table 52).

re-implement the extreme policies from the Great Leap Forward (GLF) that were abandoned in reaction to the famine. China experienced several aggregate production drops of approximately 5%-10% in per capita terms, but never experienced another fall as large as that of 1959 (e.g, 15%). These factors may explain why there were no other famines in China after 1959 (Walker, 1967: ch. 6; Thaxton, 2008: ch. 6).

Politically, the central government engaged in various public campaigns to preserve political support during the famine's aftermath. This was necessary since the famine had primarily affected the rural population which represented the support base of the communist regime. The government limited the reports of famine and minimized the mortality numbers; it initiated large-scale propaganda campaigns such as *yiku sitan* to convince the population that bad weather and corrupt bureaucrats were to blame for low production and over-procurement; and it initiated the *fan wufeng* movement to allow peasants to punish local leaders for famine crimes (Thaxton, 2008: p. 293-99).

3 Rural Caloric Requirements and Food Availability

To motivate our analysis of the variation of famine severity across the rural population, we investigate whether average rural food availability post-procurement in 1959 is low enough to cause a massive famine when food availability is equally distributed across the rural population. The purpose of our study is to understand how the famine began, and we take it as given that once famine occurs, it may take many years for production or mortality rates to recover to pre-famine levels. Therefore, we compute per capita caloric requirements and average per capita rural food availability only for the years immediately leading up to the famine.

3.1 Per Capita Caloric Requirement

We calculate two benchmarks for caloric requirements: (1) the caloric needs for heavy adult labor and healthy child development, and (2) the caloric needs for staying alive. To adjust for the demographic structure, we use the published tables extracted from the *1953 Population Census.*

We estimate that daily average per capita requirements in 1959 were 1,871 calories for the first benchmark and 804 for the second benchmark. These estimates are lower than average caloric requirements for adult workers because they also account for young and elderly individuals in the population, who require fewer calories per person. The details of the calculation are presented in the Appendix. It is important to note that our estimates are constructed to bias away from finding there was sufficient rural food availability. We use extremely generous caloric requirement guidelines and also assume that the entire adult population engages in heavy labor.

The main caveat in interpreting these estimates is that pre-famine historical data on age and sex distribution in China is available only for 1953. This does not affect our interpretation of caloric needs on the eve of the famine since the demographic structure is unlikely to have experienced large changes between 1953 and 1959.[16] However, since the young and the elderly were more likely to have perished during the famine, the demographic distribution after 1959 is likely to be substantially different from our data. This is another motivation for our focusing the caloric exercise on 1959 and the immediately preceding years.

3.2 Per Capita Rural Food Availability

Grain production, total population and urban population data are published by the National Bureau of Statistics (NBS). Our main sample for this analysis is a panel of 29 provinces.[17] Tibet is excluded throughout this study because there is no data for it until 1978. This does not affect our study because Tibet was largely economically autonomous and not a part of the national food procurement and distribution system during the famine era. A more important omission is Sichuan, a net-exporter of food in China. There is no grain production data for Sichuan for 1959 and 1960. However, there is population data. We construct our estimates of per capita food availability to bias downwards by including the population, but not the production of Sichuan into the aggregate calculations.

The data on grain production is not disaggregated by types, which include rice, sorghum and wheat. Therefore, to convert the retained grain into calories, we use the Chinese *Ministry of Health and Hygiene's (MHH)* estimate of calories contained in the typical mix of grains consumed by an average Chinese worker; we assume that one kilogram of grain provides 3,587 calories. Moreover, we assume that individuals subsist solely on grain, which is a reasonable description of the diet of Chinese peasants in the 1950s (Walker, 1984).

The data for national grain production and total population are displayed in Table 1 columns (1) and (2). In column (3), we use these data to estimate per capita production, which is then converted into per capita food availability in terms of calories using the MHH's estimate of calories per kilogram of grain. Aggregate production in column (1) and estimated per capita food availability in column (4) show that although production and food availability declined from 1958 to 1959, national production provided approximately 2,457 calories per capita in 1959, which was well over 300% of the 804 calories necessary for preventing mortality and over 132% of the 1,871 calories minimum required for heavy labor and healthy child development.

We examine the amount of rural grain retention by using the production data described above and national procurement data reported by the Chinese Ministry of Agriculture (1983). This includes net procurement from 24 provinces over the years 1956-1966.[18] In columns (5)-(8),

[16] Applying the 1953 demographic structure to the 1959 year-end population is likely to cause us to over-estimate caloric requirements because life expectancy and fertility rates were both increasing during 1953-59. This means that there were proportionally more elderly and very young individuals in the population in 1959 than we assume for our estimates. Since the very young and elderly require fewer calories than prime age adults, this results in our calculations over-estimating population caloric needs.

[17] See the Data Appendix for details.

[18] The procurement data were generously shared with us by Kung and Chen (2011). Relative to the main sample, the national procurement excludes the three urban municipalities and the provinces of Hainan and Xinjiang. Net procurement is the difference between the grain that is procured by the central government and the transfers of

we show the data for aggregate grain production, total population, rural population and the aggregate grain procurement rate for the 24 provinces included in the aggregate procurement data. We calculate per capita rural food availability as the difference between production and procurement divided by rural population size. This is converted to calories using the MHH conversion metric. Columns (8) and (10) show that although 23% of grain production was procured in 1959, the rural population was still left with food that would provide roughly 2,338 calories per capita per day. This is approximately 25% more than the requirement for heavy labor and healthy child development and 190% higher than the requirement for avoiding mortality.

Next, we present estimated rural retention for the main sample which additionally includes the rural population and grain production from the primarily urban provinces. We assume that national procurement rates are equivalent to the aggregate procurement rates from the 24 province sub-sample. This produces very conservative estimates of rural retention since the urban municipalities were taxed at negative procurement rates (i.e., they received grain subsidies). Applying these procurement rates to the national production and rural population data (columns (1) and (11)), we estimate that average rural food availability at the end of 1959 is approximately 2,336 calories per person per day (see column (13)). This is lower than per capita food availability based only on production, but still well above the requirement necessary for heavy labor and avoiding mortality. These estimates suggest that the average rural retention was at least 31% above the level required for heavy labor and healthy child development and at least 203% more than the level required for avoiding mortality.

The main caveat for interpreting these estimates is that official production data may overstate production in order to minimize the appearance of failure of the Great Leap Forward (GLF) agricultural policies. The government may have also overstated or understated procurement, depending on whether it wished either to emphasize the successes of the GLF policies for production or to minimize the government's role in causing the famine. To address this, we have followed several recent studies on the famine in using production and procurement data that was corrected and reported during the post-Mao reform era, when the government had no incentive to glorify or undermine the GLF. Nevertheless, one should interpret the estimated rural food availability loosely. The key point is that the estimates suggest a level of food availability that is so far above the level required for avoiding mortality that it is highly unlikely to be driven by reporting error.

Note that our estimates of per capita rural caloric availability are comparable, though slightly higher than Li and Yang's (2005) estimate of 2,063 calories per rural worker. The difference arises because our estimates are based on net procurement while their estimates are based on gross procurement. However, both estimates are consistent on the main point that rural food availability was too high to cause famine mortality without the presence of inequality within the rural population.[19] The next section investigates the implication of this point.

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grain from the central government.

[19]Note that Ashton et al.'s (1984) estimates of national per capita food availability in 1959 is 1,820 calories

4 Within-Rural Variation in Famine

This section examines the extent to which the implied within-rural variation in famine intensity is spatial. There are no direct measures of famine deaths. We have data for total mortality and survival outcomes which are correlated with famine deaths. Since the variation in these outcomes across regions also reflect underlying differences other than famine, we compare the cross-regional variation in these outcomes between famine years and other years.

4.1 Province-level Variation in Mortality Rates

The examination of cross-province variation follows existing studies in using national and province-level historical data on mortality rates to proxy for famine severity. The sample used in this exercise includes 28 provinces from the NBS province-level data we presented earlier.[20]

Figure 1 shows that average province mortality rates spike upwards in 1960, following the 1959 harvest. It plots the normalized variance in mortality rates over time, which we calculate as the cross-province standard deviation divided by the cross-province mean. This normalization addresses the possibility that the standard deviation is likely to be mechanically and positively correlated with the mean. Figure 1 shows that the normalized variance also spikes upwards in 1960.[21] Note that the historical mortality data does not distinguish between urban and rural populations, an issue we address below.[22]

4.2 County-level Variation in Survival Rates

Here, we examine spatial variation in famine severity at a finer geographic level by using another proxy for famine severity: the birth-cohort size of survivors amongst the agricultural population of each county, constructed from the 1% sample of the *1990 China Population Census*.[23]

per day. This is lower than the estimates from our study and Li and Yang's (2005) because they assume that the grain remaining after gross aggregate procurement is deducted from aggregate production is used to feed the entire population (both urban and rural). In practice, most of the procured grain is used to feed the urban population and the post-procurement retention is used to feed only the rural population. However, even their estimates are sufficient for heavy labor and healthy child development, and much higher than the level needed to avoid mortality.

[20]Since Sichuan does not report production data for 1959, we exclude this provinces for all years for consistency. The inclusion of Sichuan does not affect our results. We do not report them for brevity, but they are available upon request. Recall that Tibet is never in our sample.

[21]Note that this is a conservative measure of variance in 1960 since the denominator in the normalization is the mean, which we have shown to spike upwards in 1960.

[22]If we assume that mortality only occurs within the rural population, we can address this issue by normalizing by the rural population (normalized mortality rates = total mortality rates × total population/rural population). Data for total and rural population are also reported by the NBS. This normalization does not change the observed pattern of a spike in the mean and normalized variance of mortality rates during the famine. These estimates are omitted for brevity and are available upon request.

[23]Agricultural populations are defined to be households that report as having the official status of an agricultural household registration. These statuses were assigned in the early 1950s and there was very little mobility from being an officially identified agricultural household to a nonagricultural household between then and 1990. The main distinction for agricultural households is their obligation to deliver a grain tax to the central government, their right to farm land, and their lack of access to urban public goods such as health care, schooling, and housing.

Birth-cohort size is negatively correlated with famine severity as it captures the reduced fertility and increased mortality caused by the famine. We construct this famine severity index for the county-level, which is the lowest official administrative division in China.[24] In addition to allowing us to identify rural individuals, this proxy provides several advantages over the mortality rate data. First, it allows us to disaggregate our analysis to the county-level and examine whether the same spatial variations observed at the province-level also exist at this lower level of administrative division. Second, the larger sample size gives our estimation higher statistical power and allows us to examine famine severity in provinces for which we do not have data from the NBS publications. Finally, this measure of famine severity is not vulnerable to the misreporting caused by the government's desire to understate famine severity. Given the focus of our paper on rural inequality in famine severity, we focus our analysis on agricultural populations.

Note that policies against labor migration caused there to be very little rural migration between when the famine occurred and when survivor cohort sizes are measured in our data.[25] To check that the birth-cohort size of survivors is a good proxy for famine mortality, we compare survivor cohort sizes and mortality rates at the province-level. We find that these two measures are negatively correlated such that higher mortality rates imply smaller survivor cohort sizes, and the correlation is highly statistically significant.[26]

The effect of famine can be observed in the birth-cohort size of survivors. Figure 2A plots the size of birth-cohorts in 1990 for all of China. The dotted straight line illustrates the positive trend in birth-cohort size over time, which reflects the combined forces of increased fertility, a reduction in infant and child mortality, and the effect of age on mortality. The comparison of the actual birth-cohort sizes and the projected linear trend shows that the former begins to deviate from the trend for birth-cohorts born as early as around 1954, and then sharply declines for individuals born during the 1959-61 famine, before returning to trend after the famine. The negative deviation from trend suggests that individuals who were aged approximately five years and younger when the famine began at the end of 1959 (e.g. born 1954-58) were more likely to perish than older children.[27] The steep decline for individuals born during the famine captures the additional vulnerability of very young infants to famine, together with a reduction in fertility

For these reasons, there is an unwillingness on both the government's and the farmers' sides to switch official statuses. An alternative way to identify rural populations is to identify everyone living in a non-urban county as rural. This does not affect our results. For brevity we do not report these results with the alternative data construction. They are available upon request.

