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

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Abstract

This study investigates the causes of China's Great Famine. We present two empirical findings: 1) food production in 1959, which was 13% below that of the previous year, was still almost three times as much as what was needed to avert famine-induced mortality; and 2) rural regions that produced more food per capita in 1959 suffered *higher* mortality during the famine, a *reversal* of the negative correlation between food production per capita and mortality during normal years. The first finding together with the fact that the Chinese economy was centrally-planned suggest that the famine was caused by policy failure. The second finding implies that the policy failure resulted in higher famine severity in more productive regions. We propose a simple model to show that this policy failure can be explained by the government's inability to easily collect and respond to new information. The model also allows us to compare the Chinese procurement policy of targeting quantities to an alternative policy of targeting prices.

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1 Introduction

In the twentieth century, over 100 million people have perished from famines, more than from both World Wars combined.[1] Famines do not only kill, but they reduce the quality of life of survivors for decades afterwards.[2] In this paper, we study the causes of China's Great Famine, which began in the winter of 1959-60 and lasted until 1961 and claimed the lives of between seventeen and thirty million people.[3] This paper establishes two empirical facts that suggest that government policy failure caused the famine. Based on historical evidence of the institutions at the time, we hypothesize that this policy failure was a result of *inflexibility*, a term we use to refer to the government's difficulty in collecting and responding to new information.

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

The second fact we establish is that regions that produced more grain per capita in 1959 experienced more severe famine; this was a reversal of the negative correlation between per capita production and mortality we observe during non-famine years. The principal empirical challenge for this exercise is to address potential problems in data

[1] See Sen (1991) and Ravallion (1997).

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

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

[4] The fall in 13% is the aggregate production statistics from the 27 provinces in our main sample. We use the terms grain and food interchangeably since grain makes up over 95% of diets. See Walker (1984) for evidence on the rural population. Urban workers in China during this period also consumed a grain heavy diet (as they do today). For example, in 1957, an average urban worker in Shanghai, one of the richest cities at the time, consumed approximate 270 kg of grains and 15 kg of meat in one year (Reynolds, 1981).

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

quality. In particular, we are concerned that for political reasons, the government wished to understate the magnitude of the production decline and resulting mortality. Our main exercise uses historical data on regional mortality and production that has been retrospectively corrected by the National Bureau of Statistics. However, to be cautious, we also address potential issues from measurement error in the data by repeating the exercise with alternative proxies for famine severity and grain production constructed from restrospective data: regional birth cohort size from the 1990 Population Census and suitability for grain cultivation predicted by time-invariant natural conditions. These measures are not vulnerable to politically-motivated government reporting bias. Therefore the supplementary analysis serves as a robustness check on the results from the historical data. The results support the main findings.

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

In order to explore the mechanism for this policy failure, we document several features of the historical procurement policy and we construct an economic model of procurement. The historical evidence suggests that a key feature of the centrally planned procurement system was inflexibility – the quantity of food that the government collected from farms could not perfectly adjust to aggregate food production shocks. There are several potential structural causes for this inflexibility. For example, inflexibility was likely to have been a response to the lack of local incentives to truthfully report production and a consequence of the political pressures to follow rules and the limited bureaucratic capacity of the central government.[7] Such constraints are not unique to China, but may reflect the fact that no government can always perfectly collect and respond to new information.

To see whether inflexibility could explain the policy failure of the Chinese government, we develop a model of food procurement policy in which the government is constrained by inflexibility. We consider an environment in which food production varies across regions. The government can redistribute food across regions through procurement and subsidies. For simplicity, we assume that mortality is a continuous function of food consumption and

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

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

that the government is utilitarian such that it assigns equal weight to all individuals in the social welfare criterion. To understand the effect of a fall in aggregate production, we assume that all regions are subject to a stochastic aggregate production shock. The key constraint faced by the government is that procurement policy cannot respond perfectly to this shock. For simplicity, we focus on the extreme case in which no adjustment to the shock is possible, capturing the notion that the government is either unaware of the shock or cannot be responsive to the shock. As such, the government assigns an inflexible region-specific level of procurement based on its expectations of regional production.[8] The model predicts that the procurement policy amplifies the mortality which results from a reduction in food production with spatial patterns consistent with our empirical findings. These results hold generally under very mild assumptions regarding the spatial patterns of the aggregate shock which we are able to verify with the data.

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

In addition to providing an explanation for the policy failure that is consistent with the empirical facts, the model allows us to assess the merits of the Chinese procurement policy of fixing quantities relative to an alternative policy of fixing prices. The efficiency of central planning and the tradeoff between quantity and price controls are questions of long-standing interest to economists.[9] In an exercise that is similar in spirit to the study by Weitzman (1974), we show that quantity controls dominate price controls in our

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

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

context if the rural population is sufficiently large in size relative to the urban population, and if there is little heterogeneity in the magnitude of productivity shocks across rural regions.[10]

Our results should be interpreted with the important caveat that they do not imply that the central planning system in China made the famine inevitable, a point which is evidenced by the fact that China avoided famine after 1961 even though it remained a similarly centrally-planned economy through the late 1970s. Rather, we believe that the confluence of three factors made famine in 1959 inevitable. First, the percentage drop in per capita food production in 1959 was significantly larger than any other drop experienced by the Communist Chinese government (1949-).[11] Second, the government's procurement rate was significantly higher during this period than later years, leaving rural regions with little buffer food supplies in case of over-procurement. Third, political tensions in the late 1950s generated tremendous pressure to follow rules and suppress information, a factor which undoubtedly exaggerated the inflexibility of food procurement policy.

This paper makes several contributions. First, we build on the work of Sen (1981) in showing that inequality in food consumption can generate a famine even when aggregate food production levels are sufficient for subsistence.[12] Several recent studies such as Shiue (2004, 2005) and Burgess and Donaldson (2009) have continued the exploration of factors beyond aggregate food supply that contribute to famine.[13] Our study differs by focusing on a *non-market* economy, and by illustrating a precise mechanisms through which government policy can generate a famine. This is an important context since three of the most devastating and controversial famines in history, China's Great Famine (1959-61), the Ukrainian Famine (1932-33), and more recently, the North Korean Famine (1992-95) have all occurred within non-market economies.[14] We believe that many of the insights of this paper regarding the mechanism for policy failure in a centrally planned

[10]Our theoretical model and counterfactual exercise are an extension of Weitzman (1974) which allows for multiple producers of varying productivity (i.e., multiple rural regions). Our result that fixing quantities dominates fixing prices if the rural population exceeds the urban population is a direct application of the more general results in his framework. Our result that this is also true if the heterogeneity in productivity shocks across the rural population is low is not a direct application of his framework since he assumes only one producer for each good. Weitzman's framework has been used by many studies of regulatory economics in market economies, especially in application to environmental regulation. For example, see McKibbin and Wilcoxen (2002) for an overview of this literature.

[11]In our sample of 27 provinces, per capita grain production fell by 15% in 1959, which is more than two standard deviations below the mean growth rate in per capita grain production.

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

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

[14]Demographers estimate that approximately 3.2 million died during the Ukrainian famine. The cause of this famine is a subject of intense scholarly and political debate. Explanations range from production falls due to misguided policies during the Soviet industrialization process to politically-motivated deliberate attacks on the potentially rebellious regions in the Ukraine by the Stalinist Soviet government.

economy can potentially operate in economies in which government policy and market mechanisms interact to mitigate or to amplify the impact of food production shocks. Second, we add to studies on the causes of China's Great Famine. These studies have typically focused on the drivers behind the fall in aggregate food production in China.[15] In contrast, we take the fall in production as given and provide a theory of the procurement system which is consistent with the empirical findings. Moreover, our study is the first to point out the surprising spatial patterns of famine.[16]

Our study also contributes to studies on central planning. Our mechanism for policy failure, which relies on the constraint of inflexibility, builds off of the historical arguments made by Von Mises (1921) and Hayek (1946). During the *Socialist Calculation Debate*, they argued that from the perspective of efficiency, it was, in practice, impossible for central planners to aggregate the information necessary in a timely fashion. Finally, our analysis is related to the growing number of works on institutional capacity such as those by Besley and Persson (2009) and Greif (2008).[17] As a study of the role of state capacity in responding to aggregate shocks, our work is also related to that of Cohen and Werker (2008), Kahn (2005), and Zeckhauser (1996).

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

2 Historical Background

This section briefly discusses the reforms leading up the famine and the timeline of the famine. Our purpose is to provide the relevant context for interpreting the empirical evidence. Because the policies of the early years of the "New" China government that came to power in 1949 have been a subject of many scholarly works, and it is beyond the scope of this paper to fully describe this interesting period of history, our discussion here only covers issues directly related to our study.[18] We do not discuss the Chinese

(See Vallin, 2002 for an overview). In North Korea, it is commonly believed that 2-3 million individuals, approximately 10% of the total population, died during this famine (Haggard and Noland, 2006; Demick, 2009). However, there are very few academic studies or reliable accounts of details related to this famine.

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

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

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

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

procurement policy in detail in this section, since it is described in Section 5 before we introduce the model.

2.1 New China Reforms 1949-59

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

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

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

Full collectivization, the third phase which is often also referred to as "high level collectivization" was phased in after low level collectivization. The main change was that although the farmers in each village had contributed land and capital assets for production,

Years contains documents of the details of the social and economic histories of select Chinese villages during the famine era (Wang et al., 1989).

they now only received food in return based on their labor input. Furthermore, while labor was a requirement in order to receive food and other subsidies, farmers were typically not rewarded for their marginal labor input. In other words, farmers who contributed to the collective received food and other subsidies for their own consumption. But there was no system for rewarding farmers for production beyond their subsistence level (Johnson, 1996). This effectively erased private property rights to land and assets. Private plots were abolished. By 1959, 93% of agricultural land was under high level collectivization (Spence, 1991: pp. 549-50). At this time, mutual aid teams had ceased to exist. Markets for private transactions were also banned (Fairbanks, 1985: pp. 281-85).

The central government faced two main problems as they increased the scope of collectivization. The first problem was that farmers were not incentivized to produce more than what was needed for their own consumption, which was guaranteed by the New Communist government. The collective system addressed this by forcing farmers to work under threats of severe punishment, constant monitoring, and peer pressure. The second problem was that farmers were incentivized to under-report true production or to hide production. The government attempted to address this by collectivizing the harvest and storage of grains so that harvest went directly from the field to communal storage depots. Communal kitchens were established so that the collective also controlled food preparation and consumption.[19] There are also accounts that the government attempted to collect the little grain that farmers could take in their pockets with virulent anti-hiding campaigns, where fields and even the floors of homes were dug up to expose hidden grain, and where the culprit would typically be publicly humiliated and punished (Becker, 1996: pp. 109).

Chinese peasants, like those in the USSR before full collectivization, slaughtered and ate enormous quantities of meat in anticipation of losing the property rights to their animals, reducing China's livestock by half between 1957 and 1958.[20] In response to this, the Chinese government declared that slaughtering animals without permission would be considered a crime against the state and offenders were threatened with severe punishment. By 1959, the remaining livestock and draught animals were typically under-nourished and badly tended as peasants no longer had much interest in caring for them.

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

Grain production grew almost monotonically between 1949 and 1958 (Li and Yang, 2005). Presumably, this was partly due to the recovery and political stability after decades of conflict and to efficiency gains from early phases of collectivization. It may also have been due to new farming methods that were introduced during the collectivization period. Some of these methods, such as multiple cropping, may not have been sustainable in the

[19]Collectivizing food preparation was also meant to free female labor from household production so that it could be shifted into agricultural production.

[20]See Becker (1996) for comparisons of historical accounts. See Yang (2008) for an economic comparison of the famines in China and the USSR.

long run and arguably contributed to the eventual fall in grain output in 1959. It is believed by historians and individuals who can remember the period that there was much general optimism at the time that production will continue to grow (Spence, 1991: pp. 183).[21]

2.2 The Famine 1959-61

In 1959, grain production fell by 13% after having fallen by 2% in the previous year. After harvest, in mid-October and November, approximately 38% of total production was procured by the central government (see Li and Yang, 2005).[22] Had production in 1959 grown at the same 4% per annum rate as the previous years (on average), the procurement would have been 32% of production, a less severe increase from the 26% in 1958, and the same as procurement in 1954. Although the famine lasted until 1961, the majority of famine deaths occurred in January and February of 1960, two to three months after the grain was procured (Becker, 1996: pp. 94).

The Chinese government has alleged that the fall in grain output was due to bad weather in 1959 and that this caused an aggregate food shortage which resulted in the famine (Coale, 1981; Yao, 1999; Peng, 1987; Ashton et al., 1984; and Banister, 1987). However, over time, scholars have revised the contribution of weather downwards to approximately 50% (Kueh, 1994) and 14% (Li and Yang, 2005). Li and Yang (2005) compile province-level panel data on imputed grain consumption, grain production, and potential factors that contributed to the decline in production as hypothesized by existing studies to quantify the impact of each factor.[23] They find that in addition to weather, the relevant factors were diversion of labor away from agriculture for projects such as rural industrialization during the Great Leap Forward (GLF, 1958-60) and over-procurement. Diversion of labor together with weather which was not as favorable for grain cultivation

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

[22] In our data, which includes production of 27 provinces in 1959 (all except Tibet, Hainan and Sichuan), we observe a 13% fall in aggregate production. In the Li and Yang (2005) data, which includes 24 provinces, there is a 15% fall. In this paper, when we refer to production data, we will always refer to our data. However, when we refer to procurement data, we will refer to Li and Yang (2005).

[23] Past works have hypothesized that the fall in production was associated with Great Leap Forward (GLF) era policies such as labor and acreage reductions in grain production (e.g., Peng, 1987; Yao, 1999), implementation of radical programs such as communal dining (e.g., Yang, 1996; Chang and Wen, 1997), reduced work incentives due to the formation of the people's communes (Perkins and Yusuf, 1984), and the denial of peasants' rights to exit from the commune (Lin, 1990). See Yang (2008) for a recent review of the studies on the causes of China's famine.

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

as in previous years caused production to fall in 1959. However, because the government did not accordingly revise procurement downwards, retention in the country side was too low for the workers to be productive in 1960, which caused further declines in production. Our study takes their findings and the fall in grain production in 1959 as given, and investigates the reasons why this fall transformed into a famine that winter.

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

A critical fact to keep in mind for our study is that the highest level of mortality occurred in January and February of 1960, two to three months after the grain was procured.[24] Half of the deaths are believed to have been of children under ten years of age (Spence, 1991: pp. 583).[25] The number of deaths is staggering, particularly when one considers that relatively little food is needed to stay alive in the absence of disease and the presence of clean water, which characterized rural China after drastic public health measures undertaken during the 1950s (Fairbanks, 1985: pp. 279).[26] Hence, the deficit of food supply relative to subsistence needs in rural areas, where most of the mortality occurred, must have been enormous.

