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Campaigning for Extinction: Eradication of Sparrows and the Great Famine in China
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ABSTRACT

How do large disruptions to ecosystems affect human well-being? This paper tests the long-standing hypothesis that China's 1958 Four Pests Campaign, which exterminated sparrows despite scientists' warnings about their pest-control role, exacerbated the Great Famine—the largest in human history. Combining newly digitized data on historical agricultural productivity in China with habitat suitability modeling methods in ecology, we find that, after sparrow eradication, a one-standard-deviation increase in sparrow suitability led to 5.3% larger rice and 8.7% larger wheat declines. State food procurement exacerbated these losses, resulting in a 9.6% higher mortality in high-suitability counties—implying nearly two million excess deaths.

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"Damned Creature. Criminals for thousands of years. Today is payment day"

-*Chinese anti-sparrow poem*

1 Introduction

Scientists, politicians, and popular media frequently argue that the continued degradation of ecosystems will negatively affect human well-being (Dasgupta 2021; Heal 2000; IPBES 2019). Most noticeably, warnings regarding the devastating consequences of "ecosystem collapses" have emphasized the complex non-linearities of natural systems (Cooper et al. 2020; Strona and Lafferty 2016)—agriculture in particular as it is strongly connected with its surrounding ecosystems (Foley et al. 2011; Mendenhall et al. 2014). While the potentially catastrophic costs of such tail events have long been theorized in environmental economics (Weitzman 2009), empirical evidence remains scarce. The rarity of "ecosystem collapses," the difficulty in clearly tracing their triggers, and the lack of granular data, all pose barriers to rigorous empirical investigations.

In this paper, we study one of the most cataclysmic ecosystem collapses in history, the 1958 "Four Pests Campaign" (FPC) in China, which successfully drove sparrows to local extinction within two years. As part of the FPC, which aimed to improve agricultural productivity and public health, the central government ignored scientific advice and ordered local officials to exterminate sparrows—targeted because they were eating grains. However, while adult sparrows do feed on grains, they also feed their fledgling with insects, making them an important predator of crop-damaging pests. In their absence, anecdotal evidence claims that the country experienced severe crop-pest infestations (Ashton et al. 1992; Chen and Wang 2021). A key contribution this paper makes is to provide quantitative evidence for how this local extinction event played a role in contributing to the conditions that led to the Great Chinese Famine—as long hypothesized by environmental historians (Butt and Sajid 2018; Harrell 2021; Mao 2019; Steinfeld 2018)—in which an estimated 16.5 to 45 million people starved to death between 1959 and 1961 (Meng et al. 2015; Smil 1999; Yao

1999).

Combining newly digitized data on historical agricultural production in China with well-established habitat suitability modeling methods in ecology, we compare how counties with higher habitat suitability for sparrows were differentially affected by the FPC, relative to their low-suitability counterparts. Our use of models from ecology to assign treatment status builds on previous uses of such methods to overcome the challenge of missing measurement on wildlife populations before they decline sharply (Alsan 2015; Frank and Sudarshan 2024). We find that the sparrow suitability score was orthogonal to agricultural production prior to the FPC; but after the start of the FPC, the high-suitability counties experienced a 5.3% (8.7%) drop in their rice (wheat) yields, relative to those counties less suitable for sparrow habitation. These effects are economically significant—our calculation suggests that sparrow killing can account for 19.6% of the national crop yield reduction during the Great Famine.

We find two main channels through which farmers responded to the eradication of sparrows. First, the yield reduction caused by the FPC was primarily driven by above-ground crops such as rice and wheat, which are more vulnerable to pests (locusts and planthoppers in particular). In contrast, the yield of below-ground crops, such as sweet potatoes, increased more in sparrow-suitable counties during the same period—likely reflecting farmers' substitutions across crops to mitigate pest risks induced by the FPC. Second, the counties more suitable for sparrow habitation, which suffered from larger drops in crop yields, saw marginal increases in sown areas. These two effects, taken together, are consistent with the historical context in which the central government permitted farmers to cultivate more land and grow sweet potatoes—exempt from procurement—in order to cope with the famine.[1]

Investigating the government's response to the sparrow eradication shock, we show that the higher-suitability counties, which suffered from larger reductions in crop yields, surprisingly faced significantly *heightened* procurement quotas during the famine. This aligns with

[1] We observe an additional margin of adjustment in that farmers apply pesticides more frequently following sparrow killings, although these results are noisier and more tentative—likely reflecting constrained access to pesticides in this context.

the idea that, contrary to widespread scientific advice at the time, the central government genuinely expected sparrow eradication to boost agricultural output. It also echoes prior research on how the rigidity of the procurement system exacerbated the famine (Meng et al. 2015). The decreased agricultural output, combined with the increased procurement requirement, presented the high-suitability counties with significantly heavier burdens during the Great Famine. As a result, these counties experienced an increase in their death rates, and a drop in their birth rates, as compared to counties less suitable for sparrow habitation. Our calculation indicates that sparrow eradication was responsible for nearly two million lives lost between 1959 and 1961.

In 1960, three years after the initiation of the FPC and following the nationwide killing of approximately two billion sparrows, the central government realized their importance and removed them from the list of Four Pests, replacing them with bedbugs. Given that sparrows had already become locally extinct in most parts of the country, to reboot the sparrow population, it was reported that the Chinese government had to import 250,000 sparrows from the USSR. After this reversal of sparrow eradication, we observe rice and wheat yields gradually returning to their pre-FPC levels, while the growth in sweet potatoes persisted even after the FPC.