[24]In the famine era, each county had approximately five communes (also known as collective farms), each containing approximately 5,000 households. However, communes were not an official level of government. We know of no data that can be disaggregated to the commune level.

[25]For discussions of migration restrictions, see West and Zhao (2000), which surveys a large number of studies on internal migration in China.

[26]We aggregate birth-cohort sizes to the province and year (birth year) level and regress the log of birth cohort size on the log of mortality while controlling for the log of total population and year and province fixed effects. The correlation is -0.28 and statistically significant at the 1% level.

[27]The gap between the projected trend and actual birth-cohort size of survivors for individuals born immediately before the famine reflects child mortality unless fertility declined for those cohorts for some other reason. However, if fertility was higher than trend during the years immediately preceding the famine, then the gap between birth-cohort sizes and the linear projection understates the level of child mortality for those cohorts.

during the years of the famine, which is consistent with the fact that adult famine victims lose the biological ability to bear children before starving to death. These patterns are also consistent with qualitative accounts that very young children (and the elderly, whom we do not observe in the data) were most likely to perish and that very few children were born during the famine. It is interesting to note that the relative success of the child-bearing age population in surviving the famine is consistent with the observed rebounding of cohort sizes soon afterwards.

To adjust the cohort size in a way that is easily comparable to the mortality rate data shown in Figure 1, we calculate a ratio of birth-cohort size in each year to the average county birth-cohort size over the period 1949-1966, assuming that the latter is highly correlated with historical county population size. As with the mortality rate data, we normalize the variance of this variable by its mean. These estimates are plotted in Figure 2B, which clearly shows a simultaneous drop in cohort size and an increase in its variance for the famine years.

We next explore the variance within provinces. We construct a proxy for famine severity that is each county's famine birth-cohort size (1959-1960) relative to its non-famine cohort size (1954-1957). This proxy takes a smaller value when the famine is more severe.[28]

Table 2 columns (1)-(4) present the estimated mean, normalized variance (standard deviation divided by the mean), and the minimum and maximum values of this famine severity proxy for China as a whole and for each province. These descriptive statistics show that for China as a whole, the famine birth-cohort size is approximately 70% of the pre-famine birth-cohort size. However, there is enormous spatial variation. For the hardest hit county, famine birth-cohort size was less than 14% of the pre-famine cohort. Column (5) shows the fraction of counties within a province that suffered relatively little famine, which we measure as the fraction of counties that have famine birth-cohort sizes that are equal to or greater than pre-famine cohort sizes. Approximately 11% of counties experienced little famine according to this measure.[29]

The province-specific estimates show that there is both substantial cross-province and within-province variation in famine severity. The variation across provinces can be observed by comparing the famine birth-cohort size in the hardest hit provinces of Anhui and Sichuan, which are nearly half as large as the pre-famine birth-cohort size, to that of Beijing, where the famine and pre-famine cohort size are similar. The variation within provinces can be observed from the large standard deviations of within-province famine severity shown in column (2).

We also investigate whether the spike in variance is driven by outliers by plotting histograms of the county-level famine-to-non-famine birth-cohort size ratio. Appendix Figure A1 shows that famine severity was distributed roughly normally across counties in China. Thus, it is very unlikely for the observed variance in Table 2 to be driven by outliers. Province specific histograms in Appendix Figure A2 show that the variances of famine severity within provinces

[28]For example, it is less than one if the birth-cohort size of individuals born during the famine is smaller than that of individuals who were age two to five years when the famine began. A value that is greater than one would suggest that a county was relatively unaffected by the famine.

[29]Note that the birth-cohort sizes of those who were born during 1954-57 were also reduced by famine exposure. Thus, our proxy is likely to understate the fraction of counties that suffered famine.

are also unlikely to be driven by outliers.

5 Spatial Patterns of Famine and Grain Production

The previous section shows that there is significant variation in famine severity within rural areas. This section investigates how the spatial patterns in famine severity relate to regional food production.

5.1 Province-Level Mortality Rates and Per Capita Grain Production

We first examine the province-level relationship between grain productivity and mortality rates. Our specification uses province-year data on grain production, total population, urban population and mortality rates reported by the NBS. The sample includes the same 28 provinces as the exercise in Section 4.1 and includes all of the years for which data are available—from 1949 to 1998.

First, we document the pattern of regional grain production in 1959. Aggregate per capita production in 1959 was approximately 15% below that of 1958. The data on regional per capita production show that the fall was roughly proportional across regions in that the ranking for per capita production in 1959 was similar to previous years, but the magnitude of the fall was larger in more productive regions. The correlation between 1959 and 1958 per capita production is 0.99 (p-value 0.0001) and the correlation between the difference of 1959 and 1958 per capita production and 1958 per capita production is -0.37 (p-value 0.05), implying that the more productive regions experienced a larger absolute drop in production.[30]

Second, we explore the cross-sectional correlation between productivity and mortality rates. This can can be characterized by the following equation:

$$m_{it+1} = \alpha p_{it} + \beta p_{it} \mathcal{I}_t^{Fam} + \mathbf{Z}_{it}' \gamma + \eta_t + \varepsilon_{it}. \tag{1}$$

where m_{it+1} is the *log* number of deaths in region i during year $t+1$; p_{it} is log grain production; $p_{it}\mathcal{I}_t^{Fam}$ is the interaction of log grain production and a dummy variable for whether it is a famine year, where $I_t^{Fam} = \{0, 1\}$ is a dummy variable that equals 1 if the observation is of year $t = 1959$; $\mathbf{Z}_{it}$ is a vector of province-year level covariates; η_t is a year fixed effect; and ε_{it} is an error term.

The dependent variable is mortality in the next year because food production in a given year is harvested towards the end of the year and used to feed the population for approximately the following twelve months. Mortality rates in 1960 are the outcome of retained food from the 1959 harvest. The vector of covariates in the baseline specification, $\mathbf{Z}_{it}$, includes the log total

[30]Regional per capita production in 1959 is similarly positively correlated with regional per capita production in earlier years. For example, the correlation between 1959 and 1957 per capita production is 0.61 (p-value 0.0007) and the correlation between the difference of 1959 and 1957 per capita production and 1957 per capita production is -0.43 (p-value 0.16).

population, which normalizes our estimates so that we can interpret them in per capita terms, as well as the log urban population, since we are interested in the variation across rural areas. Year fixed effects control for all changes over time that affect regions similarly and they subsume the main effect for the famine year dummy. In order to fully capture the cross-sectional correlation between productivity and mortality rates, we do not control for province fixed effects. To address the presence of heteroskedasticity, we present Newey-West robust standard errors.[31]

Equation (1) estimates the cross-sectional correlation between productivity and mortality rates for non-famine years as $\widehat{\alpha}$, and the correlation during the famine as $\widehat{\alpha+\beta}$.

Before presenting the results, recall that the sample includes the autonomous regions of Guangxi, Xinjiang, Ningxia, Qinghai and Neimeng (also known as Inner Mongolia), which are dominated by ethnic minorities and experience different political and economic policies from the rest of the country. Also, note that the data are not available for all provinces until 1955. For example, in 1949, data on mortality is only available for 15 of the 28 provinces.

The estimates of equation (1) are reported in Table 3. Column (1) uses the entire sample, column (2) excludes the autonomous regions, and column (3) excludes the autonomous regions and the earlier years with an incomplete number of provinces. The sum of the estimates of the interaction term between grain production and the famine year dummy and the main effect for production, $\widehat{\alpha+\beta}$, is presented at the bottom of the table along with its p-value. These estimates show that per capita grain production is positively correlated with the mortality rates for the year of the famine. This correlation is statistically significant at the 1% level when we restrict the sample to exclude autonomous provinces in column (2), and it is not affected by the further exclusion of the years 1949-54 in column (3). In terms of magnitude, the point estimates in columns (2) and (3) suggest that a province which produced 10% more grain per capita experienced 2.0% higher mortality per capita during the famine.

The estimates also show that grain production per capita is negatively correlated with death per capita during non-famine years. The magnitude of the estimate is small, but it is statistically significant at the 5% and 1% levels. Interestingly, note that our estimates also show that provinces with a higher urban population experienced lower mortality, which is consistent with the fact that the famine primarily affected the rural population.

These estimates show that 1959 grain productivity was positively correlated with 1960 mortality rates, but otherwise negatively correlated on average. However, the grouping of all of the non-famine years together may cause us to mistakenly interpret these estimates if the correlation between productivity and mortality rates is very volatile. In this case, the interaction term may capture a spurious positive correlation, while our main grain productivity term averages over the other positive and negative correlations over time to produce a small negative coefficient.

To investigate this possibility, we estimate the yearly correlation between productivity and

[31] Our results are similar if we cluster the standard errors at the province level. These results are not presented for brevity and are available upon request.

mortality rates in the following equation:

$$m_{it+1} = \sum_{\tau=0}^{T} \alpha_\tau p_{i\tau} \mathcal{I}_t^\tau + \mathbf{Z}'_{it}\gamma + \eta_t + \varepsilon_{it}, \tag{2}$$

where m_{it+1}, p_{it}, $\mathbf{Z}_{it}$, η_t, and ε_{it} are the same as previously defined, but where $\mathcal{I}_t^\tau = \{0,1\}$ is a dummy variable which equals one if the observation year t is equal to the year τ, and we no longer control for the grain productivity main effect because we do not discard any years in estimating the interaction effects. Equation (2) is isomorphic to equation (1); it is more flexible in that it allows the coefficient on productivity to vary across all years. In this equation, α_t is the cross-sectional correlation between mortality rates and productivity in year t. To address the presence of heteroskedasticity, we present Newey-West robust standard errors.

Figure 3 plots the estimated coefficients of $\widehat{\alpha}_t$ and their 95% confidence intervals. The coefficients and their standard errors are presented in Appendix Table A2. The figure shows that the correlation between grain productivity and mortality rates is statistically similar to zero for most years, but spikes upwards in 1959. The point estimate for the interaction term of log grain and the dummy for 1959 is statistically significant at the 1% level. This shows that the spike in the productivity-mortality correlation is unique to the year of the famine.[32]

5.2 County-Level Survivor Birth-Cohort Sizes and Natural Conditions

Next, we examine the spatial pattern of famine severity and grain productivity across counties using the data on birth-cohort size of survivors, introduced in Section 4.2 as our proxy for famine severity. The main challenge we face in this exercise is the lack of county-level historical production data. To address this difficulty, we use three proxies for grain production. The first proxy is a time-invariant measure of a region's suitability for grain cultivation based on fixed geo-climatic conditions and the technologies used by Chinese farmers in the late 1950s (e.g., low level of mechanization, organic fertilizers, rain-fed irrigation). The second and third proxies are the average spring temperature and precipitation during the spring months of each year.[33] This is motivated by studies of historical Chinese agriculture which argue that warm spring temperatures and plentiful precipitation were typically very important to a good grain harvest (Walker, 1967, 1984). All of our proxies are highly correlated with realized production for the more recent years for which measures of county-level production exist.[34] For consistency, we restrict the sample to be the same as the province-level mortality rate analysis, and focus on the non-autonomous

[32] Due to space constraints, we only present the effects using the restricted sample which excludes autonomous regions. The estimates show a similar pattern if we use all 27 provinces, but these are less precisely estimated. They are unaffected by the exclusion of both the autonomous regions and the years 1949-54. These results are omitted for brevity but are available upon request.

[33] See the Data Appendix for more details.