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

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

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

[26] The Chinese Famine is similar to the Leningrad and Dutch famines where mortality is mostly due to starvation rather than succumbing to infectious disease (O'Grada, 2007b).

what was otherwise designated for military and industrial purposes. Production slowly recovered in the subsequent years.[27]

In addition to this chronological discussion, there are two important facts to keep in mind. First, is the fact that the Chinese famine occured in rural areas, which formed an important political base for the Mao-led government. This is very different from the Ukrainian Famine during the 1930s, which occured in a region that was historically not aligned with the Stalin-led Soviet government. Therefore, we have little reason to believe that the Chinese government would have had political motivations for desiring a famine. This is important to keep in mind for when we specify the objective function of the central planner in our model in Section 6.1. Second, unlike any other famine in history, the Chinese famine did not result in migration. The central and local governments together prevented the population of famine stricken regions from migrating to other regions in search for food. This undoubtedly exagerrated the mortality that resulted from the fall in food production. It is also directly relevant for our empirical analysis because it means that the birth cohort size of those born during the famine that we observe in 1990 can be used as a proxy for famine intensity in that region. See section 3 for more discussion.

3 Data

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

Historical Data

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

There are two main issues to keep in mind in our analysis of this province-level series. The first issue regards accuracy. For political reasons, the government has historically overstated production. Such a bias would lead us to incorrectly overestimate available food per capita in 1959. In principle, this should not be the case since the 1999 series have been corrected restropectively to account for contemporaneous reporting errors. A comparison of contemporaneous reports of grain production and the reconstructed data suggests that the production numbers have been drastically revised downwards. For example, the *People's Daily* in August 1, 1958, claimed that "Rice production exceeded 7500 kg per mu (0.067 hectare)" for a county in Hubei province. The revised statistics report that actual grain output in that province was closer to being 120 kg per mu. If we aggregate production across provinces, our production data for all thirty provinces is approximately 10% lower than the aggregated production from 24 provinces in the 1989

[27]It is difficult to retrospectively account for grain allocation in a rigorous way. Part of the reason is the lack of data. But the difficulty also comes from the fact that historical accounts typically report grain in units of tons and government expenditures in units of RMB (yuan), and we have not been able to uncover how grain was valued.

Ministry of Agriculture series used by Li and Yang (2005). This is consistent with the notion that during the ten years between when these two series were published, the National Bureau of Statistics (NBS) made a sincere effort to revise past production numbers.[28] To the best of our knowledge, this is the most conservative historical production data that has ever been used in a scholarly study of the famine or the GLF era.

The second issue regards the completeness of the province-level data. Provinces for which production could not be accurately revised such as Sichuan in 1959 seem to have been dropped from the sample. In non-famine years, Sichuan produces approximately 16% more grain per capita than the average province. This suggests that our calculation of aggregate production per capita in 1959 is lower than true production per capita. The series also does not report production and mortality rates for Tibet and mortality rates for Hainan in 1959. Therefore, for 1959, our sample contains mortality rates and production for 27 provinces. To address this issues, our regression analysis only uses data from these 27 provinces. All observations for the three provinces for which we have no mortality data in 1959 are omitted from all of the regressions. Another issue is that mortality data is not available for many provinces before 1954. For example, in 1949, data on mortality is only available for 15 of the 27 provinces. This is not surprising as the NBS was being constructed at the time and the amount of statistics it was able to gather was increasing over these early years. We will be particularly careful to ensure that the selection of provinces do not affect our results by repeating all of our estimates on a restrictied sample where the years 1949-1953 are omitted for all provinces.

The national historical data on population are based on a series recently released by the *China Population Information and Research Center* (CPIRC) in 2000. The main concern with government reported data on population is that it understates population losses. For political reasons, government officials may have wished to understate the famine severity. The CPIRC series takes into account the retrospectively corrected mortality data (see below) and fertility changes that can be observed in famine year birth cohort sizes from later population censuses. We believe that the population data is reasonably accurate. Our estimates for food need in 1959 should not be affected even if these data still understate population losses from the famine because famine deaths mostly occurred in 1960.[29]

The CPIRC series only report aggregate population. To calculate caloric needs, we use the sex and age distribution from Coale (1981) which is based off of the *1954 Population Census*. We assume that the population had the same sex and age distribution as in 1954 for all years in our sample. See Coale (1981) for details on the quality, collection, and subsequent corrections of this data. This should be a reasonable estimate for the years close

[28]Much of the recent revisions have been made possible by the uncovering of contemporaneous reports of production that were not exaggerated and not published in the past. An example of some of these "re-discovered" collective reports can be found in the multi-volume government publication *Villages for Thirty Years* (Wang et al, 1989). In theory, the NBS could have used such reports to estimate the amount of exaggeration and to make projections across similar regions. The details of how the revisions are made in practice are not reported in any source that we know of.

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

before and after 1954. But for years after the famine began, 1960 onwards, this becomes increasingly inaccurate, especially since the famine killed disproportionately more young children and elderly. However, this is not crucial for our study, which focuses on whether production before the famine began in 1959 was sufficient for aggregate population needs.

Historical data on mortality rates (deaths per 1,000) are also published by the CSDM50 series. The main concern here is that the government understated mortality. Famine induced mortality numbers vary between 16.5 million (Coale, 1981) to 30 million (Banister, 1987) due to different estimation methods (e.g. 18.5 million in Yao, 1999, 23 million in Arid, 1982 and Peng, 1987 and 29 million in Ashton et al., 1984). Our mortality data, which does not report mortality rates in 1959 for Tibet, Sichuan and Hainan due to the NBS's inability to provide accurately corrected mortality rates, show that mortality for the remaining regions during the years 1959-1961 sum to approximately 21.5 million individuals.

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

Table 2 Panel A describes the province-level data. Excluding Sichuan, Tibet and Hainan, our sample contains 27 provinces during 1949-98. On average, each province has a population of approximately 29 million people in any given year. The mortality rate is on average slightly less than 9 per 1,000. In 1960, the mortality rate was on average almost 22 per 1,000. Relative to the average mortality rate during 1954-57, this was almost twice as high. Approximately 86% of provinces had higher mortality rates in 1950 than during 1954-57. The average province in our sample produced more than ten million tons of grain in 1959. Average per capita production in the sample is approximately 318 kg per person. In 1959, it was approximately 254 kg per person. This was on average 83% of the average annual production during 1954-57. 96% of the provinces experienced a fall in production in 1959 relative to 1954-57. Xinjiang, the autonomous province in the Northwestern corner of China, was the only province that did not experience such a fall.

The descriptive statistics provide several additional facts about the fall in production in 1959 that are important for the development of our model in Section 6. First, per capita production in 1959 was larger for regions that produced more on average. The correlation coefficient between average log per capita production during 1954-57 and per capita production in 1959 is 0.84. Second, the fall in production in 1959 was larger in magnitude for regions that produce more on average. The correlation between the log of the absolute magnitude of the fall in 1959 and the log of production during 1954-57 is 0.4.

Retrospective Data

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

We proxy for historical production at the county-level with data on suitability for grain cultivation as predicted by natural conditions from the FAO.[30] This measure of suitability is based purely on the biophysical environment of a region and it is not influenced by which crops were actually adopted in an area. Factors that are easily affected by human actions, such as soil pH, are not parameters in this model.[31] The data on suitability is available at a 50 km×50 km grid cell level, where one can choose the level of agricultural inputs on which to base the calculation. Our chosen level of inputs allows for rain-fed irrigation but no heavy machinery or chemical fertilizers since GLF policies forbade chemical fertilizers and since the use of heavy machinery such as tractors would have been unlikely in this era. We aggregate grid-level data to the county data as follows. The grid-level data reports the predicted amount of output of rice and wheat. If a grid can produce 40% or more of the maximum possible output for any grid, then we code it as "suitable". The suitability measure at the county-level is the fraction of grids within a county that is suitable. We use this measure for the sake of computational ease.[32] Since procurement targets treated rice and wheat similarly, our measure of suitability is the union of land that is suitable for either rice or wheat within each county. To get a sense of the county-level agricultural suitability data, Appendix Figures A1A and A1B present maps that overlay county-level boundaries with the grid-level suitability measures for rice and wheat, respectively.

For famine severity, we use birth cohort size as measured in the *1990 Population Census*. A smaller birth cohort size during famine years reflects a more intense famine. This data has the advantage that it allows us to disaggregate down to the county-level and therefore capture much more of the variation in famine. We can also split the data into agricultural and non-agricultural households. Typically, non-agricultural households live in small cities and towns, often in the same county as agricultural populations, who live in villages surrounding the towns. Important for our study is the fact that only agricultural households face grain procurement. Non-agricultural households receive grain subsidies from the government. These categories were first assigned during the 1950s.

There are two caveats for interpreting the retrospective data. First, a small number of non-agricultural households in 1990 may have been agricultural households at the time of the famine. We believe that this number is very small because it is very difficult for households to transition one's household type from agriculture to non-agriculture. Second,

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

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

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

there may have been some cross-regional migration between the time of the famine and 1990. Recall from Section 2 that famine-driven migration did not occur in mass due to heavy restrictions. However, migration may have occured for other reasons afterwards. This is unlikely to be a big issue for us since studies have found that strict migration policies during this period actually made it extremely difficult for rural individuals to move (West and Zhao, 2000).[33] However, to be cautious, we attempt to address this with the data. The Census does not report region of birth. Therefore, we restrict the sample to households who report as living in the place they are reporting from for at least five years. This excludes approximately 5% of the sample, most of which are amongst non-agricultural households. For the purposes of our study, we then assume that for this restricted sample, the county of residence is the county of birth. As another precautionary measure, we focus our analysis on the agricultural households since most of the migration would have been concentrated among non-agricultural households between urban areas.

The county-level sample we construct is a balanced panel of birth cohorts of 1,190 counties and 18 birth years (1949-66) for agricultural households, and 667 counties and 18 birth years for non-agricultural households. The latter is smaller because there are fewer cities (which have county level status) than rural counties and outside of cities, and most rural counties do not contain non-agricultural households. Note that unlike the province-level analysis on mortality which spans the years 1949-98, we end the sample for the county-level analysis on cohort size in 1966 when the Cultural Revolution began. This is to avoid confounding factors that could have influenced fertility but are less likely to influence mortality (e.g. family planning policies which were tested in the late 1960s and began in earnest in the early 1970s).

Table 2 Panel B shows that agricultural households have approximately 5,266 individuals per cohort on average in each county. Famine cohorts are smaller on average, comprising of approximately 3,508 individuals. This is approximately 71% of the size of cohorts born prior to the famine (1954-57). If we use this ratio being below one to indicate whether there was a famine, then 89% of the counties in our sample experienced the famine to some extent. On average, 13% of the land is suitable for cultivation of rice and wheat according to our definition. The patterns for non-agricultural households are similar. However, the difference between famine cohort sizes and pre-famine cohort sizes is smaller than for agricultural households. Also, non-agricultural households typically live in agriculturally richer areas, where 20% of the land is suitable for cultivation.

To observe aggregate cohort size over time, we aggregate the county-level data to the national level and plot the number of people living from each birth year for agricultural and non-agricultural households in Figure 2. It shows that both agricultural and non-agricultural households experienced a decrease in cohort size close to the famine years, though the drop is much more dramatic for the agricultural population. The drop in

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

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

To assess whether birth cohort size from 1959-61 is a good proxy for famine severity, we compare its trend over time and across provinces to that of the mortality data. For this, we aggregate the Census data to calculate cohort size by birth year and province. The correlation between the magnitude of the percent drop in cohort size and the percent increase in mortality during 1959-61 is approximately 0.65 and is statistically significant at the 1% level. This can be illustrated visually by plotting mortality rates and cohort sizes over time for each province. Figures 4A and 4B show clearly that for every province that exhibits a spike in mortality rate during the famine in Figure 4A, there is a corresponding drop in famine birth cohort size in Figure 4B. However, there are several provinces that exhibit a drop in birth cohort size in Figure 4B for which there is no corresponding spike in mortality rate in Figure 4A (e.g. Guangdong, Henan, Jiangxi, Shandong). Moreover, using the survival measure, we are able to proxy for famine intensity for the three provinces for which there is no famine era mortality data (e.g. Sichuan, Hainan, and Tibet).

These figures suggest that survival in 1990 is a reasonable measure of famine intensity and, because it does not suffer from government reporting bias, it is likely to be a more accurate measure. Survival is also likely to be a more sensitive measure of famine as a moderate famine will typically cause affected individuals to delay fertility before it induces mortality.[34] Note that these figures also show that there was substantial variation in famine intensity across provinces.

As we described earlier, there are several caveats to interpreting the county-level proxies for production and famine severity. However, these data have three key advantages over the province-level historic data. First and most important, they are not subject of systematic government reporting bias. Second, the disaggregated nature of the data allows us to have a larger sample size, capture more of the variation in famine, and therefore obtain more precise estimates. Finally, in the county-level data, we have data on all thirty provinces whereas in the province-level data, we lack mortality data in 1959 for three provinces.[35]

[34]Note that we use both mortality and survival as proxies for famine severity. One cannot retrospectively back out true mortality rates from the cohort size data. This is because we do not know the fertility rates in the years leading up to the famine, and more importantly, we cannot observe those who were elderly at the time of the famine in the retrospective data.

[35]Historical data on production and mortality is not available for many counties. Even if it were, it would be subject to the same reporting errors as in the province-level historic data.

In summary, the empirical analysis in the next secion uses two data samples: historical data and restrospectively constructed data. This section has described in detail the advantages and disadvantages of each. The key point is that both samples provide measures (proxies) for famine severity and grain production and they are each vulnerable to very distinct measurement issues. Therefore, consistent results from these two samples would suggest that our findings are unlikley to be driven by any one of these measurement error issues.

4 Empirical Results

This section presents two empirical findings. First, we find that food production in 1959 was significantly above what was needed to avert famine-induced mortality. Second, we find that rural regions that produced more food per capita in 1959 suffered higher mortality during the famine, a reversal of the negative correlation between food production per capita and mortality during normal years. We use historical measures as well as restrospectively constructed proxies for the historical measures.

4.1 National Grain Production and Subsistence in 1959

In this section, we discuss our first finding that food production in 1959 exceeded per capita subsistence needs. We compare the historical estimates of national food production to two benchmarks for caloric needs in 1959. The two benchmarks distinguish between the caloric needs for preventing *a decrease in labor productivity* from the needs for preventing *mortality.* Because the majority of famine mortality occurred during the winter following the harvest in the fall of 1959, we focus on the level of production in 1959 only, and we do not consider the additional fall in production in 1960 which occurred after a large proportion of the rural workers had already died or were starving. Note that, *a priori*, it would not be surprising to find that production in 1959 did not fall below the needs for preventing mortality since aggregate production per capita in 1959 only dropped to the same level as in 1949-1951, a period in which there was no famine.

For this exercise, we use all of the grain production data we have and national population figures reported by the CPIRC. We do not drop any region or years from the sample. We will discuss the implications of this later in the section after we present the results.

Table 3 Columns (1) and (2) show the population age and sex distribution in 1954 as reported by Coale (1981). Caloric requirements in Column (3) for working and healthy child development are calculated based on a model published by the *United States Department of Agriculture* (USDA). In Panel A, for adults, we assume that females age 21-50 weigh 120 lbs., females age 51-100 weigh 100lbs. Males age 21-50 weigh 140 lbs., and age 51-100 weigh 120 lbs.[36] We assume that all adults age 21-50 perform a high level of physical activity, and those age 51-100 perform a medium level of physical activity. Caloric needs for staying alive in Panel B are estimated to be 43% of those in Panel A.

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

This is projected from the assumption that an adult male laborer needs approximately 900 calories to stay alive, which is approximately 43% of the requirement for heavy physical labor.[37] In Panel A, Column (5) shows that the average population caloric need for productive agricultural laborers (or for normal child development) was 1,870.7 calories per day. Panel B Column (5) shows that the average need to stay alive is approximately 804.4 calories per day.

Note that this calculation most likely grossly overstates average caloric needs for three reasons. First, we have assumed that the entire adult population works as laborers in agriculture, whereas in reality, approximately 20% of the population in 1959 worked in non-agricultural jobs which are less physically intensive. Second, our proxy for the number of calories needed to stay alive is actually the benchmark used by past economic studies of nutrition for the number of calories to do "some" work (e.g., Das Gupta and Ray, 1986). We use this because there little consensus on minimum caloric consumption necessary for staying alive.[38] Finally, post-World War II fertility rates were very high. Therefore, relative to 1954, a larger percentage of the population was made up of very young children in 1959, and children need fewer calories than the adults.

Table 4 Column (1) shows that production had increased almost monotonically by approximately 70% from 102 million tons in 1949 to almost 170 million tons in 1958. In 1959, production fell by approximately 13% to 148 million tons. Column (2) shows that population was also increasing during this period. We use the data on population and average population caloric needs from Table 3 to compute population food needs in terms of grain. For this, we follow the Ministry of Health and Hygiene of China in assuming that 1 kg of grain (in the form consumed by the average Chinese worker) provides 3,587 calories. We assume that individuals subsist solely on grain and that each individual consumes the same amount every day of the year. Therefore, a diet of 1,870 calories per day translates into per capita grain needs of 190kg per year. In column (3), we aggregate the needs for the entire population and report them in units of millions of tons. The estimates show that aggregate food needs had increased by approximately 20% between 1949 and 1959. In Column (4), we calculate the deficit in production as the difference between production as stated in Column (1) and need as stated in Column (3). The estimate shows that in 1959, there was no deficit. In fact, there was a 21 million ton surplus. Interestingly, according to our estimated needs, there was a small shortage in 1949, a year from which there were no accounts of famine. This is consistent with the fact that we are most likely overstating caloric needs.

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

[38] To the best of our knowledge, there is no systematic evidence on the minimum number of calories needed to avoid mortality through starvation. This is not surprising since the needed amount probably varies greatly depending on other factors such as disease and climate. The only experimental evidence on human starvation which controls for these compounding factors is the Minnesota Starvation Experiment, conducted on volunteer concsiencious objectors in the U.S. during World War II. However, as the focus of this experiment was mainly on the effect of a moderate reduction in calories (to simulate wartime conditions in Europe) and the subsequent recovery, it did not systematically reduce calorie intake to a level where the human subject systematically risked mortality. After a twelve week period of a diet of approximately 3,200 calories per day, the diets of the subjects were reduced to approximate 1,560 calories per day for six months, after which, they recieved a rehabilitation diet for 20 weeks. See Keys (1950).

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

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

Note that in addition to having intentionally used conservatively high benchmarks for caloric needs, the aggregate statistics could also over-state food deficit in 1959 because we lack grain production data from Sichuan and Tibet whereas the national population data includes the populations of all provinces. The omission of Tibet is unlikely to make a significant difference as it has a relatively small population that historically produced just enough food for its own subsistence. However, the omission of Sichuan most likely causes us to over-state food deficiency because Sichuan is an important grain producing region for China. On average, it produces more than three times the amount of an average province. However, it is difficult for us to make an accurate statement about the bias that is caused by the lack of data for Sichuan in 1959.

To address this difficulty and also to investigate whether there were aggregate deficits at the province level, we repeat this exercise for each province. Tables 5 lists the provinces in ascending order of mortality rate in 1960 (which captures deaths in the 1960 winter following procurement in the fall of 1959). Columns (1) and (2) show mortality rates in 1960 and production in 1959. In Columns (3) and (4), we calculate grain production that was in surplus of the two benchmarks used in the previous section. We find that all provinces produced more than what was needed to avoid mortality, and only four provinces, three of which are the primarily urban province-level municipalities (Shanghai, Beijing, and Tianjin), produced less than what was needed for a healthy labor force and normal child development. (The fourth is Hainan, for which we do not have data on 1959 mortality rates).

The data shows that not only did China produce more than enough food to avoid famine in 1959 as a country; but even at the province level, not a single region produced less than what was needed to avoid mortality.

4.2 Regional Grain Production and Famine in 1959

4.2.1 Historical Data

As we discussed in Section 3, there was significant variation in famine severity across regions. In this section, we use regional data on mortality and production to examine the spatial pattern more systematically. The pattern of regional production and death rates shown in Table 5 illustrates a striking pattern. Three of the four regions that produced less than what was needed for laborers to be productive also experienced three of the lowest mortality rates.

To investigate the cross-sectional relationship between per capita production and mortality rates more systematically, we estimate the correlation between the per capita production in province p and year t and the mortality rate in that province the following year. To allow the effect to be different for the famine, we introduce an interaction term of grain production and a dummy variable for when aggregate production fell, 1959. Note that because mortality is recorded annually and the majority of deaths are believed to have occured during the early months of 1960, we estimate the relationship between production in a given year and mortality in the following year. For this exercise, we transform the reported mortality rate data into the number of deaths in province p and year t by multiplying it by total provincial population in province p and year t.[39]

$$\begin{aligned} Ln(Deaths_{p,t+1}) &= \alpha(\ln Grain_{p,t} \times 1959Dummy_t) + \beta \ln Grain_{p,t} \\ &\quad +\gamma TotPop_{p,t} + \delta_t + \varepsilon_{p,t} \end{aligned} \tag{1}$$

The logarithm of the number of deaths in province p and year $t+1$ is a function of: the interaction between log grain production in province p year t, $\ln Grain_{pt}$, and a dummy variable for the year 1959, $1959Dummy_t$; the main effect for log grain production; the total population of a province p in year t, $TotPop_{pt}$; and, year fixed effects, δ_t. More populous provinces will naturally have more deaths and more grain production. Controlling for total population reflects the fact that we care about per capita grain and deaths. Alternatively, we could normalize the number of deaths and grain production by dividing each with the total population (as we did in Table 5). Controlling for population on the right hand side is a more flexible way of acheiving the same normalization.[40] In this estimation, β measures the average correlation between grain production and mortality rates for 1949-1958 and 1960-1997. If grain production is negatively correlated, then $\hat{\beta} < 0$. α reflects the marginal correlation in 1959. The average relationship between grain production and mortality in 1959 is the sum of the two coefficients, $\alpha + \beta$.

The estimated results are presented in Table 6. For each coefficient, we present the unadjusted and robust standard errors. The small number of provinces means that we cannot cluster the standard errors at the province level without being vulnerable to small sample bias. Column (1) shows the estimates using all 27 provinces of our sample. It shows

[39] The official documentation of the CSDM50 says that mortality rate is calculated as the total number of deaths in a year measured at the end of the year divided by the population as measured during the middle of the year. This suggests that the $Death_t = MortalityRate_t \times TotPop_t$. However, one may doubt the Chinese government's ability to collect population data during the middle of 1960, and think that instead they may have used the end of the year population in 1959 as the denominator for calculating mortality rates such that $Death_t = MortalityRate_t \times TotPop_{t-1}$. The results presented in this paper uses the latter method to be conservative. However, it does not make any difference to the results which method we use. We only report one set of results for brevity. The results using the first method are reported in the Appendix Table A1.

[40] Different ways of normalization do not change the results. For brevity, we only report the more flexible method in this paper.

that correlation between grain production and mortality is negative, but not statistically significant. However, the interaction term for grain production and the 1959 dummy variable is positive and statistically significant at the 1% level. In column (2), we omit the autonomous regions of Xinjiang, Guangxi, Ningxia, Neimeng and Qinghai. These regions had a much larger share of ethnic minorities and were often subject to different policies from those in the provinces which contained almost exclusively Han Chinese. When we exclude these, the results become more precisely estimated. The interaction term between grain production and the 1959 dummy is still large, positive and statistically significant at the 1% level. The main effect of grain production is negative in sign as in column (1) but not statistically significant at the 1% level. This coefficient shows that on average, a 1% increase in grain production is correlated with a 0.26% reduction in mortality. To see the effect in 1959, we sum this coefficient and the coefficient for the interaction term. This sum and the p-value using the two different methods of computing standard errors are reported at the bottom of the table. We see that in 1959, the correlation is reversed. A 1% increase in grain production is correlated with a 0.194% increase in mortality. The estimated p-values show that this joint statistic is highly significant regardless of whether we use unadjusted or robust standard errors.

In column (3), we add a control for government expenditure on health and education, which we use to proxy for public goods expenditure.[41] This controls for potential confounding factors such as the way in which regional governments responded to the famine. For example, governments in regions that produce less food on average may be more ready for famine and therefore respond to famine with higher spending on public health. If this is the case, then the positive correlation between production and mortality when production fell in 1959 would reflect public expenditures. The results in column (3) suggests that this is probably not the case as our estimates are very robust to this additional control.

Next, we control for province-specific time trends. This addresses the concern that regions that produce more on average experienced different mortality trends from regions that produce less on average. Column (4) shows that the estimates are robust to this control.

Finally, we address the problem that we lack mortality data for many provinces before 1954. Recall from Section 3 that our sample is only a balanced panel of 27 provinces from 1954-1997. To check that the selection of the provinces that reported data in the previous years do not drive our results, we re-estimate the same equation on a restricted sample where all provinces are omitted for the years 1949-53. The estimates are very robust.

One concern which may be raised about the estimates from equation (1) is that we are not capturing differences that are specific to the famine years. For example, one could worry that the relationship between grain production and mortality changes over time for completely spurious reasons. While we cannot completely rule out the possibility that such changes can occur, we can examine the data more carefully to see whether the relationship between grain production and mortality is positive in other years. We can estimate the correlation between grain production and mortality for each year using the following equation.

[41]This data is reported in the CSDM50.

$$Ln(Deaths_{p,t+1}) = \sum_{\tau=1949}^{1997} \alpha_\tau (\ln Grain_{p,\tau} \times YearDummy_{\tau=t}) + \gamma TotPop_{p,t} + \delta_t + \varepsilon_{p,t}, \quad (2)$$

where $YearDummy_{\tau=t}$ equals 1 if $\tau = t$ and equals 0 otherwise. This specification is similar to equation (1). The difference is that we now interact grain production with a dummy variable for each year, and because we have an interaction term for each year in the sample, we drop the main effect of grain production. Therefore, the average correlation between grain produced in a province and mortality is α_τ for each year τ. As before, we normalize by total population by controlling for that term on the right hand side. To increase precision, we use the restricted sample where we omit autonomous regions. The vector of estimated $\hat{\alpha}$'s are shown in Table 7. As with the earlier estimates, we present both unadjusted and robust standard errors. The estimates show that the correlation between production and mortality spikes in 1959 and is significant at the 1% level. This is clearly illustrated in Figure 6, which plots the estimated coefficients and the two sets of 95% confidence bands. The figure shows clearly that relative to other years, the relationship between grain production and mortality is very positive in 1959. Importantly, it shows that the time path of the correlation between grain production and mortality looks extremely similar to the time path of the raw data on mortality rates plotted in Figure 1. This means that the finding from Table 6 that the relationship between grain production and mortality changes in 1959 is specific to 1959. Therefore, it seems very unlikely that we are capturing spurious changes unrelated to the production fall in 1959.

In summary, the historical data illustrates a stark cross-sectional pattern between famine severity and food production in 1959 – it is positive, a reversal from the negative correlation observed in other years. There are several caveats to interpreting this correlation. First, there are the questions over data quality which we discussed in Section 3. Second, the results in this section do not identify whether the patterns are driven by urban or by rural households. In the next section, we address these two issues with the restrospective data

4.2.2 Retrospective Data

In this section, we conduct a similar empirical exercise with restrospective measures of famine severity, measured as regional birth cohort size from the *1990 Population Census*, and a proxy for grain production, measured as the suitability for cultivating rice or wheat as predicted by time-invariant natural conditions. This supplementary analysis has three major advantages. First, the disaggregated nature of the data allows us to capture much more of the variation in famine severity. Second, the survival data from the *1990 Population Census* can be divided into agricultural households who were subject to grain procurement by the central government, and non-agricultural households who were not and, in contrast, received grain subsidies. This allows us to identify whether the relationships in the data are driven by rural or urban households. Lastly and most importantly, the data is not subject to concerns of systematic government misreporting. Therefore, the supplementary analysis can be viewed as a robustness check for the provincial historic analysis.

We estimate the cross-sectional correlation between log birth cohort size and suitability for grain production using the following equation.

$$Ln(CohortSize_{ct}) = \alpha(Suitability_{ct} \times FamineDummy_t) + \beta Suitability_{ct} + \gamma AvgLn(CohortSize)_c + \delta_t + \varepsilon_{ct} \quad (3)$$

Log birth cohort size for birth county c in birth year t is a function of: the interaction term between the predicted suitability for county c for cultivating grain, $Suitability_c$, and a dummy variable indicating whether a cohort was born during 1959-61, $FamineDummy_t$; the main effect of suitability for grain cultivation; the average of the logarithm of cohort size for each county c; and birth year fixed effects, δ_t. This equation is conceptually similar to equation (1), except that now we use birth cohort size as the dependent variable, have a time-invariant proxy for production and control for the average of the log of each county's average cohort size (over birth years) on the right hand side. Controlling for average log cohort size is analogous to controlling for log total population in equation (1). This additional covariate allows us to control for a proxy for the population of each county on the right hand side in order to scale each observation by its relevant population. This is important since we are interested in comparing these results to the province-level correlations which document the structural relationship between mortality rate and production per capita. Given the absence of these exact measures at the county level, it is important to control for a county's average population which can be proxied by average cohort size on the right hand side.[42] The standard errors are clustered at the county level.

The average correlation between suitability and grain production is reflected by β. One would expect that regions suitable for grain production would typically have larger cohort sizes (from higher fertility rates or child survival rates) such that $\beta > 0$. α is the marginal correlation between suitability and cohort size for those born during the famine such that the average correlation between suitability and cohort size for these cohorts is reflected by the sum of the two coefficients, $\alpha + \beta$.