[34] The only production data available at the county-level comes from the *1997 China Agricultural Census*. These data show that our natural conditions measures are all positively and statistically significantly correlated with county-level production. They explain 78%-85% of the cross-county variation in production in 1997. These estimates are available upon request.

provinces.[35] The limited number of historical weather stations additionally restricts the final sample, which includes 511 counties. Our sample begins with 1950, the first year for which there is disaggregated weather data, and ends in 1966 to avoid potentially confounding effects of post-famine political events on fertility.[36]

Recall that the province-level production data from the previous section indicates that the rank ordering of productivity across provinces in 1959 was similar to other years. We can check whether this is also true at the county-level by examining the correlation between weather conditions in 1959 to that of earlier years. We find that the correlation between log spring temperatures in 1959 and 1958 is 0.99, and the correlation between log spring rainfall in 1959 and 1958 is 0.96. Both of the correlation coefficients are statistically significant at the 1% level. Thus, the rank ordering of productivity is most likely to be be similar between 1959 and earlier years.

The estimating equation for assessing the correlation between survivor birth-cohort size and our proxies for productivity is similar to equation (1). However, the dependent variable is now log birth-cohort size measured at the county and year level and the main explanatory variables are the proxies for productivity and their interactions with the famine dummy. Recall that when famine struck, the birth-cohorts most dramatically affected in our data are those born during the famine (see Figure 2A). Thus, we define the "famine cohort" as those born during 1959-61.[37] For consistency with our earlier estimates, the dependent variable of our estimate is m_{it+1}, the cohort size for survivors from county i born in year $t+1$. Therefore, we define the famine dummy, $\mathcal{I}_t^{Fam}$, to have a value of one if the year is 1958-60.

Since larger counties will have a larger survivor cohort size, we need to normalize the estimates with county population size. Because there is no historical data for population at the county-level, we control for a time-invariant measure of the average log cohort size in county i between 1949 and 1966. This allows us to interpret the estimated coefficients as the correlation between grain productivity and famine severity, but the magnitude of the estimated coefficients cannot be literally interpreted in per capita terms. All of the county level estimates control for year (e.g. birth year) fixed effects. Standard errors are clustered at the county-level to control for serially-correlated shocks within counties.

We present two sets of estimates. The first set of results does not control for region fixed effects and shows the cross-sectional correlation between famine severity and productivity across counties within China. The second controls for province fixed effects to show the correlation across counties within provinces.

The results are reported in Table 4. Columns (1)-(4) present the estimates without province

[35] The results from using a sample with the autonomous regions are very similar and are available upon request.

[36] The results are similar if we extend the panel to include those born after 1966. These results are not reported due to space constraints, but are available upon request.

[37] By leaving individuals from cohorts that were less affected by the famine (e.g., cohorts born immediately before the famine who were very young when famine struck) in the control group, we bias the interaction term of the famine birth-cohort dummy and productivity towards the estimated main effect of productivity.

fixed effects. They show the same pattern for each of our proxies, regardless of whether we estimate their effects separately (columns (1)-(3)) or in one equation (column (4)). The productivity proxies are positively correlated with survivor cohort size for non-famine birth-cohorts, but negatively correlated for famine birth-cohorts. The latter is the sum of the coefficients for the proxy and its interaction with the famine dummy presented at the bottom of the table, together with the p-value. The estimates are statistically significant at the 1% level when each proxy is estimated separately in columns (1)-(3). In column (4), when we estimate the correlations of all three proxies and their interactions simultaneously, the signs for all three proxies are similar to the individual estimations. The estimated coefficients for log spring temperature, suitability and their interactions are statistically significant at the 1% level.

In columns (5)-(8), we present the estimates with the additional control of province fixed effects. A comparison of the joint estimates in column (8) with those in column (4) shows that the estimates of within-province fixed effects are similar to the previous estimates. The p-values show that the estimates for log spring temperature and suitability are statistically significant at the 1% level. These results show that the positive correlation between productivity and famine severity is present at the county-level within provinces. We introduce additional controls in columns (9)-(10). They are discussed later when we consider alternative explanations.

Next, we estimate the correlation between productivity and birth-cohort size for each birth year in an equation similar to equation (2). The dependent variable is the log of the size of the birth-cohort of survivors born in year $t+1$. The main explanatory variables are the interaction terms between each of the three productivity proxies and the full set of year dummy variables. The estimation also controls for the log of average birth-cohort size in each county and year fixed effects. To focus on the within province variation, we include province fixed effects. For brevity, we only present the estimates where all three proxies and their interactions are included in one equation.[38] The coefficients of the estimated interaction terms and their 95% confidence intervals are plotted in Figures 4A-C. The coefficients and the standard errors are shown in Appendix Table A3.

These figures show that suitability and weather conditions are negatively correlated with birth-cohort sizes of survivors for cohorts born close before the famine and during the famine, but is either positively correlated or uncorrelated for those born in other years. The estimates of the correlations between birth-cohort size and suitability and spring temperature in Figures 4A-B are very precise. The estimates of the correlation between survivor birth-cohort size and spring precipitation in Figure 4C exhibit similar patterns over time, but are less precise. We focus our discussion below on the estimates in Figures 4A-B.

The interpretation of the negative correlation between natural conditions (suitability and spring temperature) and survivor birth-cohort size for individuals born during the famine in 1960 is straightforward. Smaller survivor birth-cohort sizes in productive regions show that

[38] We find similar patterns when we do not control for province fixed effects and when the effect of each proxy is estimated in a separate equation. These estimates are available upon request.

famine was more severe in those regions. It reduced fertility and increased infant mortality.

To interpret the correlation for those born prior to the famine, recall that being born in a county that produces high levels of food per capita has two potentially offsetting effects. On the one hand, higher food availability may cause higher fertility rates, which increases the cohort sizes of survivors. On the other hand, these individuals are exposed to a more severe famine at very young ages, which reduces the cohort size of survivors. Therefore, finding a positive or no correlation between survivor birth-cohort size and natural conditions for those born between 1950 and approximately 1957 implies that the positive effects of higher food availability in the first few years of life cancelled or outweighed the negative effects of famine exposure when these cohorts were two to nine years of age. In contrast, finding a negative correlation between cohort size and natural conditions for those born during 1958 and 1959 implies that the negative effects of famine exposure when these victims were less than two years of age outweigh the positive effects.

Similarly, being born in a productive region has offsetting effects on survivor birth-cohort size for those born after the famine. On the one hand, survivors living in productive regions were likely to have had more food relative to less productive regions after the famine.[39] This could speed the recovery from famine, increase fertility, reduce infant mortality, and thereby, increase survivor cohort sizes. On the other hand, famines of greater severity in productive regions mean that these regions suffer larger population losses, which results in a smaller population base for bearing and rearing children after the famine. The finding that the correlation between survivor birth-cohort sizes and natural conditions are zero or positive for those born after the famine implies that the positive effects outweigh or cancel the negative effects. This is not altogether surprising since individuals of child bearing age suffered the least from famine and are believed to have emerged relatively intact.

In summary, the patterns we uncover at the county level are similar to those at the province level – productivity and population well-being are negatively associated during the famine, but not during other years. This is important for several reasons. First, it motivates us to develop an explanation that is consistent with variation at high and low levels of government administration. Second, finding that the spatial patterns exist across rural counties within provinces addresses the potential concern that our province-level estimates are driven by the possibility that grain production may be spatially clustered in a few provinces, and these provinces may also suffer severe famine for spurious reasons. Finally, finding similar results using the county-level data, which is not subject to the manipulation of the famine era government, means that our results from using the province-level data are unlikely to be driven by mis-measurement in the data.

[39] Recall from Section 2 that many of the GLF policies were lifted in response to the famine. If people can eat what they produce, then there will naturally be more food per capita in regions with good natural conditions. In addition, our hypothesis that the inflexible grain procurement policy caused the spatial patterns between productivity and famine severity predicts that those living in more productive regions have more food per capita during normal years. See Section 6 for details.

6 The Inflexible Grain Procurement Policy

Thus far, we have motivated the examination of within-rural famine variation by showing that average rural food availability was too high to have caused mortality without significant variation in food availability within the rural population. Then, we documented two facts in the data: 1) there is significant variation in rural famine severity both across and within provinces; and 2) population well-being is negatively correlated with productivity during the famine, although there is either a positive or no correlation during non-famine years. The data also show that the fall in production was roughly proportional across regions in 1959.

This section proposes an explanation for unequal within-rural food distribution at the end of 1959 that is consistent with all of the facts above. First, we document that the historical grain procurement policy was very inflexible and could not easily respond to aggregate shocks. Then, we use a stylized example to argue that the inflexible procurement policy caused the spatial patterns of famine severity and productivity observed in the data. Finally, we explore alternative explanations. Note that our finding that famine severity and food productivity are positively correlated cannot be easily explained without understanding the government's food redistributive policy. This is because, absent any redistribution, one would conjecture that food productivity and famine severity would be negatively correlated. In this light, our focus on government procurement policy is consistent with the belief that government procurement played an important role in the famine.

6.1 Grain Procurement System in 1959

The grain procurement system in 1959 was inflexible in that it could not aggregate and respond to information in a timely manner. The central government aimed to procure all grain production beyond what was necessary for sustaining the rural population and for future production (e.g. seed). It set each region's procurement level in advance according to a region-specific production target, and it could not easily adjust this procurement level following the drop in production in 1959. More specifically, production and procurement targets were set at the beginning of the year for each local region (Walker, 1984: ch. 2). The central government set procurement targets for the provinces and "the provincial party secretary divided the provincial target among the different prefectures" (Oi, 1989).

The methods for determining procurement levels for each region are outlined in initiatives such as the "Three Fix Policy" in which procurement targets were based on past production and estimates of subsistence needs.[40] Procurement occurred after harvest in October and November.

[40] In 1956, this policy 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. See Johnson (1998) for a discussion of the food 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.

No reliable data exist on regional procurement or targets for procurement from the famine era. However, such data from the 1980s, a period during which the formula for setting procurement targets was largely the same, The central government would then count the harvest to update production estimates, which was, in turn, used to determine procurement for the following year. Collectives delivered the targeted amount of grain even if they were left with too little for their own consumption.[41]

In the late 1950s, the government typically did not have an accurate estimate of production from the previous year until August of the following year (Walker, 1967: p. 82). These delays in information gathering implied that the system could not respond to shocks in an accurate or timely fashion. For example, reports of the government's response to regional production shortfalls in 1954 found that relief was made, but not made in proportion to the regional decline in output (Walker, 1984, p. 48).[42]

The long delays in gathering and responding to information are not surprising given the limited bureaucratic capacity of China in the late 1950s. At that time, virtually all decisions regarding procurement were made centrally by a Standing Committee of approximately seven individuals (Fairbank, 1986: pp. 297-341; Spence, 1991: pp. 542). Information on the effectiveness of policies was collected locally, aggregated by the regional government, and then eventually reported upwards to the Standing Committee (Fairbank, 1986: pp. 297-341; Spence, 1991: pp. 542). Information collection and policy response proved challenging given China's massive geographic size and poor communication and transportation infrastructure, and this led to significant delays and inefficiencies.[43]

These fundamental limitations in bureaucratic capacity were exacerbated by various historical factors in the late 1950s. First, for budgetary reasons, the bureaucracy was understaffed (Eckstein, 1977: pp. 186). Second, the Anti-Right purges in 1957 sent many of the able bureaucrats to re-education in 1958. This reduced the number of statisticians and demographers to project production figures in 1959, and the central government had to wait longer than usual to know the true production figures (Spence, 1991: pp. 580). Third, political tension during the Great Leap Forward era led to an environment of suspicion and further reduced communication within the government. There was an unwillingness by Mao and his followers to believe reports of low production from local leaders (Dikotter, 2010; Thaxton, 2008; p. 193-8). This reduction in the effectiveness of government was exacerbated by Mao's attempts to solidify his power by reducing the frequency of Standing Committee meetings from twice a week to six times a year

show clearly that procurement targets were an increasing function of the previous year's production. We do not show these data for brevity, but they are available upon request.

[41] Contemporaneous and retrospective survivor accounts show that peasants and local leaders believed that the government, which rose to power with promises of ending famines, would replenish rural grain supplies once they were depleted. For example, Thaxton (2008: p. 109) provides examples of how peasants and village leaders recalled the government's commitment to prevent food crises and examples of food assistance prior to 1959. He also provides examples of how local leaders delivered grain based on a combination of faith in the new regime and its promise to deliver them from privations and a fear of punishment (Thaxton, 2008: p. 117).

[42] These delays also implied that procurement targets were often revised during the spring and summer months to adjust for updated estimates of production from the past year.

[43] Transportation networks were almost completely destroyed by decades of civil unrest and the war with Japan, and repairs had only recently begun (Fairbank, 1986: pp. 278). Urban centers were relatively few and geographically concentrated, and it could take many weeks to reach an outlying collective. Moreover, rural areas were typically not connected by telecommunications infrastructure.

and by removing decision-making power from local governments (Fairbank, 1986: pp. 303).

Aside from limited bureaucratic capacity, one can argue that another reason for the inflexibility of the system is that it helped the central government limit problems of asymmetric information. Relative to the central government, local leaders had much better information on the level of production of their collective, but also had incentives to misreport production to the central government. Historically, local leaders often under-reported production in order to increase their support among local peasants, to retain the unreported grain for personal profit, and to suppress the central government's expectations of future harvests (Thaxton, 2008: p. 293-312).[44] Local leaders were also known to have over-reported production when they felt pressure to meet procurement targets or when promoting themselves politically by meeting or exceeding yield expectations. For the central government, both types of misreporting were problematic: under-reporting reduced government procurement while over-reporting risked government over-procurement and political instability in the countryside, which provided the core support for the communist party.[45] As such, there was an advantage for the central government in preserving a system in which local procurement levels did not solely rely on local reports. Clearly, the incentives to misreport production would be minimized if the central government was committed to procuring a fixed target.[46]

6.2 Implications for Famine Mortality

Here we use a stylized example to demonstrate how the combination of an inflexible procurement policy and a proportional fall in production, such as occurred in 1959, can generate the observed spatial variation between production and mortality.[47]

Table 5 presents the case of a country with three hypothetical regions: two rural regions (A and B) and a city. Each region has a similar population and therefore similar subsistence needs. For simplicity, we assume the latter to be 100 tons of food. However, agricultural endowments differ across regions. Region A is better endowed than region B and hence produces more food per capita. The city produces no food. As was the case in China, the government restricts

[44]The government made extensive campaigns against under-reporting. The fact that this was a prevalent problem in the years leading up to the famine is consistent with under-reporting by local officials being included in a list of "ten evils" that was published in daily newspapers in the late 1950s (Walker, 1984: p. 65). For example, see *Jilinjipao* [*Jilin Daily Newspaper* in Chinese], 1957 December 20th.

[45]The government's concerns over over-reporting is evidenced by the continued political discussions that local leaders should not implement "commandism" during both the first and second Five Year Plans (1953-57, 1958-62) (Walker, 1967: p. 8). In a meeting in Changchou in 1957, Mao personally warned party members to not commit "Stalin's mistake" in terms of over-procurement, which he believed to have turned Soviet peasants against their government (Walker 1984: p. 149). For a detailed example, see Thaxton (2008, p. 132).

[46]This idea can be easily formalized in a mechanism design framework in a setting where the planner tries to induce an agent with a preference for misreporting to truthfully reveal the amount produced. See an earlier version of this paper (Meng, Qian and Yared, 2010).

[47]In a previous version of the paper, we present a formal version of the model and show that the constrained optimal policy of a central planner with utilitarian preferences will cause higher over-procurement in regions that are more productive when there is a fall in output that is broadly proportional across regions. We also evaluate the tradeoffs between a policy that targets quantities versus an alternative policy that targets prices (Meng, Qian and Yared, 2010). Due to space constraints, the formal model is excluded from this version.

population movements so that individuals from low production regions cannot move to high production regions.

There are two states of the world. In the normal state, which occurs with 80% probability, region A produces 250 tons and region B produces 170 tons. The second state is caused by an aggregate shock which occurs with 20% probability, and production is 20% lower for each region, reducing production in regions A and B to 200 and 136 tons. The government expects the aggregate shock to occur with 20% probability. It follows that its expected production of regions A and B are 240 ($250 \times .8 + 200 \times .2$) and 163 ($170 \times .8 + 136 \times .2$) tons, which sum to 403 tons of total production.

In accordance with historical evidence on the inflexible grain procurement policy, the government consistently procures a fixed amount from each region in all states of the world. Since we do not know the precise historical objective function of the Chinese government, we assume for simplicity that the government chooses procurement to equalize expected consumption across its citizens, giving each of the three regions 134 tons of expected consumption. Thus, the government consistently procures the difference between expected production and expected consumption in all states of the world, taking away 106 (240-134) and 29 (163-134) tons from regions A and B and giving the city a subsidy of 134 tons. Actual consumption is not constant across states of the world since it equals the difference between actual production and procurement. Therefore, in the good state, regions A and B consume 144 (250-106) and 141 (170-29) tons of grain; in the bad state, they consume 94 (200-106) and 107 (136-29) tons. The city always consumes 134 tons.

The key insight from this stylized example is that when production falls proportionally, the inflexible procurement policy can cause high levels of famine mortality even though average rural retention is sufficient for avoiding mortality. Since procurement targets are set for each locality, our explanation is consistent with the observation that famine severity varies across across counties within provinces as well as across provinces. More importantly, the example provides a clear illustration of how the inflexible procurement policy would have over-procured more in the more productive regions in 1959, even though this would not have been true during normal years. Mechanically, the absolute drop in production is larger for the more productive region, implying a larger gap between actual and expected production, and this results in over-procurement from the more productive region.

There are several interesting points to keep in mind. First, the main insight from our example of how more productive regions have less food for consumption when there is an aggregate shock to production is not unique to our assumed objective function. For example, if the government's objective is to equalize consumption across rural regions in the normal state of the world, there will still be a negative correlation between productivity and consumption in the presence of a negative shock. A second and related point is that the correlation between productivity and consumption during normal years need not be strongly positive. For instance, in the previous example with the alternative objective function or in the case that the probability of a negative shock is near zero, there will be little or no correlation between productivity and consumption during normal years.[48]

Finally, note that our hypothesis of the inflexible grain procurement system causing the spatial patterns we observe in the data after the proportional production fall in 1959 is consistent with accounts that some local bureaucrats historically exaggerated production reports in 1958. This could cause the government to over-estimate expected production if the government's post-harvest audits do not fully account for the exaggeration, which would in turn exacerbate over-procurement and further reduce aggregate consumption in 1959. Moreover, if the level of exaggeration was positively correlated with actual production, then exaggerated production from previous years could also exacerbate the difference in consumption between productive and less productive regions in 1959. Thus, inflexibility and historical over-reporting are complementary explanations. The key point for our hypothesis is that inflexibility is still necessary for generating these spatial patterns because a flexible procurement system would have avoided over-procurement by adjusting procurement levels after the harvest was realized.

6.3 Alternative Explanations

The main caveat for interpreting our descriptive results as evidence for our hypothesis of inflexible procurement is that it assumes that the within-rural spatial patterns we uncover are not due to omitted factors that could have affected both regional famine severity and food productivity. *A priori*, it seems difficult for alternative factors to explain our findings because such factors would have to cause food productivity and mortality to be positively correlated after the production fall in 1959, but not in other years. A careful review of Chinese history reveals no historical events or policy changes specific to 1959 (other than the production fall) and it is difficult to imagine another mechanism that is built into a permanent policy that would cause this pattern. Moreover, this omitted factor would need to systematically generate the same patterns across all administrative levels of government.

Nevertheless, to be cautious, we investigate the extent to which our results can be explained by other factors. First, we examine the robustness of our empirical results to controlling for factors that are commonly believed to have contributed to the famine. We control for measures of each factor and the interaction of that factor with the famine year dummy in our baseline equation, equation (1). If our main results for the correlation between grain productivity and famine mortality are robust to these controls, then we can conclude that the empirical patterns that match our hypothesis are not the outcome of omitted factors.

Second, we examine the robustness of our results to the possibility that the production falls in 1959 were not fully reported. In particular, we address the concern that in 1959, there were

[48]For interpreting our empirical analysis, which use data for mortality rather than consumption, an additional reason for observing a weak (or no correlation) during non-famine years is that the relationship between food consumption and mortality is highly non-linear such that once a certain level of consumption is achieved, marginal consumption does not correlate as strongly with survival probabilities.

larger, but unreported, production falls in historically productive regions such that the negative correlation we observe between mortality and productivity during the famine does not reflect the true relationship.

For these exercises, we only present results from using the restricted sample of provinces that exclude the autonomous regions. Since many of the variables used here are available only at the province level, we focus the discussion on the province-level results.

6.3.1 Urban Bias

Previous research has established that over-procurement from rural areas was one of the main causes of the famine. Lin and Yang (2000) argue that high government procurement was partly motivated by the government's commitment to feeding the urban population, even if it came at the cost of under-feeding the rural population. If the more productive provinces had higher urban bias (or larger urban populations that continued to be provided with high levels of food rations) after production dropped in 1959, then the interpretation of our main results could be confounded. To address this, we add a control for the interaction term between the log of province-level urban population and the famine year dummy. Recall that the baseline already controls for the log of urban population. The estimates are shown in Table 6 column (2). The estimate for the main effect of log urban population is negative and statistically significant as in all of the earlier estimates, which means that mortality rates are on average lower in provinces with larger urban populations. However, the interaction term is negative and insignificant and shows that the effect of urban bias is not different in 1959. Most importantly, a comparison of the estimates of our main explanatory variables, log grain production and its interaction with the famine dummy in column (2) with the baseline estimate in column (1) shows that our main result is very robust to this control. As before, the two variable joint estimate, which show the correlation in 1959, is shown at the bottom of the table along with its p-value. Our main estimates are both highly statistically significant and similar in magnitude.

6.3.2 Great Leap Forward and Political Radicalism

The famine occurred during the second year of the GLF, a five year period when many misguided policies were often carried out with extreme zealousness. The implementation of these policies is often thought to be a contributing factors to both the production drop in 1959 and the subsequent mortality rates during the famine. It is natural to wonder whether more productive regions implemented GLF policies more zealously, leading to higher food procurement in 1959, and thereby causing higher famine severity. To examine the importance of GLF policies in explaining our results, we examine the existing literature and control for the specific policies that are thought to contribute to either the fall in production or the mortality rates.

First, we consider Li and Yang's (2005) finding that zealousness in pursuing GLF policies contributed to the production fall in 1959. Their proxies for zealousness are the annual growth rate in areas sown for grain and in steel production, because one of the main policies of the GLF was to divert resources from agriculture into manufacturing. Not surprisingly, the data for these two measures, which are reported by the NBS for all the years and provinces of our sample, show a stark drop in areas sown for grain and a marked increase in steel production during 1958 and 1959. We follow Li and Yang (2005) by using these two measures as regional proxies for GLF zealousness and control for each variable and its interaction with the famine dummy. The estimates are shown in columns (3) and (4). Recall that since we control for log total population, the coefficients should be interpreted in per capita terms. The estimate for growth in per capita area sown for grain and its interaction with the famine dummy show that per capita sown area is usually uncorrelated with mortality rates, but in the famine year it is negatively correlated. The estimated interaction effect is large in magnitude and statistically significant at the 10% level. In column (4), we find similar results for the growth in provincial steel production and its interaction with the famine dummy. The interaction effect of per capita growth in steel production and the famine dummy is positive and statistically significant, indicating that there was higher mortality in provinces that experienced higher growth in per capita steel production during 1959.

These estimates support Li and Yang's (2005) argument that GLF policies contributed to the famine. However, the key for our paper is the robustness of main results. The estimates of our main explanatory variables are unchanged by the inclusion of the additional controls. We still find that grain productivity is positively correlated with famine mortality in 1959. The estimates for the joint effects shown at the bottom of the table are statistically significant at the 1% level.