Table 8 columns (1)-(4) present the estimates for agricultural households. Column (1) uses a full sample of all provinces. Unlike the historical analysis, this includes the provinces of Tibet, Sichuan and Hainan. It shows that grain suitability is on average positively correlated with cohort size. The estimate for the interaction term shows that the marginal correlation for those born during famine years. It is negative. Both of the estimates are statistically significant at the 1% level. As with the historical estimates, the average correlation between grain suitability and cohort size for those born during the famine is the sum of the two coefficients presented at the bottom of the table. It is negative and statistically significant. Therefore, for those born during the famine, the usual positive relationship between suitability for grain cultivation and cohort size is reversed. In columns (2)-(4), we omit the autonomous provinces Tibet, Xinjiang, Neimeng,

[42]The fact that the control is averaged over birth years and time invariant for each county means that the coefficients of interest are identifical to those in a specification which controls for county fixed effects.

Ningxia, Guangxi and Qinghai. Column (2) shows that this changes our estimates very little. In column (3), we introduce province fixed effects. This controls for time-invariant differences between provinces such as ethnic composition or the fact that certain provinces may have been favored by the central government or always had better leaders. As before, the estimates are very robust to this control. In column (4), we add province-specific time trends as additional controls to address the possibility that fertility trends may have differed between provinces. The estimates are again very robust. In column (5), we add the most rigorous set of controls, province-year-specific fixed effects. This controls for any changes across provinces and over time in a fully flexible manner. For example, if certain provincial governments implemented particular policies in response to the famine, these policies will be controlled for in this regression where we compare the differences across counties within years. As before, the estimates change little in magnitude. All of the estimates presented in columns (2)-(5) are statistically significant at the 1% level.

Next, we repeat the same estimation on a sample of non-agricultural households. The estimated coefficients are much smaller in magnitude and statistically insignficiant. Towards the bottom of the table, we see that the sum of the coefficients are all very small in magnitude and statistically inignificant. These estimates suggest that on average, cohort size of urban households are not correlated with local grain production.

For consistency with the historical analysis, we estimate the correlation between grain suitability cohort size for each birth year. This is the analogous exercise to the estimate in equation (2) with historical data.

$$\ln(CohortSize_{ct}) = \sum_{\tau=1949}^{1966} \alpha_\tau \left(Suitability_\tau \times YearDummy_{\tau=t}\right) + \gamma AvgLn(CohortSize_c) + \delta_t + \varepsilon_{ct}, \tag{4}$$

where $YearDummy_{\tau=t}$ equals 1 if $\tau = t$ and equals 0 otherwise. The log cohort size of individuals born in year t in county c, $\ln(cohortsize_{ct})$, is a function of: the interaction terms between the fraction of land that is suitable for rice or wheat production in county c and dummy variables for each year; the average of log cohort size in a county across birth cohorts, $AvgLn(CohortSize_c)$; and birth year fixed effects, δ_t. All standard errors are clustered at the county level. The inclusion of year fixed effects controls for secular changes in fertility and mortality that may affect cohort sizes. The inclusion of average log cohort size normalizes the outcome variable and suitability by population.

The estimates for the agricultural and non-agricultural households are presented in Appendix Table A2. For brevity, we only plot the estimates for non-agricultural households. They and their 95% confidence intervals are plotted in Figure 7. It shows that relative to cohorts born far before the famine, the cohort sizes for those who were born close before the famine (and were very young when the famine began) and those born during the famine are negatively correlated with grain suitability. This is consistent with patterns in the data we have seen thus far.

The results from the retrospective data provide several insights. First, they support the results from the historical data in showing that famine was more severe in regions that were able to produce more food even though these regions were typically better off. Therefore, our findings from the historical data cannot be solely driven by reporting error. Second, they provide evidence that the patterns in the historical data are primarily driven by agricultural households. Finally, this reversal is not affected by controls for time-varying differences across provinces. This is important because it means that even allowing for the possibility that each provincial government enacted different policies in response to the aggregate production fall in 1959, there is still a reversal in the relationship between grain production and well-being (as measured by cohort size or mortality) during the famine.[43]

5 The Grain Procurement System

The previous section provides evidence for two findings that point to grain procurement policy as a main driving force of the famine. The first finding that food production in 1959 was sufficient for subsistence implies that the famine could not have been solely caused by the drop in food production, a traditional explanation for why famines occur.[44] It is consistent with Sen's (1981) thesis that historically, famines have not been caused by aggregate food shortages, but instead are caused by the unequal distribution of food consumption. According to this theory, income is negatively correlated with famine severity, implying that more productive farmers should experience lower famine mortality relative to less productive farmers. However, the second finding that regional famine severity was increasing with per capita production in 1959 is inconsistent with this prediction. A likely explanation for the difference is that China was a centrally-planned economy in which many of the market mechanisms studied by Sen (1981) were not in operation; China's food procurement system determined procurement and transfers of food for every region. Therefore, the empirical evidence suggests that certain features of the procurement system must have caused the famine and its surprising spatial patterns.[45]

Historical evidence suggests that a key feature of the centrally planned procurement

[43]In a similar empirical exercise, we investigated the cross-sectional correlation between famine severity and weather for agricultural and non-agricultural households. We regressed the ratio of famine birth cohort size relative to the average annual birth cohort size of those born prior to the famine (1954-57) on several weather variables that were important for agricultural production (average annual temperature, average annual spring temperature, average annual precipitation, and average annual spring precipitation). The results are presented in Appendix Table A3. They show that weather conditions have some explanatory power for the cross-sectional variation in famine severity for agricultural populations (colums 1-2), but is uncorrelated with famine severity for non-agricultural households (columns 3-4). These results are consistent with the findings fo Kueh (1994) and Li and Yang (2005) that weather was a partial contributor to the fall in production in 1959. More importantly, they are consistent with our main results that the well-being of agricultural households are much more highly correlated with local agricultural conditionsthan that of non-agricultural households.

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

[45]Interestingly, even after one accounts for the aggregate level of procurement as reported by Li and Yang (2005), households on average retained enough food to prevent mortality. Appendix Table A4 reports data from their paper. It shows that average per worker retention in 1959-60 was almost 195 kg per capita, more than the 190 kg needed for workers to stay productive and more than twice as large as the 75 kg needed to stay alive. This suggests that variation in retention levels across rural households must have been sufficiently large to generate any famine.

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

Grain procurement was planned centrally. The central government decided on the production targets each year. These made their way down to regional government officials, who traveled to collectives each spring to announce the expected production (e.g. production targets) for that collective. In the fall, around mid-October and November, procurement would take place. The government's formula for procurement can be seen in policies such as the "Three Fix Policy". In 1956, it stipulated that to "fix" procurement levels for each collective, expected local production levels in 1956 should be based on production in 1955, and subsistence levels of consumption and seed retention should be based on population and production needs.[46]

The main reason for setting procurement based on expected production is that peasants and local officials were not incentivized to report actual production truthfully. Discussions amongst the top party leadership show that they were well aware that peasants had a clear incentive to under-report production in order to retain a larger amount of grain. In addition, they would have wanted to under-report to prevent the government from demanding greater production in the future. Local leaders were similarly unreliabe as they could share the incentives of the peasants, or could be incentivized by potential political reasons to over-report production (Fairbank, 1985: pp. 305-8). Given that reported information could have been very unreliable, it made sense for the government to condition procurement on historic information.

To a large extent, bureaucrats seemed to have followed the prescribed procurement rules. This was especially true in 1958 and 1959, when political tensions were intensified between Mao and members of the Politburo who did not support his GLF policies. At the height of tensions, Mao purged a significant proportion of moderate political leaders from the upper and middle levels of government, creating an environment where few were willing to report that production in 1959 was lower than expected before the production numbers could be aggregated and presented to Mao in an impersonal manner.[47] In other

[46]See Johnson (1998) for a description of the procurement system. Historical grain policies are outlined in public government archives. See http://2006.panjin.gov.cn/site/gb/pj/pjjz/pjjz_detail.php?column_id=2382.

[47]The political climate in 1959 was extremely tense and most likely caused leaders to follow rules, even those that were likely to prove problematic later. The GLF had been received with cynicism from the very beginning, and its failures and successes were crucial to Mao's political leadership. In December 1958, at a meeting of the Central Committee of the CCP in Wuhan, party leaders refused to fully endorse GLF policies. Following this meeting, Liu Shaoqi replaced Mao, who remained Party Chairman, as the Head of State in early Spring of 1959 (Spence, 1991: pp. 581). Many historians view this as an unwilling step by Mao. It is therefore not surprising that further challenges of the GLF resulted in a strong response from Mao. In July 1959, Mao famously purged Peng Dehuai, a field marshal of extremely high political standing, for criticizing collectivization and other GLF policies and expressing forebodings of famine. These problems of the collective system mandated by the GLF were a source of contention between communist party moderates and hard-liners who backed Mao. However, with the exception of Peng Dehuai, a field marshal who did a tour of the countryside during the spring of 1959, there is no

words, the rules, together with the political pressure to follow them led to a very inflexible policy.[48]

An alternative source of inflexibility that is entirely independent of incentive issues is limited bureaucratic capacity together with the centralization of political power. The Standing Committee of around seven Politburo members was the only government organ with the power of making major policy decisions. It attempted to directly control 21 provinces, five autonomous regions, and two municipalities, which in turn governed approximately 2,300 county-level governments that supervised over one million branch offices of the Chinese Communist Party (CCP) in towns, villages, army units, factories, mines and schools. Policies were decided from the top and implemented by lower level governments. Information on the effectiveness of policies was collected locally, aggregated by the regional government, and then eventually reported upwards to the Standing Committee (Fairbank, 1985: pp. 297-341; Spence, 1991: pp. 542).

Part of the difficulty for a centrally planned regime to govern a country like China was its size. China is the third or fourth largest country in terms of geographic size.[49] Therefore, conditions which determine agricultural production, amongst other concerns of the central government, were very heterogeneous across regions. The poor conditions of China's transportation and communications infrastructure at this time greatly added to the central government's difficulties in obtaining and aggregating information.[50]

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evidence that any top leader ever obtained an accurate picture of the problems of collectivization and the danger of famine. Peng discretely reported these problems to Communist Party Chairman Mao Zedong in a personal letter. The problems he mentioned included reduced incentives to work, a diversion of labor away from agriculture, and over-procurement of grain by mid-level party leaders who were under-pressure to fulfill grain target quotas that had been set too high. Fearing a political revolt against his leadership based on perceived failures of the GLF, Mao used the contents of this letter to purge Peng as a rightist at the historic Lushan conference in July of 1959. Peng was put under house arrest and later executed during the Cultural Revolution. At this conference, the top party leaders made clear that the first year of the GLF was a success and that collectivization was increasing grain harvest more than ever (Becker, 1996, pp. 87-92).) The Lushan conference had important consequences. The removal of Peng was accompanied by a violent purge of all of his supporters amongst top party members as well as any moderate mid-level party leaders who had expressed concerns about collectivization and the dangers of famine (Fairbank, 1985: pp. 303-335; Becker, 1996, pp. 93). It put remaining leaders under enormous pressure to deliver the high targets for grain quotas for the harvest of 1959 in order to not be grouped with the critics of Mao (Spence, 1991: pp. 574-583).

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

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

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

Traveling between cities, where information was accumulated and policies made, and rural areas, where the food was produced, was very time consuming. Transportation networks were almost completely destroyed by decades of civil unrest (e.g. the civil war between the Sun-Yat Sen led Guomingtang

In the late 1950s, three factors significantly exacerbated these structural difficulties in administration. First, in order to reduce the budget deficit, the government severely cut expenditure on administration, which declined from 19.3% of total government budget expenditure in 1950 to only 7.8% in 1957 (Eckstein, 1977: pp. 186). Since both China's economy and government expenditures were increasing during this period, these figures suggest that government administration did not grow even though the economy and the scope of central planning had increased substantially. Second, the government lost much of its able personnel from the bureaucracy. Approximately 700,000 of its most educated bureaucrats were purged in 1957 after the Hundred Flowers Movement.[51] Moreover, in 1958, Mao actually abolished the State Statistical Bureau, which meant that there were no statisticians or demographers in 1959 to project national production figures before all of the harvests were procured and aggregated across regions (Fairbank, 1985: pp. 300; Spence, 1991: pp. 580).[52] Third, for political reasons, Mao implemented measures which further decreased the structural flexibility of the system. For example, after the Lushan meeting in 1959, in order to solidify his power, Mao banned the twice-weekly meetings of the Standing Committee and further removed decision-making powers from regional governments, two institutions which helped the leadership to address unexpected shocks. By the end of 1959, the Standing Committee met only once every two months, and the regional leadership had little power for independent decision making (Fairbank, 1985: pp. 303).

One obvious question that arises in trying to understand this context is why local leaders allowed grain to be procured in 1959 when they knew that this would leave them with less than subsistence needs. To the best of our knowledge, there is no good answer to this question as the historical evidence on the local political process during this time and personal accounts of survivors on this subject are almost non-existent. Therefore, we are forced to provide several speculative explanations. One is that political pressure from the central government caused local leaders to be willing to risk falling below subsistence later over being immediately punished for failing to produce enough grain. A complementary explanation comes from the fact that the New Communist government came to power partly because of their promise of "no more famines". Therefore, in these early years of

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

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

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

the new government, local leaders may have naively believed that once people began to starve, they will be given grain replenishments by the central government. In this case, a reasonable response for local leaders is to give the government the planned amount of procurement and postpone their plea for grain (and potential punishment) from the central government. This is consistent with accounts of collective kitchens providing large quantities of food even after the smaller fall harvests were realized (e.g., Yang, 1996; Chang and Wen, 1997). Note that our model will not formalize the microfoundations of inflexbility. Please see the next section for more discussion.

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

6 Model of Procurement

We have argued in the previous section that the famine was the consequence of a policy failure and that one salient feature of the Chinese procurement system was the government's difficulty in collecting and responding to new information. In this section, we develop a model of procurement policy which shows that this inflexibility could have generated a famine with spatial patterns consistent with China's Great Famine. The model is also useful for understanding the contribution of additional factors (e.g., misreporting of production, miscalculation of production, preferential treatment of certain regions, transport costs) to the famine. Moreover, it allows us to interpret the merits of the Chinese procurement policy relative to the alternative central planning policy of fixing prices.

6.1 Model

We consider procurement policy in an environment in which different regions produce different quantities of food. A key feature of our environment is that all regions are subject to an aggregate shock that reduces food production. The government can procure food from some regions and subsidize other regions with food. Given our discussion in Section 5, the key constraint faced by the government is that procurement policy cannot respond perfectly to this shock. For simplicity, we focus on the extreme case in which no adjustment to the shock is possible, capturing the notion that the government is either unaware of the shock or cannot be responsive to the shock. Given this constraint on policy, our model is therefore in the spirit of Weitzman (1974) who studies the optimal choice of quantities in a centrally planned economy in which quantities cannot respond to aggregate shocks.

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

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

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

Assumption 1 states that more productive regions produce more food per capita during both the high and the low shock. Assumption 2 states that more productive regions experience a higher variance in production (i.e., a sharper drop during the aggregate food downturn). Recall from section 3 that both of these assumptions are true in the historical data.