Next, we proxy for zealousness with the year and month in which the province was officially "liberated" by the Communist Party. Past studies such as Yang (1996) and Kung and Lin (2003) argue that a later liberation is positively correlated with political radicalism because more zealous leaders were more likely to be appointed to newly liberated provinces. We expand the data sample of these previous studies to cover all provinces in our study by collecting liberation dates and months from the *Report on the Liberation of the Peoples Republic of China* (housed in the archives of the National Library in Beijing). We construct the liberation date as $year \times 100 + month$. Alternatively, we can construct a dummy for whether a province was liberated before or after the official liberation date of October 1st, 1949. Since both proxies produce similar results, we present only the former for brevity. In column (5), we show the estimates where we control for the liberation date and its interaction with the famine year dummy. The estimates are statistically insignificant and our main results are similar to the baseline estimates.

A recent study by Kung and Chen (2011) argues that political zealousness during the GLF is highly correlated with the magnitude of the Anti-Right purges, which occurred in 1957, a year before the GLF began. In their study, they find that Anti-Right purges are highly correlated with famine mortality rates. In column (6), we control for their measure of Anti-Right purges, the number of individuals purged in each province, which they generously shared with us. Since this variable only exists for 1957, we construct a time invariant value for each province that takes the value of the 1957 purges for all years, and then construct an interaction term of this time-invariant variable and the famine year dummy. The estimates show that, on average, provinces that experienced more purges per capita also experienced lower mortality rates, but during the famine, more purges per capita is correlated with higher mortality rates. The estimates for both the main and interaction effects are statistically significant at the 10% and 1% levels. These results support the findings of Kung and Chen (2011). However, as before, our main results are very robust to these additional controls.

Our final proxy for zealousness is the participation rate in communal dining halls (Yang, 1996). By the eve of the famine, almost all workers ate in communal dining halls. However, past studies, such as Yang (1996), have argued that communal dining participation rates during the mid-1950s, before the famine, can be used as a proxy for GLF zealousness. Using the data reported by Yang (1996) on GLF communal dining participation rates across provinces during the years before the famine, we compute a time-invariant measure of GLF participation rates for each province and construct an interaction term of this measure and the famine year dummy.[49] Column (7) shows that the estimated main effect of the time invariant participation rate variable and its interaction term are both positive and statistically significant at the 1% level. The estimated interaction effect is significantly larger in magnitude than the main effect. These estimates support past findings that communal dining participation rates are correlated with high famine mortality.[50] The key point is that our main results are robust. The joint estimate at the bottom of the table shows that grain productivity is still positively correlated with famine severity. It is still significant at the 1% level.

Finally, to address the concern that perhaps some combination of these alternative factors can explain our main results even if each factor cannot individually do so, we control for all of the factors described above and their interaction with the famine dummy in one regression. Column (8) shows that our main results are similar to the baseline estimates.

In summary, our main results are extremely robust to controls for factors related to the GLF. The estimated interaction effect of grain productivity and famine dummy and the joint estimate of this interaction effect and the main grain productivity effect, are all positive in sign, similar in magnitude to the baseline and statistically significant across specifications. The estimated main effect of grain productivity is sometimes less precise, but always negative in sign, and similar in magnitude across specifications. These results support our argument that the within-rural spatial correlation between grain productivity and famine severity reflects the inflexible grain procurement policy under the 1959 proportional production shock. In addition, the statistical significance of the coefficients for the interaction of the famine dummy and the growth in grain area sown, growth in steel production, liberation date, the extent of the anti-right

[49] Yang (1996) does not report dining hall participation rates for the urban municipalities. We expand this sample by assuming that all workers in the three urban municipalities ate in communal dining halls. Alternatively, we can omit these three provinces from the estimation. The results are similar and are available upon request.

[50] Note that we cannot distinguish between the explanations that communal dining is a proxy for GLF zealousness or that it has a direct effect on mortality through food wastage (or some other channel) as argued by Chang and Wen (1997).

purges and communal dining hall participation rates support arguments from recent studies that GLF zealousness and political incentives contributed to overall famine mortality (e.g., Yang, 1996; Li and Yang, 2005; Kung and Chen, 2011).

Our county-level results are also robust to these controls. Table 4 columns (9)-(10) present the county-level estimates with all of the GLF controls included in one equation, both without and with province fixed effects.[51]

6.3.3 Mis-measurement of Production

A related concern arises from potential misreporting of grain production. In particular, one may worry that the production fall in 1959 was actually larger in historically productive regions, but political pressure to glorify GLF policies caused these production falls to be unreported such that the observed production overstates true production in productive regions. This mis-measurement of production would cause famine severity and productivity to be positively correlated.

A priori, this is unlikely to drive our results since the county-level analysis uses data that is not subject to misreporting by the famine-era government. Similarly, our province-level analysis uses data reported and corrected in the post-Mao era, when such pressures from the GLF were no longer present. Nevertheless, to be thorough, we investigate whether our province-level results are driven by misreporting.

We predict production for 1959 by applying data for agricultural production inputs from 1959 to an estimated production function, which is based on reported data on production and inputs from before the GLF (1954-57), when there was presumably little pressure to misreport production. We then repeat the estimation of equation (1) with the predicted measure of production. If the results are similar to our main results, then we can be confident that our main results are unlikely to be driven by systematic misreporting. Note that this exercise is conceptually analogous to using weather condition data for the county-level analysis in that we are using a measure of production that is not subject to government misreporting errors during the famine.

The province-level data on historical inputs are limited to areas sown for grain, total population and rural population (e.g., the difference between total and urban population). These data are not available for all of the provinces in the main estimation. We estimate a simple production function using data on reported production and inputs from the pre-GLF era 1949-57.

$$lngrain_{pt} = I'_{pt}\alpha + \mu_{pt}. \tag{3}$$

This cross-sectional estimate assumes that the log of grain produced in province p at time t is a function of a vector of inputs, I_{pt}, which include the log of area sown for grain, the log of total population, the log of urban population and their squared terms. μ_{pt} is an error term.

To estimate "true" production for 1958 and 1959, we apply the estimated coefficients, which

[51] Note that the sample for this estimation is smaller than the sample for those without the GLF controls because the latter are not available for all provinces.

are shown in Appendix Table A3, to the reported inputs of 1958 and 1959. To estimate GLF over-reporting for each province, we calculate the difference between reported and estimated production for these two years, and then take the maximum of the two differences as the amount of over-reporting for each province. By taking the maximum, our estimates conservatively allow there to be as much over-reporting as the data allow.

Our estimates imply that provinces may have exaggerated 1959 per capita production by up to 14% on average. In Table 7 column (1), we re-estimate our baseline equation with the real production data using the sample for which we also have input data. In column (2), we assume that there is over-reporting in both of the first two years of the GLF and calculate true production in 1958 and 1959 as reported production minus the estimated over-reported production. In column (3), we assume that there is only over-reporting in 1959 and therefore subtract the estimated over-reported production from the reported production for only 1959. We re-estimate equation (1) with these measures of predicted production and their interactions with the famine dummy. The estimates in columns (2) and (3) of Table 7 show that the results are very similar to the baseline estimates in column (1), which are obtained from using reported production data.

From these results, we conclude that it is highly unlikely for the interpretation of our results to be confounded by the misreporting of grain production in 1959.

7 Conclusion

During the twentieth century, millions have perished from famine and sixty percent of total famine mortality have occurred in centrally-planned economies. The most deadly of these and of all famines in history was the Chinese Great Famine, which killed approximately thirty million individuals in just a few months in the early part of 1960. This paper argues that one cannot really understand the causes of this human devastation, which mostly occurred in the countryside, without understanding what caused famine to be unequal across rural areas. This is because average rural food retention after aggregate procurement was taken into account was too high to cause a massive rural famine. Perhaps not surprisingly, when we examine the data, we find that there is indeed substantial variation in famine intensity across rural areas, even at very disaggregated levels (e.g. counties). We also document a very surprising *positive* relationship between food productivity and famine severity. The finding that famine severity is not higher in regions that produced less food per capita is consistent with the widely held belief that the famine was driven by government policy. However, the patterns we uncover cannot be easily reconciled with existing explanations of the Chinese Famine (see Section 6.3). Thus, we develop a novel explanation based on the inflexible historical grain procurement policy. We argue that inflexibility was a necessary ingredient for producing the within-rural variation in famine severity that we uncover in the data. Since the presence of rural inequality in food distribution was necessary for famine to take place, this suggests that inflexibility was an important factor in causing the famine.

It is interesting to note that inflexibility existed not only China, but also in other centrally planned economies. Therefore, the insights from our work can potentially speak to the causes of famines in these other contexts. In particular, there are striking similarities between the Chinese Famine and the Soviet Famine during 1932-33, which killed up to 6.5 million people in just one year (Davies and Wheatcroft, 2004). Besides obvious similarities in the design of the centrally planned grain procurement policy, the two contexts have several other traits in common. First, in both cases, the transportation and telecommunication infrastructure was poor, and the leaders of the central government distrusted locals to report production truthfully, which contributed to the inflexibility of the grain procurement policy. Second, there is a consensus on the role of high government procurement from rural areas in causing the famine in both cases. However, like the Chinese case, the most conservative estimates of rural retention in the most severely stricken state, the Ukraine, show that average rural food availability after procurement was deducted was approximately 170 kg the year the famine began (Conquest, 1986). While this amount, which provides a diet of approximately 1,671 calories per day, is not a rich diet, it is undeniably more than the level needed to avoid mortality. Most interestingly, one observes similar spatial patterns in mortality rates – they are highest in the most productive regions.[52] These provocative similarities suggest that exploring the role of the inflexible procurement policy in this other historical human tragedy is a worthy topic of future research. In addition, it is important to develop a more generalized framework for understanding the conditions under which the rigid food distribution mechanisms in centrally planned economies can cause famine. The evidence offered in this study is only a small first step in this research agenda.

[52] Conquest (1986) discusses the extremely high mortality rates in the states that produced the most food such as the Ukraine and Khazakastan. A recent study by Sharygin (2011) uses the RLMS data to construct regional famine mortality rates within Russia and finds that the highest mortality rates were suffered by the agriculturally rich regions near the Volga.

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APPENDIX Calculation of Caloric Requirements in 1959-1960

The first benchmark is constructed by combining data on caloric requirements by age and sex, as recommended by the United States Department of Agriculture (USDA), with data on the age and sex distribution in China from the *1953 Population Census*. The recommended consumption by the USDA for working adult and healthy child development is extremely generous and approximately 20% higher than the average caloric consumption of East Asian countries during the mid 1960s.[53]

The second benchmark is calculated to be 43% of the first benchmark due to the scant medical evidence on the amount of calories needed to stay alive. Therefore, we follow Dasgupta and Ray's (1986) assumption that 900 calories are required for an adult male to do some work, and conservatively assume that a similar amount is needed to stay alive. Since 900 calories is 43% of the USDA recommendations for heavy labor by an adult male, we construct the benchmark calories for survival by assuming that the requirement is 43% of USDA recommendations for all age and sex groups.[54]

The estimation for average caloric requirements once the demographic breakdown is taken into account is shown in Appendix Table A1. We estimate that for China, as a whole, 1,871 calories were needed per person per day on average for heavy labor and normal child development, and 804 calories were needed per person per day on average to stay alive.

DATA APPENDIX

Aggregate and provincial-level production, population, urban population and mortality data are reported by the *China Data and Statistical Materials for 50 Years, 1949-98* (CDSMA50), which is published by the National Statistics Bureau (NBS). Historical province-level demographic breakdowns are published as tables from the *1953 Population Census*, and made available to us by the NBS. The typical concern for using production and mortality data reported by the Chinese government is that it has historically under-reported mortality and over-reported production to minimize the severity of the famine for political reasons. The data we use were published in the post-Mao reform era and have been carefully corrected by the NBS to address potential reporting errors from the Mao-years. The difficulty in such revisions results in missing data for some provinces and some years (e.g., there is no data for Tibet until 1978, data for Sichuan are missing for several years). The data reported by the NBS during the post-Mao era are the best

[53]Average per capita food consumption is reported for different time periods and regions by the Food and Agriculture Organization (2002).

[54]Note that our calculated thresholds are generally extremely generous and more than sufficiently take into account additional calories needed for cold winter conditions. See an earlier version of this paper, Meng et al. (2010) for a discussion of the medical evidence. When comparing the caloric needs between our two benchmarks, one should also note that the relationship between calories consumed and work capacity is potentially highly non-linear, as suggested by the nutritional poverty trap theory (Das Gupta and Ray, 1986). This does not play an important role for our study since production in 1959 was in excess of both benchmarks.

that are available to researchers today and have been used by recent studies such as Lin and Yang (2000), Li and Yang (2005) and Kung and Chen (2011). Comparisons across data sources show that these demographic and production data have been adjusted from the Mao-era reports (Ashton et al., 1984). For example, the official figure for 1959 national grain production was 270 million tons according to 1959 reports, but revised downwards to 200 million tons in the official reports in 1980, which was similar to the amount reported by the United States Department of Agriculture and the U.S. Agriculture Attache in Hong Kong (Ashton et al., 1984: Table 6).

The weather data is reported by the *Terrestrial Air Temperature and Precipitation: Monthly and Annual Time Series (1950 - 1996)* data set. Similar data has been used by Dell, Jones and Olken (2008) and Nunn and Qian (2011b). The Chinese weather data were never meant to be publicly released and therefore unlikely to have been manipulated by the famine-era government.[55] We use ArcGIS to calculate the monthly mean temperature and precipitation for each county for the years 1950-66. The measure of suitability for grain cultivation is constructed from a model and data provided by the *Food and Agriculture Organization's GAEZ* (2002) database. It is based purely on the biophysical environment of a region and is not influenced by which crops are actually adopted in an area. Factors that are easily affected by human actions, such as soil pH, are not parameters in this model. The suitability measure at the county level is the fraction of grids within a county that is suitable for the production of all types of grains that were produced in China during the 1950s, a measure we use for the sake of computational ease. These data and measures have recently been used in Nunn and Qian (2011a, 2011b) and Jia (2011). See Nunn and Qian (2011a) for more details on these.

[55]The data was made available only very recently for historical climatology studies. Detailed documentation is provided at http://climate.geog.udel.edu/~climate/html_pages/README.ghcn_ts.html.

Table 1: Production and Food Availability

	National Production				Post-Procurement Average Rural Food Availability: Subsample with Aggregate Procurement Data						National Sample with Imputed Aggregate Procurement**		
	Grain Prod	Total Pop	Per Capita (PC) Production		Grain Prod	Total Pop	Rural Pop	National Proc Rate	Rural PC Retention		Rural Pop	Rural PC Retention**	
Year	(Millions Tons) (1)	(10000 Persons) (2)	(Kgs/Yr) (3)	(Calories/ Day) (4)	(Million Tons) (5)	(10000 Persons) (6)	(10000 Persons) (7)	(Proc/Prod) (8)	(Kgs) (9)	(Calories/ Day) (10)	(10000 Persons) (11)	(Kgs/Yr) (12)	(Calories/ Day) (13)
1957	174.372	61261.4	285	2797	169.574	59077.8	50727.9	0.16	281	2762	51782.7	283	2783
1958	169.817	57691.3	294	2893	164.6	54848.3	46120.5	0.19	290	2846	47404.7	291	2856
1959	148.149	59257.5	250	2457	143.409	55995.1	45784.9	0.24	238	2338	47327	238	2336

Notes: Columns (1-)-(4) include data from 29 provinces. Columns (5)-(8) report data for the 24 provinces included in aggregate procurement accounts. **Assume that the national procurement rate is the same as in column (8). Source: CDSM50 (1999), CPIRC (2000), the Ministry of Agriculture (1983) and the authors' computations.

Table 2: Cross-sectional Variation in Famine Severity Across Counties

Region	Famine Birth-Cohort Size (59-60)/ Pre-famine Birth-Cohort Size (1954-57)				
	Mean (1)	Normalized Standard Deviation (Standard Deviation/Mean) (2)	Min (3)	Max (4)	>1 (5)
China	**0.706**	**0.354**	**0.137**	**1.987**	**0.111**
Beijing	0.966	0.079	0.877	1.082	0.400
Tianjin	0.775	0.249	0.497	1.109	0.200
Hebei	0.708	0.251	0.226	1.105	0.095
Shanxi	0.834	0.304	0.399	1.697	0.216
Neimeng	0.897	0.243	0.517	1.733	0.246
Liaoning	0.725	0.181	0.410	1.162	0.020
Jilin	0.858	0.176	0.424	1.206	0.160
Heilongjiang	0.862	0.254	0.519	1.641	0.278
Shanghai	0.730	0.298	0.407	1.018	0.200
Jiangsu	0.591	0.263	0.243	0.917	0.000
Zhejiang	0.691	0.171	0.463	0.993	0.000
Anhui	0.448	0.452	0.169	0.861	0.000
Fujian	0.720	0.205	0.400	1.042	0.028
Jiangxi	0.742	0.228	0.553	1.071	0.158
Shandong	0.633	0.259	0.211	1.095	0.034
Henan	0.564	0.227	0.320	0.908	0.000
Hubei	0.666	0.251	0.373	1.125	0.043
Hunan	0.517	0.253	0.258	0.769	0.000
Guangdong	0.789	0.286	0.513	1.787	0.068
Guangxi	0.669	0.254	0.313	1.284	0.035
Hainan	0.888	0.215	0.613	1.143	0.300
Sichuan	0.514	0.442	0.162	1.368	0.048
Guizhou	0.547	0.363	0.137	1.171	0.034
Yunnan	0.751	0.379	0.267	1.886	0.153
Tibet	1.371	0.152	1.071	1.765	1.000
Shaanxi	0.872	0.182	0.652	1.409	0.220
Gansu	0.719	0.396	0.213	1.987	0.137
Qinghai	0.623	0.340	0.213	0.949	0.000
Ningxia	0.619	0.226	0.389	0.882	0.000
Xinjiang	0.948	0.322	0.333	1.973	0.392

Note: Each observation is a county. Source: Authors' computations using the *1990 Population Census*.

Table 3: The Correlation between Grain Productivity and Mortality Rates Across Provinces

	Dependent Variable: Ln Deathsin year *t+1*		
Sample:	All	Omit Autonomous	Omit Autonomous and 1949-53
	(1)	(2)	(3)
Ln Grain Production x Famine Dummy	0.121	0.262	0.265
	(0.115)	(0.0701)	(0.0700)
Ln Grain Production	-0.0516	-0.0530	-0.0669
	(0.0184)	(0.0159)	(0.0171)
Ln Total Population	-0.149	-0.174	-0.175
	(0.0170)	(0.0142)	(0.0148)
Ln Urban Population	1.194	1.203	1.222
	(0.0218)	(0.0210)	(0.0225)
Obs	1291	1074	995
R-squared	0.957	0.955	0.953
Joint Ln Grain Production + Ln Grain Production x Famine Dummy	**0.0693**	**0.209**	**0.198**
p-value	**0.547**	**0.00289**	**0.00469**

All regressions control for year fixed effects. Newey-West robust standard errors are presented in parentheses. Notes: These estimates use a province-level panel that include 28 provinces and the years 1949-98 constructed from data reported in the CDSM50 (1999).

Table 4: The Correlation between Natural Conditions and the Birth Cohort Size of Survivors Across Counties

	Dependent Variable: Ln Birth Cohort Sizein year *t+1*									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Ln Spring Temperature			0.292	0.263			0.0772	0.0743	0.499	0.337
			(0.0428)	(0.0489)			(0.0654)	(0.0690)	(0.0625)	(0.128)
Ln Spring Temperature x Famine Dummy			-1.528	-1.415			-1.524	-1.410	-1.118	-1.161
			(0.245)	(0.291)			(0.246)	(0.292)	(0.269)	(0.272)
Ln Spring Rainfall		0.0421		0.00949		0.0410		0.0167	-0.00005	0.0126
		(0.00938)		(0.0105)		(0.0192)		(0.0196)	(0.0152)	(0.0281)
Ln Spring Rainfall x Famine Dummy		-0.222		-0.0278		-0.225		-0.0291	-0.0712	-0.0747
		(0.0523)		(0.0610)		(0.0525)		(0.0613)	(0.0588)	(0.0594)
Suitability	0.0557			0.0511	0.0610			0.0607	0.0290	0.0411
	(0.0159)			(0.0152)	(0.0168)			(0.0164)	(0.0186)	(0.0210)
Suitability x Famine Dummy	-0.447			-0.426	-0.447			-0.426	-0.410	-0.414
	(0.0943)			(0.0911)	(0.0944)			(0.0913)	(0.0987)	(0.0990)
Controls										
Province FE	N	N	N	N	Y	Y	Y	Y	N	Y
GLF Controls	N	N	N	N	N	N	N	N	Y	Y
Observations	8176	8176	8176	8176	8176	8176	8176	8176	5536	5536
R-squared	0.914	0.913	0.914	0.916	0.914	0.914	0.914	0.916	0.905	0.906
Ln Spring Temperature + Ln Spring Temperature x Famine Dummy			**-1.236**	**-1.151**			**-1.447**	**-1.336**	**-0.619**	**-0.824**
p-value (x 100,000)**			**0.000466**	**0.474**			**0.00001**	**0.0333**	**0.00973**	**0.00201**
Ln Spring Rainfall + Ln Spring Rainfall x Famine Dummy		**-0.180**		**-0.0183**		**-0.184**		**-0.0124**	**-0.0713**	**-0.0621**
p-value		**0.00006**		**0.726**		**0.00029**		**0.832**	**0.164**	**0.314**
Suitability + Suitability x Famine Dummy	**-0.391**			**-0.375**	**-0.386**			**-0.365**	**-0.381**	**-0.373**
p-value (x100,000)**	**0.106**			**0.14**	**0.141**			**0.247**	**0.664**	**0.971**

Regressions in all columns control for birth year fixed effects. The GLF controls in columns (9)-(10) include: province ln urban population and province ln urban population x famine dummy, province sown area growth x famine dummy, province sown area growth, province steel prod growth x famine dummy, province steel prod growth, province anti-right purges x famine dummy, province anite-right purges, province liberation date x famine, province liberation date, province communal dining participation x famine dummy, province communal dining participation rate. The standard errors are clustered at the county level. The (**) p-values for joint significance presented at the bottom of the table are scaled for presentation purposes. Notes: These estimates use a county-level panel of birth cohorts that include 511 counties for the years 1949-66 constructed from the *1990 Population Census,* the *Terrestrial Air Temperature and Precipitation: Monthly and Annual Time Series* and the FAO GAEZ database.