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

$$c_i(s) = e_i(s) - \tau_i \text{ for } s = H, L. \tag{5}$$

Note that while food consumption and production depend on the aggregate shock s, the level of procurement τ_i *does not depend on the aggregate shock*. This assumption is motivated by our discussion in Section 5 where we argue that a central feature of the Chinese procurement is its inflexibility. Though we focus on the extreme situation of complete inflexibility, all of our results apply to a more general setting in which the government observes an imperfect noisy signal about the state of the economy, or alternatively to a setting in which the government can adjust planned policies at a cost.[53] More generally, we take this inflexibility as given and do not microfound it since our discussion in Section 5 indicates that there are multiple historical factors behind it.

Since the shock σ_i equals 0 for urban regions, the level of consumption $c_i(s)$ is independent of the aggregate shock for these households. The government runs a balanced budget and does not engage in any public spending so that its budget constraint is:[54]

$$\sum_{i=1}^{M+N} p_i \tau_i = 0. \tag{6}$$

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

$$\sum_{i=1}^{M+N} p_i \left((1-\mu)\, \pi\left(c_i(H)\right)\chi + \mu \pi\left(c_i(L)\right)\chi \right) . \tag{7}$$

[53] Details available upon request.

[54] One can easily incorporate transport costs in our framework without changing our results. For instance, one can subtract $\delta_i \tau_i^2/2$ from the right hand side of (5) for $\delta_i \geq 0$ representing a region-specific transport cost.

$\pi(c_i(s))$ corresponds to the probability of survival as a function of consumption $c_i(s)$ and χ corresponds to the value of life.[55] We assume that $\pi(\cdot)$ is continuously differentiable, strictly increasing, and strictly concave, so that the probability of survival rises with food consumption, but this is subject to diminishing returns.[56]

The government knows the productivity $\widehat{e}_i$ and the volatility σ_i of each region and the probability of the aggregate shocks. It is clear in this environment that if the government could condition procurement τ_i on the shock s, then it would provide all households with the same level of food consumption conditional on the shock. In such an environment, there would be no cross-regional variation in mortality in response to an agricultural shock.[57]

In our environment, such a redistributive policy is not possible because procurement cannot respond to the shock. More specifically, consider a hypothetical procurement policy $\tau = \{\tau_i\}_{i\in\{1,M+N\}}$. Given Assumption 2 and equation (5), it is clear that the variance in consumption for a given region is increasing in $\widehat{e}_i$ (i.e. more productive regions experience a higher variance in production). Thus, under an inflexible procurement policy, it is not possible for the government to equalize consumption across regions in all states of the world. More specifically, the government in choosing the optimal policy solves the following program:

$$\max_{\tau}(7) \text{ s.t. } (5) \text{ and } (6).$$

Letting ψ correspond to the Lagrange multiplier on constraint (6), the first order conditions to the government's program yield:

$$(1-\mu)\,\pi'(c_i(H)) + \mu\pi'(c_i(L)) \;= \psi \;\forall i. \tag{8}$$

Therefore, the government equates the expected marginal utility of food consumption of all households, taking into account that more productive households will inevitably experience a higher variance in food consumption. Equation (8) has some important implications which are summarized in the below proposition. All of the proofs are in the Appendix.

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

[55] One can alternatively interpret $\pi(c_i(s))$ as corresponding to the fraction of the population in region i which dies from starvation in an environment in which a minimal level of consumption $\underline{c}$ is required to stay alive. Specifically, one can imagine that the food consumption of a given individual z in region i equals $c_i(s) + \varepsilon_{iz}$ for ε_{iz} which represents an idiosyncratic shock. Thus $\pi(c_i(s)) = \Pr\{c_i(s) + \varepsilon_{iz} \geq \underline{c}\}$.

[56] One can easily incorporate in our framework a motive for the government to save or deplete its current stock of food by ignoring (6) and adding an additional term in the government objective:

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

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

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

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

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

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

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

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

The second part of Proposition 1 states that procurement is increasing in productivity $\widehat{e}_i$, so that more productive regions experience a higher procurement tax relative to less productive regions. This follows from the fact that by Assumption 1, more productive regions produce more in all states of the world, so that a government wishing to redistribute towards the less productive regions should procure more food from these more productive regions. This is consistent with data we collected on province level procurement targets and production for the years 1980-88, which to the best of our knowledge (based on interviews with government officials) used a similar formula for setting procurement as in the 1950s and 60s. The main difference between the famine era and subsequent decades is that the government aimed for a lower level of procurement, but the method for determining the differences in amount by region did not change. Appendix Figure A2 plots procurement targets as a function of a moving average of per capita production over the past for years. It shows a strong positive correlation.

The third part of Proposition 1 states that during a food production boom, mortality and productivity are negatively correlated across regions. In contrast, during a food production downturn, mortality and productivity are positively correlated across regions. This prediction is consistent with our empirical findings regarding the spatial distribution of famine intensity. Intuitively, recall that more productive regions have more volatile production (Assumption 2) though all regions are subject to an inflexible and non-volatile procurement policy. Thus, more productive regions experience more volatile consumption, a result which is stated formally in Corollary 1. Since the government cares about all households equally, it follows that households subject to more volatile consumption experience relatively higher consumption during the food production boom and relatively lower consumption during the food production downturn, leading to the spatial patterns of mortality.[58] For an illustration of the mechanics of this model, recall the simple stylized example presented in the Introduction and Table 1.

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

In addition to capturing patterns associated with the famine, our model makes several general predictions regarding mortality outcomes under an inflexible procurement system. For instance, consider a generalization of our setting in which every single region's stochastic food endowment $e_i(s)$ is subject to a set of aggregate and idiosyncratic shocks, where the level of procurement is independent of the realized shock because of inflexibility. In such an environment, the following two patterns emerge: (1) mortality is negatively correlated with food production *within* a region, and (2) variance in food production is positively correlated with variance in mortality *across* regions. These two patterns emerge precisely because of the imperfect insurance resulting from the inflexibility of the food procurement system; regions must bear a portion of the risk associated with their own stochastic production. We find that these two patterns are present in the data. More specifically, if we re-estimate (1) with province fixed effects, we find that the coefficient on per capita grain production is negative and that the sum of this coefficient plus the interaction effect is also negative. Moreover, we find that the correlation between the within-province standard deviation in log mortality and the within-province standard deviation in log production per capita is positive.[59] These patterns which point to the presence of imperfect insurance provide additional evidence regarding the inflexibility of the procurement system.

6.2 Additional Mechanisms

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

First, we explore whether misreporting of production could have contributed to the famine beyond the mechanisms illustrated in the model.[60] In a dynamic extension of our environment, one can imagine that the government estimates the productivity $\widehat{e_i}$ of each region based on the history of reports of production. In such an environment it is clear that a tendency by officials to over-report in previous years may cause the government to over-procure from certain regions in the current year, and this can amplify the rise in deaths due to an aggregate food production downturn. More generally, one can imagine that incompetence on the part of the government could cause it to miscalculate many of the parameters of the model. For instance, if the government underestimates region-specific food production volatility, σ_i, or the probability of a food production downturn, μ, then one can show that that these types of systematic biases by the government could serve to reinforce our conclusions since they could result in over-procurement. However,

[59]For brevity, we do not report these results in the paper. They are available upon request. In addition, we collect historic data on weather conditions from scientific weather stations, and we find that the within-county standard deviation in log cohort size is positively correlated in the within-county standard deviation in rainfall.

[60]As discussed in Section 5, one interpretation of the inflexible policy is that it is a response to problems of misreporting.

in the absence of the constraint of an inflexible procurement policy, such biases on their own would not generate the empirical spatial distribution of mortality.[61]

A second issue to consider is the possibility that the government was too committed to high levels of grain procurement and this caused the aggregate procurement level to be very high during the famine. This could have been the case historically for two reasons. First, it is possible that the government wished to send the grain abroad in order to use the revenue to invest in industry. Second, the government may have wished to procure more and more grain from rural regions as a means of providing incentives for farmers to raise production levels and productivity.[62] In the context of our model, the motive to procure grain would further amplify the mortality consequences of the reduction in food production, since this is equivalent to increasing the Lagrange multiplier ψ in (8) which represents the shadow value of food consumption.[63] However, note that a commitment to high levels of procurement on its own could not generate the spatial inequality that we observe in the data since it would lead to a uniform distribution of mortality.[64]

A third issue to consider is the possibility that the government favored certain regions over others and that this may have contributed to the famine. More specifically, one could interpret the self-interest or malevolence of politicians as manifesting itself in our model as some regions receiving more weight in the social welfare function. For the famine, this means that the government could have favored urban areas over rural areas.[65] In

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

[62] For example, the government may have been trying to learn to aggregate capabilities of each rural region by procuring more and more over time. This is a very relevant to the context of grain procurement in China as the data on procurement targets from the 1980s show that targets were a positive function of past production (see Appendix Figure A2). (These data are from the 1980s, when the government still set production quotas. We were unable to obtain procurement target data from the famine era). In addition to potentially causing the downturn in production, the theory proposed by Li and Yang (2005), high levels of procurement could have exacerbated the impact of the downturn by creating large inequalities in food consumption.

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

[64] Empirically, our discussion in Footnote 45 also suggests that even after one takes into account aggregate procurement levels, there was enough food in the aggregate to prevent famine, which suggests that aggregate procurement levels alone cannot explain the famine.

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

the context of our model, this could lead to further inequality in food consumption and a higher famine intensity, particularly if this favoritism is towards cities over rural regions.[66] It is important to note that favoritism on its own would cause some regions to consistently experience higher mortality both during a food production boom and during a downturn. It cannot explain the reversal in the correlation between food production and mortality between famine and non-famine years that we find in the data.[67] Moreover, recall that the results in Section 4.2.2 show that the reversal of the relationship between food production and well-being exists even if we examine a sample of only agricultural households and even when we control for all province-year specific differences. This means that even after accounting for time-varying differences in regional policies, we still observe the reversal, which implies that there must have been factors other than regional policy differences which caused the famine.

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

6.3 Counterfactual Exercise: Fixing Quantities vs. Prices

A natural question given our interpretation of this historical episode is the extent to which the Chinese government could have chosen a better policy. More specifically, in the context of an inflexible central planning environment, the government could have chosen to have redistributed food from farms to cities by paying a fixed price to farmers for this food. This style of policy was used under central planning regimes such as the Soviet Union during the New Economic Policy. In China, it was used in the early 1950s and again from the mid-1990s to today.

In this section, we use the model developed in Section 6.1 in order to discuss the

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

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

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

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

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

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

for some parameter $\alpha > 0$.[68]

The government fixes the price of food as follows. It commits to purchasing any quantity of food from rural households at a price P and it redistributes this food to urban households. To finance these purchases, the government taxes the non-food endowment of households. Note that because preferences over non-food consumption are linear, the government does not care about the inequality in non-food consumption from this taxation, so that we can effectively ignore non-food consumption in the government's optimization program. For simplicity, imagine that the government chooses an interior price $P \geq \max_{i \in \{1,M\}} \pi'(e_i(L))$ so that it is sufficiently high that all rural households would choose to sell food to the government in all states of the world.[69] Moreover, to facilitate interpretation, suppose that the implied level of consumption under the optimal policy always satisfies $\overline{c} \geq c_i(s) \geq \overline{c} - \alpha^{-1/2}$ so that the value of $\pi(\cdot)$ is always between 0 and 1. In this circumstance, the first order conditions for rural households would imply that

$$\pi'(c_i(s)) = P \text{ for } s = \{H, L\} \ \forall i. \tag{9}$$

so that all rural households have a level of food consumption that is independent of the aggregate shock and which sets the marginal utility of food consumption equal to the price of food. This means that during the food production boom, they would sell more food to the government, and during the food production downturn, they would sell

[68] Given our assumption on preferences in this extension, the utilitarian optimum could be achieved with perfectly competitive markets. For this exercise, we rule out this possibility to examine the less dramatic measure of fixed supplier prices which the Chinese government may have been able to pursue during this time period.

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

less food to the government. Consequently, urban households would all have a volatile consumption and would endure the entire risk associated with the aggregate production shock. Interestingly, this is the exact *opposite* situation as in an environment with fixed quantities in which the entire burden of the aggregate production shock is borne by rural households.

By analogous reasoning as in the environment with fixed quantities, optimal policy implies the first order condition in equation (8) (where ψ must be interpreted as the Lagrange multiplier for the resource constraint of the entire economy). More specifically, the government equates the expected marginal utility of food consumption across households, taking into account that this level of consumption is deterministic for rural households and stochastic for urban households. In addition to treating all rural households symmetrically, the government treats urban households symmetrically, so that they all equally bear the burden of the aggregate shocks.

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

$$\left[\sum_{i=1}^{M} p_i / \sum_{i=M+1}^{M+N} p_i\right]\left[\left(\sum_{i=1}^{M} \frac{p_i}{\sum_{i=1}^{M} p_i}\sigma_i\right)^2 / \sum_{i=1}^{M} \frac{p_i}{\sum_{i=1}^{M} p_i}\sigma_i^2\right] > 1 \tag{10}$$

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

The intuition for this proposition is as follows. Imagine for simplicity that all rural regions are identical so that condition (10) collapses to $\sum_{i=1}^{M} p_i > \sum_{i=M+1}^{M+N} p_i$. This means that quantity controls dominate price controls if the urban population is in the minority. To understand this result, note that if the rural households are a majority, then the government faces a choice between having a majority of the population experiencing small consumption fluctuations under fixed quantities versus having a minority of the population facing large consumption fluctuations under fixed prices. The government prefers to let a majority experience the shock because large volatilities in consumption are extremely costly to the government from a welfare perspective and it is better to pool this risk across rural households.[70]

To understand why quantity controls dominate price controls only if the cross-sectional variance in the magnitude of shocks is low, imagine for simplicity that rural and urban

[70] This insight is related to Weitzman's (1974) result that quantity controls dominate price controls if the absolute value of the second derivative of the benefit function with respect to quantity exceeds the second derivative of the cost function with respect to quantity. This is also true in our setting if one interprets the benefit function as the portion of social welfare attributable to the urban population and the cost function as the negative of the portion of social welfare attributable to the rural population. In this light, the relative curvature of each function depends on the relative size of the urban and rural population.

regions have the same population size so that (10) collapses to $0 > Var(\sigma_i)$. Thus, if rural households are homogeneous, then quantity and price controls are equivalent from a welfare perspective for reasons previously discussed. However, if there is any heterogeneity in the productivity shocks across rural households, then price controls dominate quantity controls. The reason is because price controls make it possible for the urban population to pool all of the differential risk faced by the rural population. For example, if there were two rural regions of equal size, one with a higher value of the shock σ_i than the other, then the government would prefer to let the urban half of the population experience an intermediate level of consumption volatility under price controls versus having one half of the farmers experiencing very high volatility and one half of the farmers experiencing very low volatility under quantity controls.[71]

In conclusion, a retrospective evaluation of the merits of the Chinese procurement policy of fixing quantities versus fixing prices relies on two factors. On the one hand, it is clear that the urban population represented a small minority of the population, and this fact provides support for the relative benefit of the procurement policy. On the other hand, the Chinese rural regions were not identical, as is evidenced by the fact that more productive regions experienced a larger reduction in total production during the famine. The government could have in principle been able to pool the risk associated with this heterogeneity by fixing a price at which farmers would sell their food to the cities, though this would have come at a cost of volatile mortality outcomes in cities. The extent to which the procurement policy dominated price controls is an important quantitative question for future research.[72]

7 Conclusion

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

Our analysis leaves open several interesting directions for future research. A natural future direction is to study the geographic patterns of other famines that have occurred in history and to use these patterns to understand the role of policy failures in causing the famine. It would be interesting to understand whether similar mechanisms contributed to

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

[72]Our analysis also ignores the fact that the government may have also put a lot of weight on the accumulation of grain either for storage purposes or for exportation. To the extent that this was a major concern, this would bias the government away from choosing a policy of fixing prices and towards a policy of fixing quantities.

the Ukrainian Famine (1932-33) and the North Korean Famine (1992-95). Furthermore, our model leaves open several interesting theoretical questions. Specifically, our model of inflexible government policy, which is inspired by historical evidence and which builds on the model of Weitzman (1974), assumes that government procurement policy cannot adjust to aggregate shocks. An interesting question for future research is to understand why some government policies are more flexible than others and whether concrete policy recommendations can be made during food production declines to avoid famine, both in market and non-market economies.

8 Appendix

Proof of Proposition 1 and Corollary 1

An equal distribution of consumption maximizes (7) but cannot be achieved given constraint (5) and (6) by Assumption 2 which proves the first part of the proposition. Consider two regions k and l with $\widehat{e}_k > \widehat{e}_l$. If $\tau_k \leq \tau_l$, then $c_k(s) > c_l(s)$ for $s = \{H, L\}$ by Assumption 1, but given the concavity of $\pi(\cdot)$, this violates (8), which proves the second part of the proposition. If $c_k(L) > c_l(L)$, then by (5) and Assumption 2, this implies that $c_k(H) > c_l(H)$ which violates (8). Therefore, $c_k(L) < c_l(L)$ and satisfaction of (8) implies that $c_k(H) > c_l(H)$, and this proves the third part of the proposition. To prove the corollary, note that $Var(\pi(c_i(s))) = \mu(1-\mu)[\pi(c_i(H)) - \pi(c_i(L))]^2$. Since $c_i(H)$ is rising in $\widehat{e}_i$ and $c_i(L)$ is declining in $\widehat{e}_i$, $\pi(c_i(H)) - \pi(c_i(L))$ is rising in $\widehat{e}_i$, which implies that $Var(\pi(c_i(s)))$ is rising in $\widehat{e}_i$. **Q.E.D.**

Proof of Proposition 2

Under fixed quantities, (8) together with (5) and (6) imply that if $i \in \{1, M\}$, then

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

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

$$c_i(H) = c_i(L) = \sum_{i=1}^{M} p_i(\widehat{e}_i - \mu\sigma_i) / \sum_{i=1}^{M} p_i \tag{11}$$

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

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

Under fixed prices, (9) and the resource constraint of the economy implied by the substitution of (5) into (6) imply that if $i \in \{1, M\}$, then (11) holds, and if $i \in \{M+1, M+N\}$, then

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

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

$$1 - \alpha \sum_{i=1}^{M+N} p_i \left(\bar{c} - \sum_{i=1}^{M} p_i(\widehat{e}_i - \mu\sigma_i) / \sum_{i=1}^{M+N} p_i \right)^2 - \alpha\mu(1-\mu) \left(\sum_{i=1}^{M} p_i\sigma_i \right)^2 / \sum_{i=M+1}^{M+N} p_i. \tag{13}$$

(12) exceeds (13) if and only if condition (10) holds. **Q.E.D.**

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Table 1: Illustration of the Model

	Region A	Region B	City
Subsistence Needs	100	100	100
Production under High Shock (Probability 80%)	225	150	0
Production under Low Shock (Probability 20%)	180	120	0
Expected Production (0.8 x High + 0.2 x Low)	216	144	0
Expected Consumption	120	120	120
Procurement/Subsidy (Expected Production - Expected Consumption)	96	24	-120
Consumption under High Shock (High Production - Procurement)	129	126	120
Consumption under Low Shock (Low Production - Procurement)	84	96	120

Table 2: Descriptive Statistics

	A. Historical Province-Year Level Data 1949-98					
	Obs	Mean	Std. Err.			
Population (10,000 People)	1307	2938.39	54.11			
Mortality Rate (per 1,000 People)	1307	8.58	0.12			
Mortality Rate in 1960 (per 1,000 People)	1307	21.97	0.41			
Mortality Rate in 1954-57 (per 1,000 People)	1307	11.55	0.06			
Ratio of Mortality Rate 1960/Death Rate 1954-57	1307	1.84	0.03			
Fraction of Provinces where the Ratio of Mortality Rate 1960/ Death Rate 1954-57>1	1307	0.86	0.01			
Grain Production in 1959 (10,000 Tons)	1307	1009.29	23.69			
Annual Per Capital Grain Production (Kg Per Person)	1307	317.79	3.42			
Annual Per Capital Grain Production in 1959 (Kg Per Person)	1307	254.02	2.55			
Annual Per Capital Grain Production in 1954-57 (Kg Per Person)	1307	305.41	2.37			
Ratio of Per Capital Grain Production in 1959/1954-57	1307	0.83	0.00			
Fraction of Provinces where the Ratio in Per Capita Grain Production 1959/1954-57>1	1307	0.96	0.01			
	B. Retrospective County-Birth Year Level Data (1949-66)					
	Agricultural Households			Non-Agricultural Households		
	Obs	Mean	Std. Err.	Obs	Mean	Std. Err.
Average Cohort Size Born in 1949-66 (1%)	21420	52.66	47.86	12006	39.55	45.00
Average Famine Cohort Size born in 1959-61 (1%)	21420	35.08	29.49	12006	32.77	36.29
Average Pre-Famine Cohort Size born in1954-57 (1%)	21420	53.14	44.88	12006	40.92	44.72
Ratio of Famine 1959-61/Pre-Famine 1954-57 Cohort Size	21420	0.71	0.25	12006	0.83	0.30
Fraction of Counties where Ratio of Famine 1959-61/Pre-Famine 1954-57 Cohort Size <1	21420	0.89	0.31	12006	0.76	0.43
Fraction of Land Suitable for Rice or Wheat Cultivation	21420	0.13	0.24	12006	0.20	0.30

In Panel A, the sample contains 27 provinces. Tibet, Sichuan and Hainan are omitted. Each observation is a province in a given year. In Panel B, the sample contains all 30 provinces. Each observation is a birth year x birth county cell.

Sources: Panel A -- CSDM50 (1999), Panel B -- 1990 Population Census, GAEZ (2002)

Table 3: Population Caloric Needs

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

Source: Coale (1981) and authors' computations.

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

Table 4: Production and Caloric Needs 1949-76

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

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

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

Table 5: Province Level Production and Caloric Needs in 1959

Famine Mortality and Production by Province				
Province	1960 Death Rate	1959 Grain Prod	1959 "Surplus"	
		Kg/Person	1,870 Calories	804 Calories
	(1)	(2)	(3)	(4)
Shanghai	6.9	107.02	-82.98	36.02
Beijing	9.14	82.01	-107.99	11.01
Neimeng	9.4	412.16	222.16	341.16
Jilin	10.13	401.07	211.07	330.07
Tianjin	10.34	91.42	-98.58	20.42
Heilongjiang	10.52	505.95	315.95	434.95
Shanxi	11.21	244.48	54.48	173.48
Liaoning	11.5	235.91	45.91	164.91
Zhejiang	11.88	382.06	192.06	311.06
Shan'xi	12.27	251.99	61.99	180.99
Ningxia	13.9	303.70	113.70	232.70
Guangdong	15.24	242.70	52.70	171.70
Xinjiang	15.67	304.35	114.35	233.35
Hebei	15.8	195.12	5.12	124.12
Jiangxi	16.06	314.36	124.36	243.36
Jiangshu	18.41	231.42	41.42	160.42
Fujian	20.7	259.23	69.23	188.23
Hubei	21.21	241.07	51.07	170.07
Shandong	23.6	195.24	5.24	124.24
Yunnan	26.26	265.26	75.26	194.26
Hunan	29.42	300.32	110.32	229.32
Guangxi	29.46	246.98	56.98	175.98
Henan	39.56	195.72	5.72	124.72
Qinghai	40.73	200.49	10.49	129.49
Gansu	41.32	223.95	33.95	152.95
Guizhou	52.33	242.67	52.67	171.67
Anhui	68.58	204.55	14.55	133.55
Hainan	N/A	181.51	-8.49	110.51
Tibet	N/A	N/A	N/A	N/A
Sichuan	N/A	N/A	N/A	N/A

Source: CSDM50 (1999) and authors' computations.

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

Table 6: Correlation between Production and Mortality

		Dependent Variable: Ln Number of Deaths in Year t+1				
		(1)	(2)	(3)	(4)	(5)
		All	Omit Autonomous	Omit Autonomous	Omit Autonomous	Omit Autonomous & 1949-53
A	Ln Grain Prod x 1959 Dummy	0.119	0.256	0.242	0.237	0.262
		(0.0432)	(0.0482)	(0.0436)	(0.0370)	(0.0485)
	Robust SE	*(0.123)*	*(0.0876)*	*(0.0795)*	*(0.0776)*	*(0.0876)*
B	Ln Grain Prod	-0.0182	-0.0619	-0.0929	-0.0523	-0.0731
		(0.0189)	(0.0192)	(0.0178)	(0.0353)	(0.0205)
	Robust SE	*(0.0205)*	*(0.0237)*	*(0.0174)*	*(0.0192)*	*(0.0412)*
	Ln Total Population	1.050	1.134	1.280	0.978	1.142
		(0.0221)	(0.0256)	(0.0255)	(0.0440)	(0.0277)
	Robust SE	*(0.0318)*	*(0.0224)*	*(0.0299)*	*(0.0544)*	*(0.0243)*
	Controls					
	Gov Exp on Public Goods	N	N	Y	N	N
	Province-Time Trends	N	N	N	Y	N
	Observations	1290	1055	1032	1055	968
	R-squared	0.946	0.931	0.944	0.961	0.927
	Joint A + B	0.101	0.194	0.149	0.185	0.189
	p-value	0.0287	0.0001	0.0011	0.0002	0.0002
	p-value (Robust)	*0.419*	*0.0271*	*0.0641*	*0.0120*	*0.0315*

All regressions control for year fixed effects. All regressions use a sample where Tibet, Hainan and Sichuan. In Columns (2)-(5), we also exclude all autonomous regions: Xinjiang, Guangxi, Ningxia, Neimeng and Qinghai.

Table 7: Yearly Correlation between Production and Mortality

	Dependent Variable: Ln Cohort Size		
	(1)	(2)	(3)
	Coefficient	SE	Robust SE
Ln Grain Prod x Year = 1949	-0.0396	(0.0515)	(0.0423)
Ln Grain Prod x Year = 1950	-0.0720	(0.0554)	(0.0458)
Ln Grain Prod x Year = 1951	0.0129	(0.0575)	(0.0347)
Ln Grain Prod x Year = 1952	0.0210	(0.0542)	(0.0371)
Ln Grain Prod x Year = 1953	0.0793	(0.0528)	(0.0432)
Ln Grain Prod x Year = 1954	0.0127	(0.0494)	(0.0311)
Ln Grain Prod x Year = 1955	0.0563	(0.0513)	(0.0388)
Ln Grain Prod x Year = 1956	-0.0211	(0.0522)	(0.0504)
Ln Grain Prod x Year = 1957	-0.0032	(0.0546)	(0.0695)
Ln Grain Prod x Year = 1958	0.0537	(0.0497)	(0.0425)
Ln Grain Prod x Year = 1959	***0.2030***	***(0.0502)***	***(0.0900)***
Ln Grain Prod x Year = 1960	-0.0195	(0.0509)	(0.0528)
Ln Grain Prod x Year = 1961	-0.0005	(0.0529)	(0.0335)
Ln Grain Prod x Year = 1962	-0.0125	(0.0518)	(0.0442)
Ln Grain Prod x Year = 1963	0.0112	(0.0556)	(0.0712)
Ln Grain Prod x Year = 1964	0.0255	(0.0550)	(0.0581)
Ln Grain Prod x Year = 1965	-0.0306	(0.0585)	(0.0655)
Ln Grain Prod x Year = 1966	0.0256	(0.0531)	(0.0544)
Ln Grain Prod x Year = 1967	-0.0479	(0.0552)	(0.0516)
Ln Grain Prod x Year = 1968	-0.0977	(0.0564)	(0.0614)
Ln Grain Prod x Year = 1969	-0.0466	(0.0552)	(0.0402)
Ln Grain Prod x Year = 1970	-0.0484	(0.0568)	(0.0451)
Ln Grain Prod x Year = 1971	-0.0800	(0.0555)	(0.0456)
Ln Grain Prod x Year = 1972	-0.0539	(0.0510)	(0.0346)
Ln Grain Prod x Year = 1973	-0.0612	(0.0532)	(0.0348)
Ln Grain Prod x Year = 1974	-0.0931	(0.0566)	(0.0394)
Ln Grain Prod x Year = 1975	-0.1350	(0.0556)	(0.0597)
Ln Grain Prod x Year = 1976	-0.0715	(0.0536)	(0.0259)
Ln Grain Prod x Year = 1977	-0.0932	(0.0518)	(0.0244)
Ln Grain Prod x Year = 1978	-0.0921	(0.0535)	(0.0274)
Ln Grain Prod x Year = 1979	-0.0888	(0.0525)	(0.0273)
Ln Grain Prod x Year = 1980	-0.0907	(0.0526)	(0.0251)
Ln Grain Prod x Year = 1981	-0.0831	(0.0497)	(0.0274)
Ln Grain Prod x Year = 1982	-0.0633	(0.0501)	(0.0374)
Ln Grain Prod x Year = 1983	-0.0627	(0.0478)	(0.0280)
Ln Grain Prod x Year = 1984	-0.0792	(0.0490)	(0.0259)
Ln Grain Prod x Year = 1985	-0.0580	(0.0492)	(0.0239)
Ln Grain Prod x Year = 1986	-0.0780	(0.0493)	(0.0313)
Ln Grain Prod x Year = 1987	-0.0807	(0.0493)	(0.0281)
Ln Grain Prod x Year = 1988	-0.1020	(0.0501)	(0.0267)
Ln Grain Prod x Year = 1989	-0.0684	(0.0504)	(0.0237)
Ln Grain Prod x Year = 1990	-0.0726	(0.0505)	(0.0291)
Ln Grain Prod x Year = 1991	-0.0855	(0.0523)	(0.0272)
Ln Grain Prod x Year = 1992	-0.1050	(0.0514)	(0.0279)
Ln Grain Prod x Year = 1993	-0.0966	(0.0505)	(0.0260)
Ln Grain Prod x Year = 1994	-0.0967	(0.0496)	(0.0279)
Ln Grain Prod x Year = 1995	-0.1050	(0.0492)	(0.0243)
Ln Grain Prod x Year = 1996	-0.0942	(0.0488)	(0.0258)
Ln Grain Prod x Year = 1997	-0.1180	(0.0486)	(0.0237)
Observations	1055		
R-squared	0.935		

All regressions control for year fixed effects. Column (2) presents unadjusted standard errors. Column (3) presents robust standard errors. The sample excludes Tibet, Sichuan and Hainan, and all autonomous regions: Xinjiang, Guangxi, Ningxia, Neimeng and Qinghai.