Table 5: A Stylized Example of Grain Procurement and Rural Food Availability

	Region A	Region B	City
Subsistence Needs	100	100	100
Production under High Shock (Probability 80%)	250	170	0
Production under Low Shock (Probability 20%)	200	136	0
Expected Production (0.8 x High + 0.2 x Low)	240	163	0
Expected Consumption	134	134	134
Procurement/Subsidy (Expected Production - Expected Consumption)	106	29	-134
Consumption under High Shock (High Production - Procurement)	144	141	134
Consumption under Low Shock (Low Production - Procurement)	94	107	134

Table 6: The Correlation between Grain Productivity and Mortality Rates -- Robustness to Additional Controls

	Dependent Variable: Ln $Deaths_{t+1}$							
Additional Factors:	Baselne (1)	ln Urban Population (2)	Growth in Sown Areas (3)	Growth in Steel Production (4)	Liberation Year (5)	Anti-Right Purges (6)	Mess Hall Participation (7)	All Additional Factors (8)
Ln Grain Production x Famine Dummy	0.262	0.319	0.299	0.217	0.294	0.220	0.405	0.227
	(0.0701)	(0.0584)	(0.0865)	(0.0429)	(0.0771)	(0.0839)	(0.0909)	(0.103)
Ln Grain Production	-0.0530	-0.0561	-0.0538	-0.0374	-0.0273	-0.0465	-0.00456	-0.0272
	(0.0159)	(0.0154)	(0.0155)	(0.0176)	(0.0148)	(0.0170)	(0.0162)	(0.0174)
Ln Urban Population x Famine Dummy		-0.413						-0.161
		(0.252)						(0.257)
Sown Grain Area Growth x Famine Dummy			-6.608					-8.393
			(3.730)					(2.160)
Sown Grain Area Growth			0.0416					-0.0961
			(0.154)					(0.168)
Steel Production Growth x Famine Dummy				0.307				0.614
				(0.0659)				(0.238)
Steel Production Growth				-0.000341				-0.00541
				(0.0147)				(0.0162)
Liberation Date x Famine Dummy					0.215			-0.520
					(0.231)			(0.267)
Liberation Date					-0.0260			-0.0312
					(0.00944)			(0.0106)
Anti Right x Famine Dummy (x 1,000) **						0.0143		0.0227
						(0.0075)		(0.0078)
Anti Right (x 1,000)**						-0.0011		-0.0022
						(0.0005)		(0.0006)
Communal Dining Participation x Famine Dummy							0.0108	0.00527
							(0.00340)	(0.00362)
Communal Participation							0.000572	0.000885
							(0.000215)	(0.000245)
Ln Urban Population	-0.174	-0.169	-0.175	-0.200	-0.254	-0.241	-0.237	-0.216
	(0.0142)	(0.0138)	(0.0143)	(0.0123)	(0.0137)	(0.0142)	(0.0142)	(0.0166)
Ln Total Population	1.203	1.206	1.204	1.177	1.154	1.178	1.127	1.164
	(0.0210)	(0.0205)	(0.0200)	(0.0232)	(0.0190)	(0.0230)	(0.0200)	(0.0223)
Observations	1074	1074	1030	984	1043	994	1043	892
R-squared	0.955	0.955	0.956	0.955	0.953	0.942	0.956	0.953
Ln Grain Production + Ln Grain Production x Famine Dummy	0.209	0.263	0.245	0.18	0.267	0.174	0.4	0.2
p-value	0.002890	0.000007	0.004520	0.000062	0.000631	0.042100	0.000018	0.055400

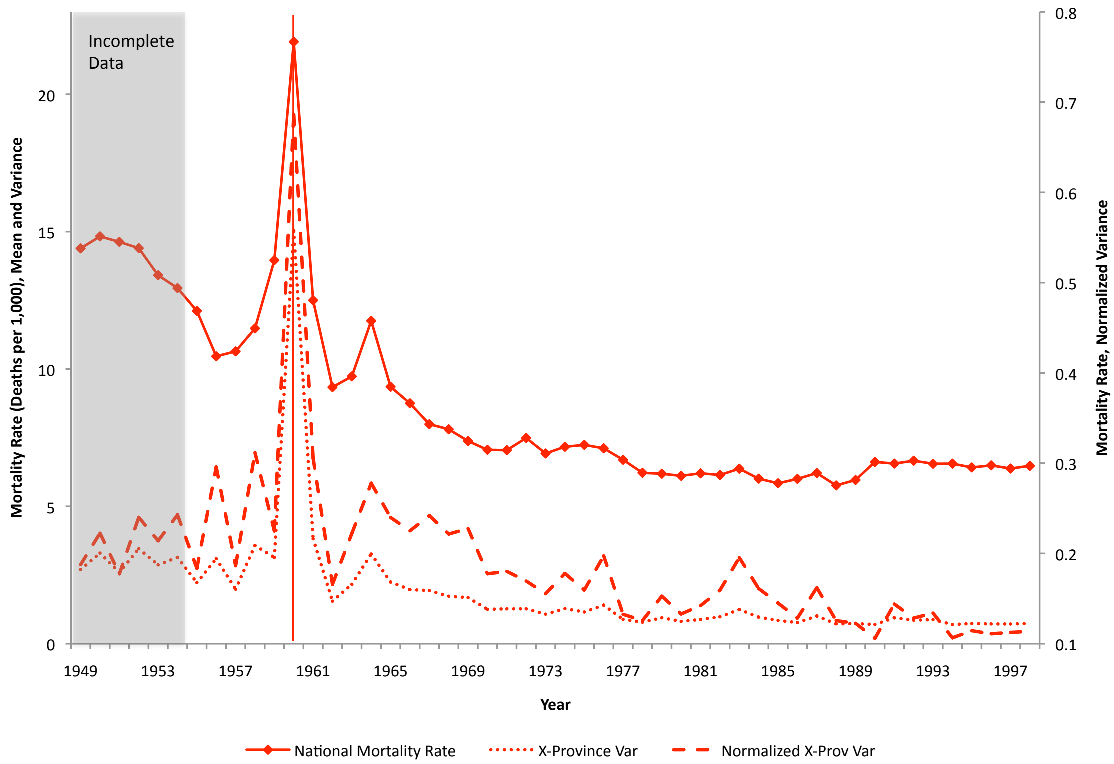
Regressions all control for year fixed effects. Newey-West robust standard errors are presented in the parentheses. The (**) values are scaled for presentation purposes. Notes: The estimates use a province-level panel that includes the years 1949-98 constructed from data reportedin the CDSM50 (1999) and other sources. The number of provinces vary across the columns depending on the availability of the control variables.

Table 7: The Correlation between Grain Productivity and Mortality Rates -- Robustness to Mis-reporting of Production in 1959

	Dependent Variable: Ln Deaths in year *t+1*		
	Baseline (1)	Predicted Production (Assume there is over reporting in 1958-59) (2)	Predicted Production (Assume there is over reporting in 1959) (3)
Ln Grain Production x Famine Dummy	0.276	0.233	0.233
	(0.0699)	(0.0722)	(0.0722)
Ln Grain Production	-0.0305	-0.0370	-0.0367
	(0.0161)	(0.0173)	(0.0176)
Ln Total Population	1.159	1.168	1.168
	(0.0205)	(0.0227)	(0.0230)
Ln Urban Population	-0.254	-0.254	-0.254
	(0.0138)	(0.0138)	(0.0138)
Observations	996	996	996
R-squared	0.953	0.952	0.952
Ln Grain Production + Ln Grain Production x Famine Dummy	**0.245**	**0.196**	**0.196**
p-value	**0.00041**	**0.00830**	**0.00830**

All regressions control for year fixed effects. Newey-West robust standard errors are shown in parentheses. Notes: These estimates use a panel of provinces that includes 25 provinces and the years 1949-98 constructed from data reported in the CDSM50 (1999).

Figure 1: Mortality Rates Over Time



Note: The normalized variance is calculated by dividing the variance by the mean.

Figure 2A: Survivor Birth-Cohort Size Over Time

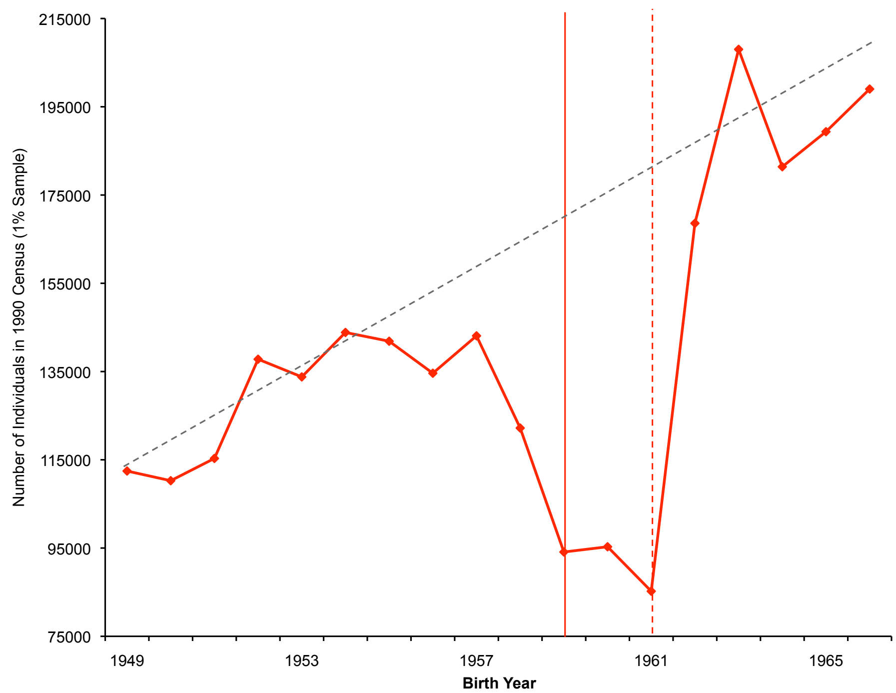
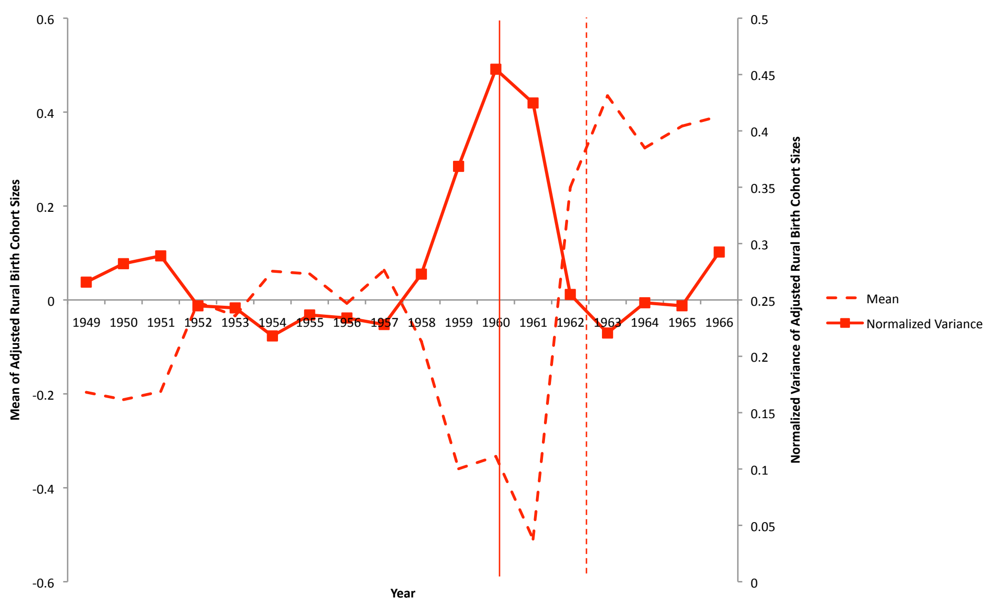
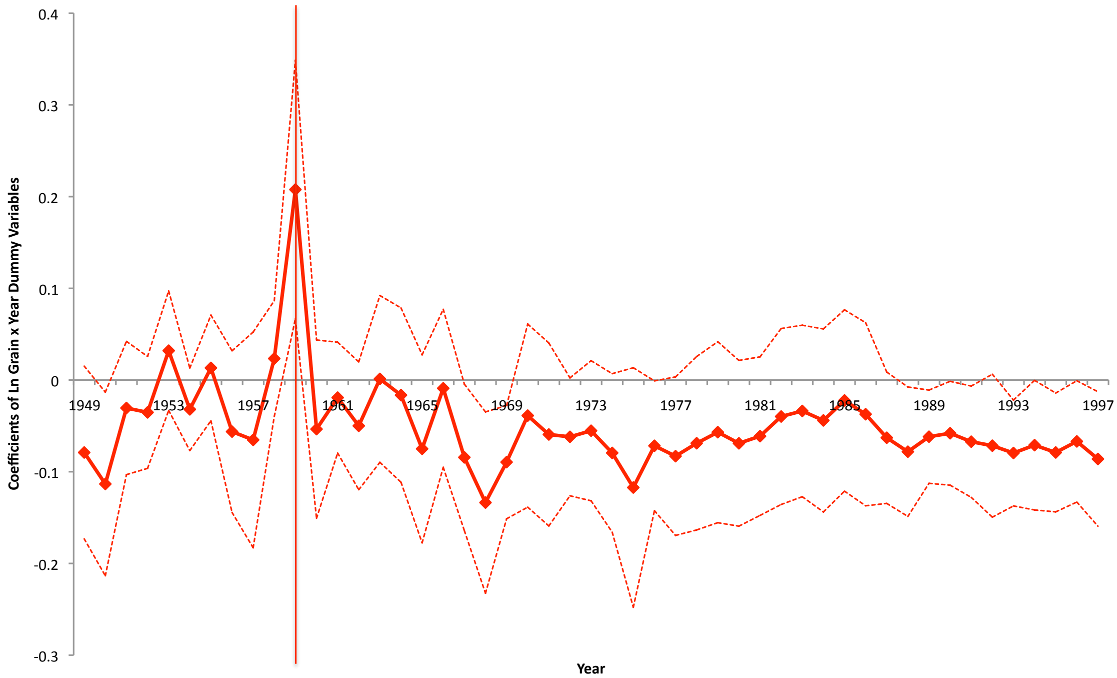


Figure 2B: Adjusted Survivor Birth-Cohort Size Over Time



Note: The adjusted survivor birth-cohort size is calculated by dividing the birth cohort size of each county by the average county birth-cohort size during 1949-66.