Table 8: Correlation between Grain Suitability and Cohort Size

		Dependent Variable: Ln Cohort Size									
		Agricultural Households					Non Agricultural Households				
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
		Full Sample	Omitting Autonomous Provinces	Omitting Autonomous Provinces	Omitting Autonomous Provinces	Omitting Autonomous Provinces	Full Sample	Omitting Autonomous Provinces	Omitting Autonomous Provinces	Omitting Autonomous Provinces	Omitting Autonomous Provinces
A	Grain Suit x Born 1959-61	-0.289	-0.251	-0.251	-0.224	-0.126	-0.0560	-0.0383	-0.0383	-0.0104	0.0152
		(0.0495)	(0.0507)	(0.0507)	(0.0513)	(0.0458)	(0.0414)	(0.0427)	(0.0428)	(0.0432)	(0.0405)
B	Grain Suitability	0.0481	0.0418	0.0418	0.0373	0.0210	0.00933	0.00638	0.00638	0.00173	-0.00253
		(0.00825)	(0.00845)	(0.00846)	(0.00856)	(0.00763)	(0.00690)	(0.00712)	(0.00713)	(0.00721)	(0.00675)
	Controls										
	Province FE	N	N	Y	Y	N	N	N	Y	Y	N
	Province Time Trends	N	N	N	Y	N	N	N	N	Y	N
	Province FE * Year FE	N	N	N	N	Y	N	N	N	N	Y
	Observations	21420	17622	17622	17622	17622	12006	10368	10368	10368	10368
	Adjusted R-squared	0.904	0.907	0.907	0.910	0.925	0.873	0.873	0.873	0.877	0.881
	Joint A + B	-0.241	-0.209	-0.209	-0.186	-0.105	-0.0466	-0.0319	-0.0319	-0.00865	0.0127
	p-value	0.00000	0.00000	0.00000	0.00001	0.00591	0.17700	0.37000	0.37100	0.81100	0.70700

All regressions control for average ln county population and year fixed effects. Standard errors are clustered at the county level.

The sample in Columns (2)-(5) and (7)-(10) excludes all autonomous regions: Tibet, Xinjiang, Guangxi, Ningxia, Neimeng and Qinghai. All regressions use birth cohorts born during 1949-1966.

Figure 1: Mortality Rates Over Time

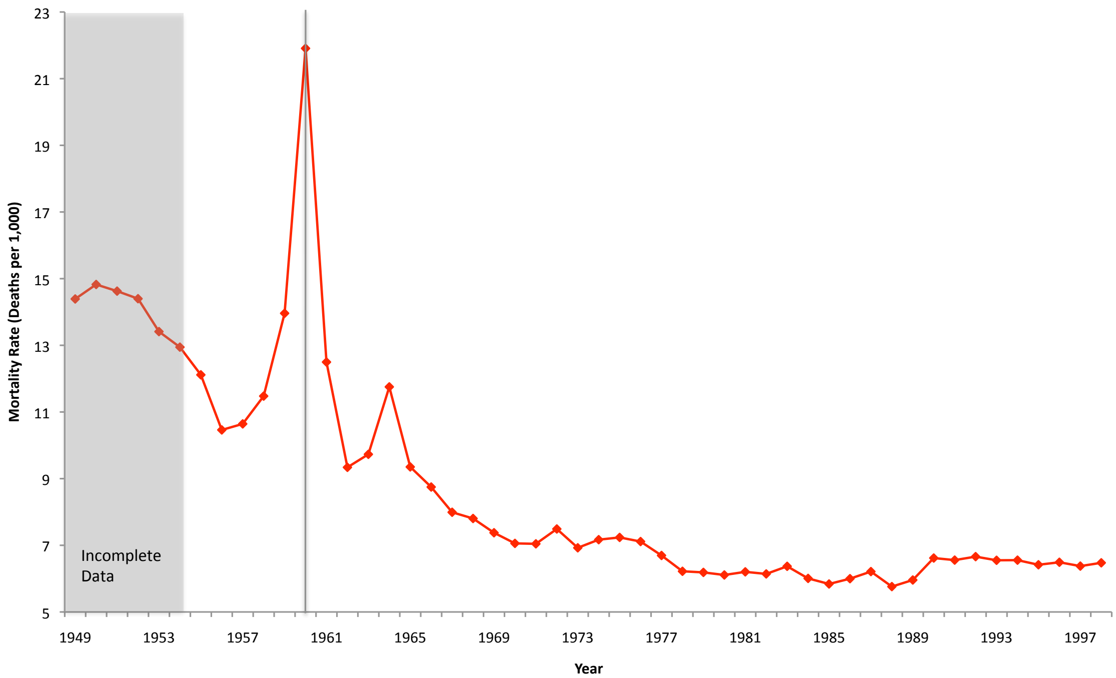

Figure 2: Cohort Size Over Birth Years

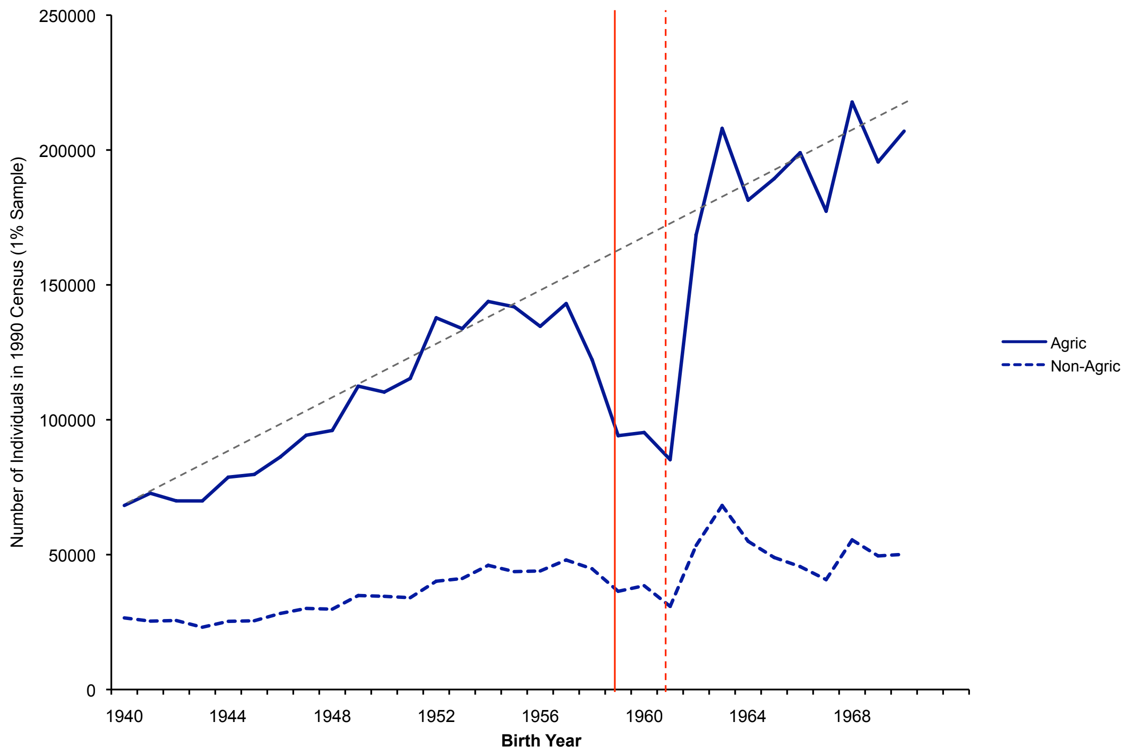

Figure 3: Cross Section Famine Variation

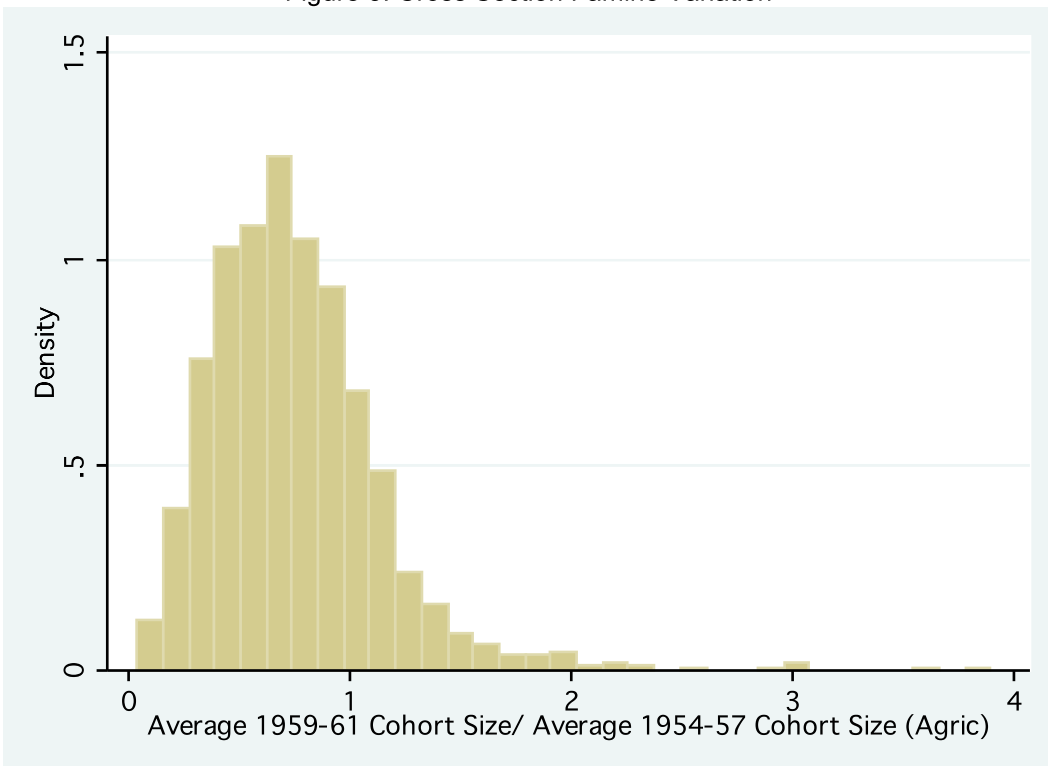

Figure 4A: Province Mortality Rates over Time

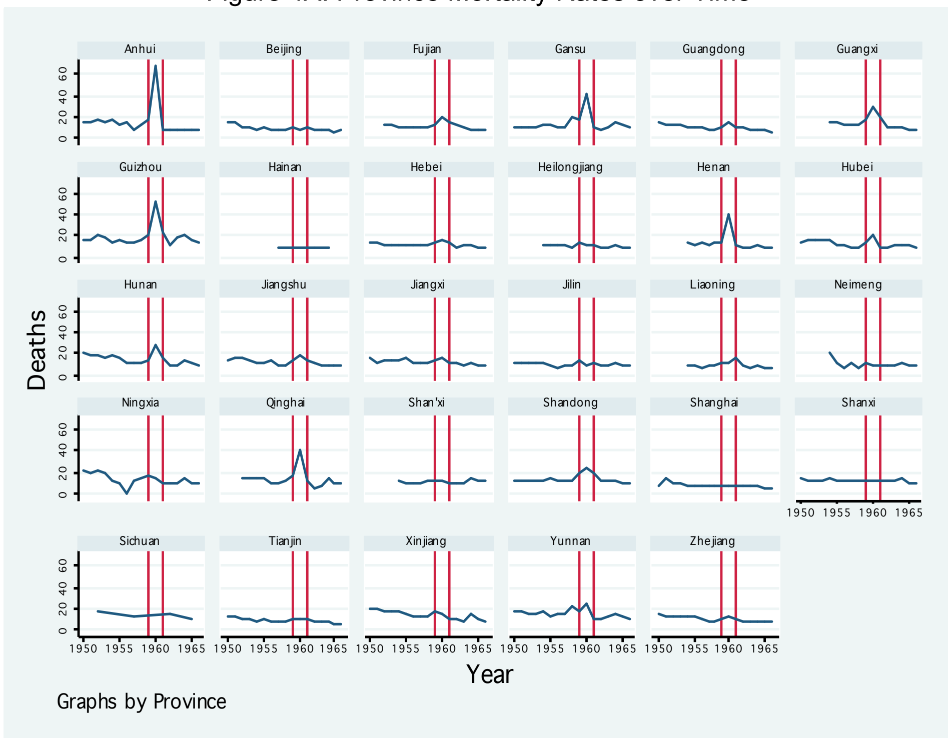

Figure 4B: Province Cohort Size over Birth Years

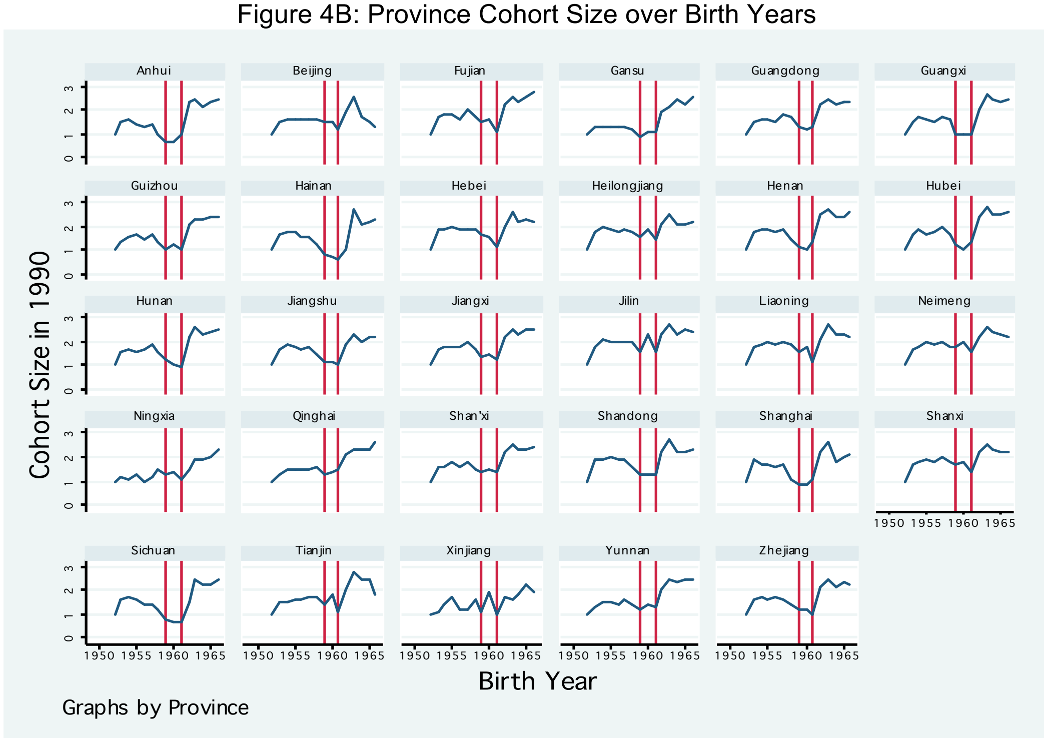

Figure 5: Food Production and Subsistence Needs

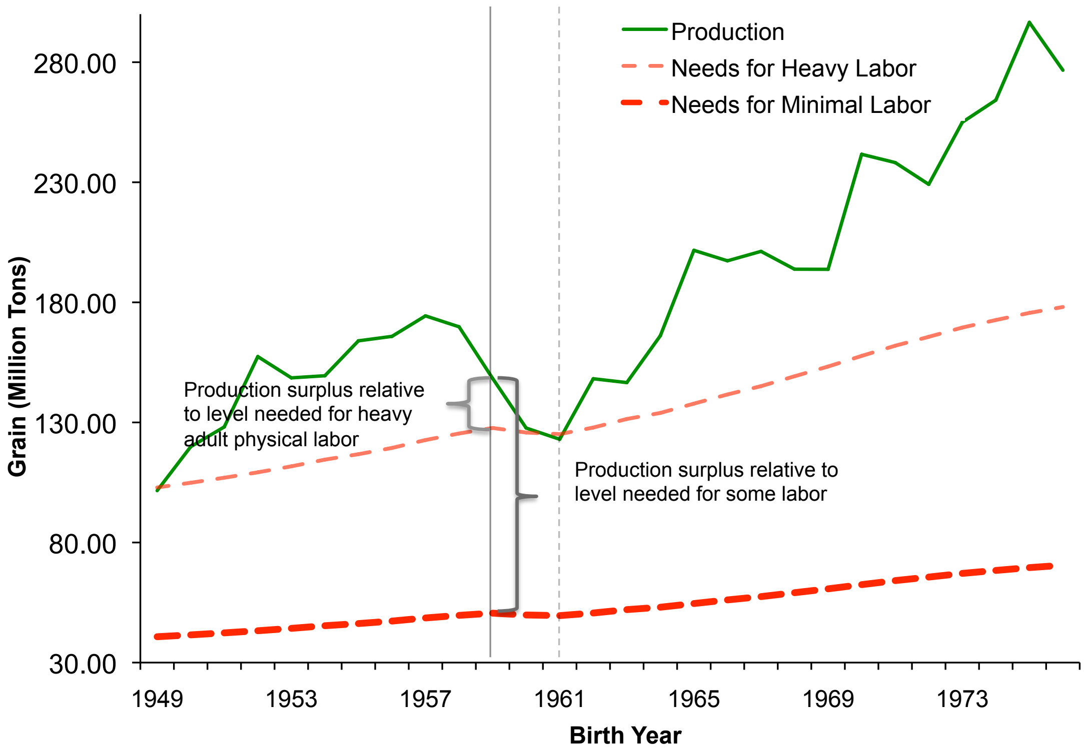

Figure 6: Yearly Correlation between Mortality and Production

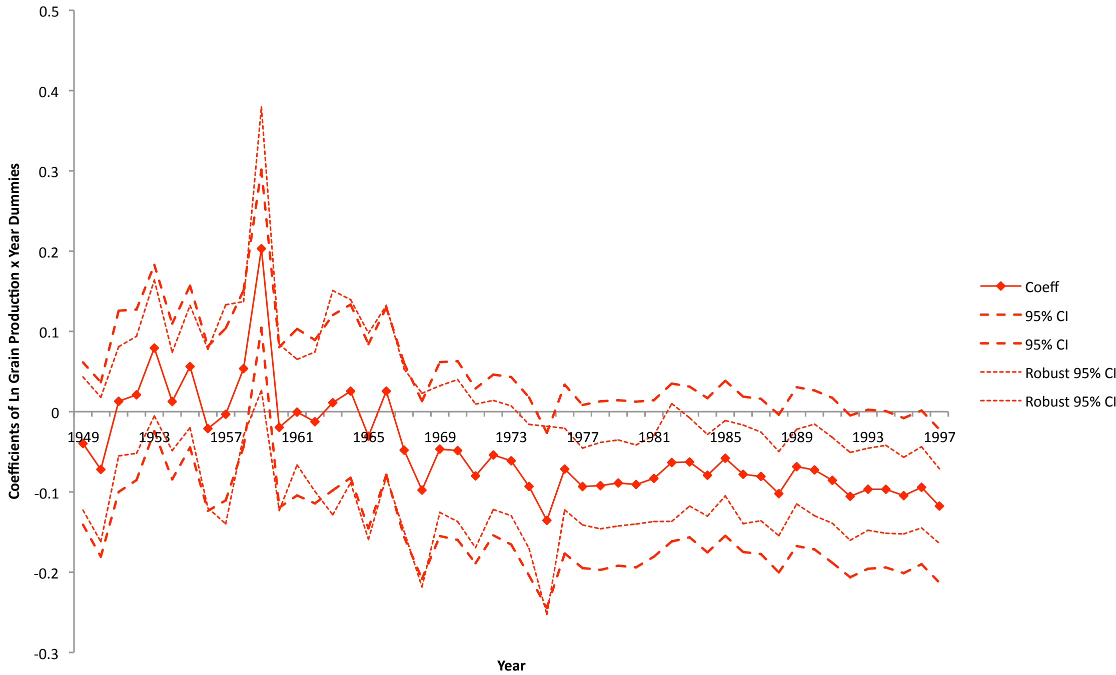

Figure 7: Birth-Yearly Correlations between Grain Suitability and Cohort Size

Appendix Table A1: Correlation between Production and Mortality

		Dependent Variable: Ln Number of Deaths in Year t+1				
		(1)	(2)	(3)	(4)	(5)
			Omit	Omit	Omit	Omit
		All	Autonomous	Autonomous	Autonomous	Autonomous
A	Ln Grain Prod x 1959 Dummy	0.110	0.239	0.226	0.209	0.245
		(0.0458)	(0.0505)	(0.0468)	(0.0391)	(0.0511)
	Robust SE	*(0.113)*	*(0.0838)*	*(0.0762)*	*(0.0721)*	*(0.0838)*
B	Ln Grain Prod	0.0337	-0.0299	-0.0581	-0.0416	-0.0388
		(0.0200)	(0.0202)	(0.0191)	(0.0373)	(0.0217)
	Robust SE	*(0.0432)*	*(0.0301)*	*(0.0369)*	*(0.0434)*	*(0.0343)*
	Ln Total Population	0.982	1.084	1.220	0.748	1.090
		(0.0234)	(0.0269)	(0.0274)	(0.0465)	(0.0292)
	Robust SE	*(0.0556)*	*(0.0472)*	*(0.0667)*	*(0.169)*	*(0.0545)*
	Controls					
	Gov Exp on Public Goods	N	N	Y	N	N
	Province-Time Trends	N	N	N	Y	N
	Observations	1290	1055	1032	1055	968
	R-squared	0.938	0.923	0.935	0.955	0.918
	Joint A + B	0.144	0.209	0.168	0.168	0.206
	p-value	0.00316	7.44e-05	0.000640	0.00144	0.000129
	p-value (Robust)	0.231	0.0174	0.0463	0.0174	0.0214

All regressions control for year fixed effects. All regressions use a sample where Tibet, Hainan and Sichuan. In Columns (2)-(5), we also exclude all autonomous regions: Xinjiang, Guangxi, Ningxia, Neimeng and Qinghai.

Table A2: Yearly Correlations between Birth Cohort Size and Grain Suitability

	Dependent Variables: Ln Cohort Size	
	(1)	(2)
	Agric HH Omitting Autonomous Regions	Non-Agric HH Omitting Autonomous Regions
Grain Suitaiblity x Birth Year = 1950	0.0187	0.0600
	(0.0358)	(0.0507)
Grain Suitaiblity x Birth Year = 1951	0.182	0.124
	(0.0316)	(0.0500)
Grain Suitaiblity x Birth Year = 1952	0.173	0.149
	(0.0307)	(0.0473)
Grain Suitaiblity x Birth Year = 1953	0.164	0.132
	(0.0289)	(0.0397)
Grain Suitaiblity x Birth Year = 1954	0.144	0.138
	(0.0265)	(0.0386)
Grain Suitaiblity x Birth Year = 1955	0.0129	0.0639
	(0.0282)	(0.0357)
Grain Suitaiblity x Birth Year = 1956	0.121	0.106
	(0.0283)	(0.0333)
Grain Suitaiblity x Birth Year = 1957	0.0545	0.151
	(0.0260)	(0.0415)
Grain Suitaiblity x Birth Year = 1958	-0.0902	-0.0308
	(0.0408)	(0.0440)
Grain Suitaiblity x Birth Year = 1959	*-0.183*	*0.00969*
	(0.0519)	*(0.0423)*
Grain Suitaiblity x Birth Year = 1960	*-0.196*	*-0.125*
	(0.0612)	*(0.0477)*
Grain Suitaiblity x Birth Year = 1961	-0.0804	0.0447
	(0.0516)	(0.0511)
Grain Suitaiblity x Birth Year = 1962	-0.0453	-0.0317
	(0.0350)	(0.0401)
Grain Suitaiblity x Birth Year = 1963	0.0276	-0.0633
	(0.0281)	(0.0390)
Grain Suitaiblity x Birth Year = 1964	-0.115	-0.182
	(0.0318)	(0.0465)
Grain Suitaiblity x Birth Year = 1965	-0.0977	-0.261
	(0.0299)	(0.0588)
Grain Suitaiblity x Birth Year = 1966	-0.143	-0.262
	(0.0444)	(0.0636)
Observations	18162	10872
R-squared	0.909	0.874
F-Stat Grain Suitability x 1959 and Grain Suitability x 1960	7.29	4.79
p-value	0.001	0.009

All regressions control for average ln population and birth year fixed effects. Standard errors are clustered at the county level. The omitted autonomous regions are Xinjiang, Tibet, Qinghai, Guanxi, Ningxia and Neimeng.

Table A3: Correlation between Weather and Survival

	Dependent Variable: Famine Cohort Size/ Pre Famine Cohort Size			
	Agricultural Households		Non Agricultural Households	
	(1)	(2)	(3)	(4)
Average Temp	0.0246	0.0114	0.00841	-0.0121
	(0.00537)	(0.00386)	(0.0134)	(0.0136)
Average Spring Temp	0.103	0.119	-0.665	-0.760
	(0.0521)	(0.0344)	(0.536)	(0.523)
Average Rainfall	0.272	0.0865	0.136	-0.143
	(0.109)	(0.118)	(0.161)	(0.164)
Average Spring Rainfall	0.0685	0.0486	-0.0386	-0.0170
	(0.104)	(0.0790)	(0.0923)	(0.113)
Province FE	N	Y	N	Y
Observations	1398	1398	865	865
Adjusted R-squared	0.032	0.299	0.006	0.063

Standard errors are clustered at the province level.

Table A4: Production and Procurment (Li and Yang, 2005)

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

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

Figure A1A: Suitability for Cultivation Rice

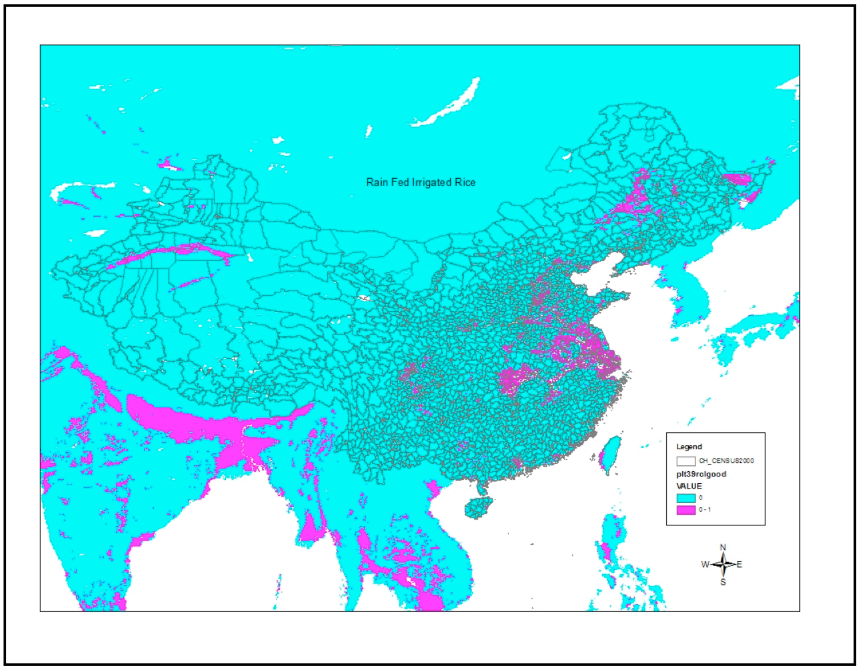

Figure A1B: Suitability for Wheat Cultivation

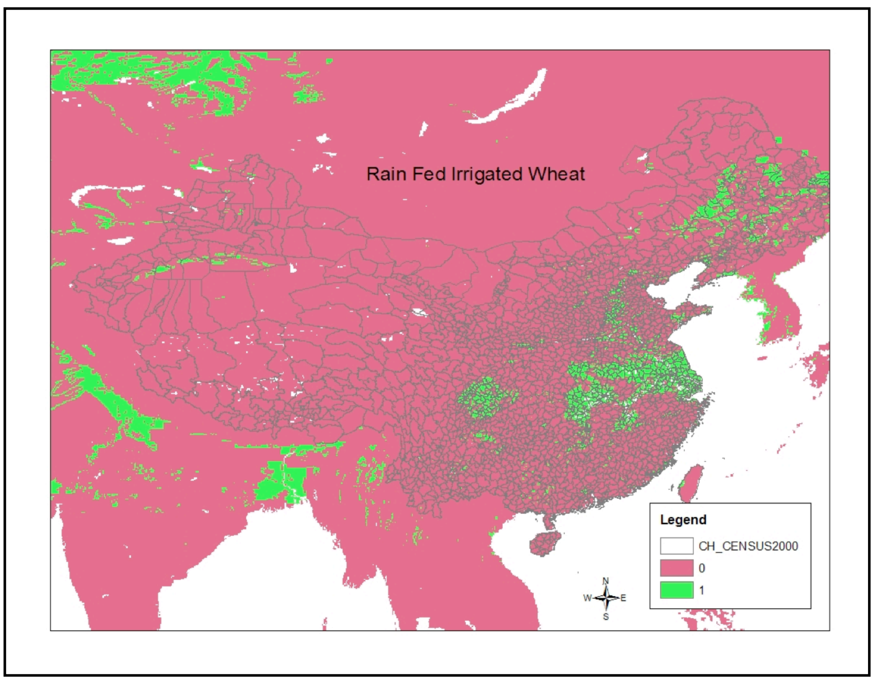

Figure A2: Procurement Targets and Past Production