Figure 3: The Correlation between Grain Productivity and Mortality Rates
-- Coefficients and 95% Confidence Intervals



Note: The coefficients are estimated from regressing log number of deaths in year t+1 on log grain production, controlling for log total population, log urban population and year fixed effects. See Appendix Table A2.

Figure 4A: The Correlation between Suitability for Grain Production
and Ln Survivor Birth-Cohort Size -- Coefficients and the 95% Confidence Intervals

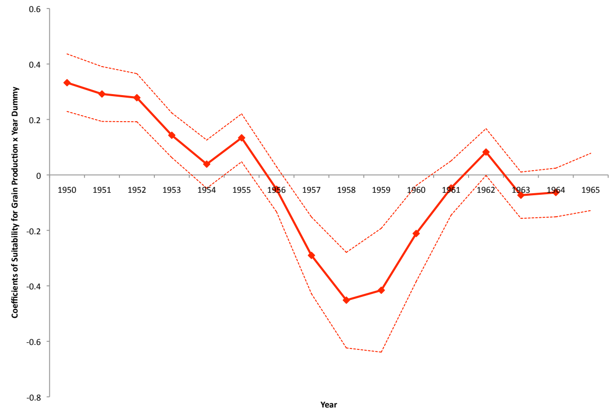


Figure 4B: The Correlation between Ln Spring Temperature
and Ln Survivor Birth-Cohort Size -- Coefficients and the 95% Confidence Intervals

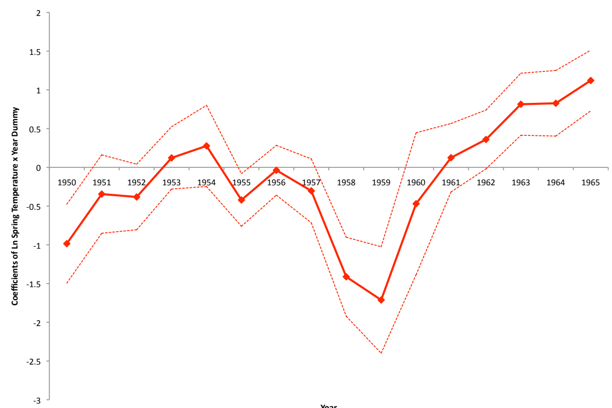


Figure 4C: The Correlation between Ln Spring Rainfall
and Ln Survivor Birth-Cohort Size -- Coefficients and the 95% Confidence Intervals

Notes: The coefficients are estimated from regressing log birth cohort size for survivors born in year t+1 on the interactions of suitability and year fixed effects, the interactions of log spring temperature and year fixed effects and the interactions of log spring rainfall and year fixed effects, controlling for average log birth cohort size in each county, year and province fixed effects. See Appendix Table A3.

APPENDIX Table A1: Historic Population Structure and Caloric Requirements

Age Bracket (1)	Population (100 Persons) (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**

Notes: Caloric requirements are calculated based on guidelines provided by the USDA. In Panel A, for adults, we assume females age 21-50 weigh 120 lbs, females age 51-100 weigh 100lbs. Males age 21-50 weigh 140 lbs, and age 50+ weigh 120 lbs. We assume that all adults age 21-50 perform a high level of physical activity; and those above age 50 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 observation that an adult male laborer needs approximately 900 calories to stay alive, which is approximately 43% of the requirement for heavy physical labor. Source: Coale (1981) and authors' computations.

Table A2: The Correlation between Grain Productivity and Mortality Rates Across Provinces

	Dependent Variable: Ln Deaths during year *t+1*	
	(1)	(2)
	Coefficient	Std. Err.
Ln Grain Production x Dummy Year=		
1949	-0.079	(0.048)
1950	-0.113	(0.051)
1951	-0.030	(0.037)
1952	-0.035	(0.031)
1953	0.032	(0.033)
1954	-0.032	(0.023)
1955	0.013	(0.029)
1956	-0.056	(0.045)
1957	-0.065	(0.060)
1958	0.023	(0.032)
1959	0.208	(0.072)
1960	-0.054	(0.050)
1961	-0.019	(0.031)
1962	-0.050	(0.036)
1963	0.001	(0.046)
1964	-0.016	(0.048)
1965	-0.075	(0.052)
1966	-0.009	(0.044)
1967	-0.084	(0.041)
1968	-0.134	(0.050)
1969	-0.090	(0.031)
1970	-0.039	(0.051)
1971	-0.059	(0.051)
1972	-0.062	(0.033)
1973	-0.055	(0.039)
1974	-0.079	(0.044)
1975	-0.117	(0.067)
1976	-0.072	(0.036)
1977	-0.083	(0.044)
1978	-0.069	(0.048)
1979	-0.057	(0.050)
1980	-0.069	(0.046)
1981	-0.061	(0.044)
1982	-0.040	(0.049)
1983	-0.034	(0.048)
1984	-0.044	(0.051)
1985	-0.022	(0.050)
1986	-0.037	(0.051)
1987	-0.063	(0.036)
1988	-0.078	(0.036)
1989	-0.062	(0.026)
1990	-0.058	(0.029)
1991	-0.067	(0.031)
1992	-0.072	(0.040)
1993	-0.080	(0.029)
1994	-0.071	(0.036)
1995	-0.079	(0.033)
1996	-0.067	(0.034)
1997	-0.086	(0.037)
Observations	1043	
R-squared	0.955	

The regression controls for log total population, log urban population and year fixed effects. Newey-West robust standard errors are in parentheses. Notes: The estimates use a province-level panel that includes 28 provinces for the years 1949-98 constructed from data reported in the CDSM50 (1999).

Table A3: The Correlation between Natural Conditions and Survivor Birth Cohort Size Across Counties

		Dependent Variables: Ln Birth Cohort Size in year *t+1*								
		(1)	(2)			(3)	(4)			(5)	(6)
		Coefficient	Std. Err.			Coefficient	Std. Err.			Coefficient	Std. Err.
Suitability x				Ln Spring Temperature x				Ln Spring Rainfall x			
	1950	0.333	(0.0528)		1950	-0.985	(0.259)		1950	0.0581	(0.0475)
	1951	0.292	(0.0503)		1951	-0.345	(0.258)		1951	0.0828	(0.0494)
	1952	0.278	(0.0442)		1952	-0.382	(0.215)		1952	0.0449	(0.0346)
	1953	0.143	(0.0409)		1953	0.122	(0.205)		1953	0.0268	(0.0377)
	1954	0.0389	(0.0443)		1954	0.277	(0.267)		1954	-0.0887	(0.0433)
	1955	0.134	(0.0440)		1955	-0.421	(0.173)		1955	0.0206	(0.0414)
	1956	-0.0517	(0.0414)		1956	-0.0372	(0.163)		1956	0.109	(0.0372)
	1957	-0.290	(0.0704)		1957	-0.304	(0.210)		1957	0.0828	(0.0521)
	1958	-0.452	(0.0877)		1958	-1.412	(0.260)		1958	0.111	(0.0683)
	1959	-0.416	(0.114)		1959	-1.712	(0.350)		1959	-0.148	(0.0906)
	1960	-0.211	(0.0882)		1960	-0.470	(0.466)		1960	-0.00755	(0.0817)
	1961	-0.0471	(0.0498)		1961	0.124	(0.225)		1961	0.131	(0.0440)
	1962	0.0825	(0.0430)		1962	0.360	(0.193)		1962	0.0870	(0.0299)
	1963	-0.0731	(0.0426)		1963	0.815	(0.204)		1963	0.0356	(0.0461)
	1964	-0.0633	(0.0447)		1964	0.827	(0.216)		1964	0.0280	(0.0584)
	1965	-0.0252	(0.0526)		1965	1.121	(0.199)		1965	0.0137	(0.0476)
Observations						8176					
R-squared						0.918					

The regression controls for log average county birth cohort size, year and province fixed effects. The standard errors are clustered at the county level. Notes: The estimates use a county-level panel of birth cohorts that includes 511 counties for the years 1950-66 constructed from the *1990 Population Census*, *the Terrestrial Air Temperature and Precipitation: Monthly and Annual Time Series* and the FAO *GAEZ* database.

Table A4: Predicting Grain Production

	Dependent Variable: Ln Grain Production
	(1)
Ln Sown Area	5.985
	(0.432)
Ln Total Population	-1.477
	(0.360)
Ln Urban Population	1.718
	(0.747)
Ln Sown Area^2	-0.346
	(0.0276)
Ln Total Population^2	0.139
	(0.0262)
Ln Sown Area^2	-0.136
	(0.0653)
Observations	138
R-squared	0.959

Notes: The estimates use a panel of 25 provinces for the years 1949-57. The data are reported by the CDMS50 (1999).

APPENDIX Figure A1: Histogram of Famine Severity Across Counties

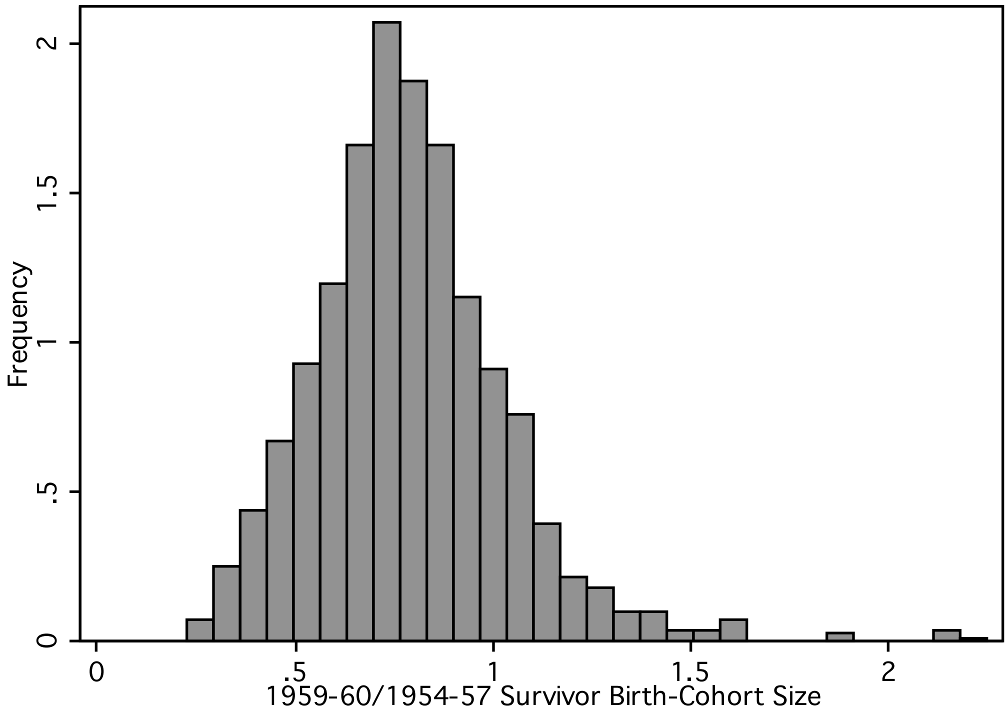


Figure A2: Histograms of Famine Severity Across Counties for Each Province