Through several robustness checks, we address a variety of concerns regarding the internal validity of our analysis and its interpretation. We validate that sparrow suitability—our approach to assigning treatment intensity—correlates with scientifically collected data on bird abundance. To rule out that our sparrow suitability measure is simply capturing variation in crop suitability, we demonstrate the weak correlation between the different suitabilities, and report that the environmental conditions that are most predictive of sparrow suitability fail to predict rice and wheat suitability. Throughout the paper, we report that our results hold whether we use the suitability score as a continuous measure or as a dummy variable for being above the median sparrow suitability, and that the results persist when controlling for the interaction of baseline population or crop suitabilities with year fixed effects. To benchmark our results on agricultural productivity, we simulate a predator–prey model—commonly used in ecology to describe the population dynamics of interacting species—and validate that our baseline estimates of reduced rice and wheat production are compatible with the magnitudes we obtain from the simulation.

In addition, we establish that spatial clustering of the standard errors does not meaningfully affect the precision of our results. Furthermore, we report results for balanced and unbalanced panels of the data, where we show that different sample compositions yield similar effects, and that the chance of data being missing in any given year is uncorrelated with sparrow suitability. Finally, we report detailed estimation results where we include multiple controls in the form of more fine-scaled time trends, procurement quotas and prices, changes in livestock, growth in the production of steel, and the use of mechanized tools in agriculture. These additional controls help us reject that other features of the Great Leap Forward might be driving the observed patterns. Taken together, our findings highlight the dire consequences of ecosystem collapse, and echo the conjectures proposed in historical research that the eradication of sparrows was an important contributing factor to the largest famine in human history.

Relevant Literature.— Our distinctive contribution is documenting the consequences of a sweeping, nationwide ecosystem collapse—a classic tail event in environmental degradation (Weitzman 2009). The empirical setting we study—where a government policy first decided to eradicate sparrows, and then proceeded to exacerbate food shortage conditions—speaks to the caution that is required when implementing momentous interventions to the environment. Notably, our findings on the agricultural impacts of eradicating sparrows provide some of the first rigorous evidence on the extent to which large, non-marginal disruptions to agricultural ecosystems—canonical examples of the economic importance of ecosystem balance—can have dire consequences for humans (Cardinale et al. 2012; Jenkins 2003).[2] Our

[2] Severely destabilizing agro-ecosystems can increase food insecurity, potentially culminating in famines (Diamond 2005; O'Rourke 1994; Ravallion 1997), yet there is scarce causal evidence on this relation-

study expands the scope of a growing body of work in environmental economics examining how changes in species abundance can affect various outcomes, such as air pollution from invasive-species–induced tree die-offs (Jones and McDermott 2018), road-safety impacts via wolf–deer interactions (Raynor et al. 2021), malaria incidence after declines in mosquito-eating amphibians (Springborn et al. 2022), agrichemical pollution when bats' pest-control services are replaced (Frank 2024), and human mortality risk following the loss of vultures' sanitation services (Frank and Sudarshan 2024).

This paper speaks to two additional strands of literature. Our findings shed new light on the determinants of China's Great Famine, the largest in human history. An extensive body of literature has investigated various political economic determinants of the Great Famine, such as farmers' free-riding incentives (Lin 1990), urban bias in food distribution (Lin and Yang 2000), excessive grain procurement (Li and Yang 2005), political promotion incentives (Chen and Kung 2011), rigid procurement quotas (Meng et al. 2015), grain export (Li and Kasahara 2020), and social capital (Cao et al. 2022). However, while environmental historians have long suspected that the elimination of sparrows contributed to these disasters and thus the famine (Shapiro 1999; 2001; Dikötter 2010; Becker 1998; MacFarquhar and Fairbank 1987; Manning and Wemheuer 2011; Yang 2012; Marks 2017; Harrell 2021), to the best of our knowledge, there has been little rigorous examination of this explanation. Our paper fills in this gap by providing systematic evidence that echoes this hypothesis, that the intentional disruption of the ecosystem was another substantial contributing factor to the famine. In addition, our findings also support those of Meng et al. (2015), in showing that the procurement quota failed to properly adjust according to FPC-induced output losses until 1961, highlighting how the rigidity of the procurement system exacerbated the famine.

More broadly, our findings also add new evidence to the perils of over-centralization and campaign-style policy initiatives that have little regard for scientific evidence, which could

ship. Historically, large human-induced disruptions to ecosystems occurred when species were locally extirpated either due to their roles as pests (Musiani and Paquet 2004) or their value as resources (Taylor 2011). Birds, for instance, have long been recognized for limiting the abundance of crop-damaging insects (Evenden 1995; Garcia et al. 2020).

distort well-intended policies and lead to disastrous policy outcomes (Kornai 1960; Nove 1971; Lin 1990). Our results imply that, the ecological system, very much like the economic system that it is connected to, functions in subtle and complicated ways, making it hard to accurately foresee the general equilibrium consequences of a man-made non-marginal shock without sufficient *ex-ante* learning through trial and error.[3] Beyond the Chinese context, one can also view our findings as a general cautionary tale for more prudence and deliberation in environmental policymaking (Weitzman 1998; 2009; Nordhaus 2019).

The remainder of this paper is organized as follows. In Section 2, we introduce the background of the FPC and the Great Famine. Section 3 explains the construction of various historical and ecological datasets, and presents the summary statistics. In Section 4, we elaborate on the identification strategy. In Section 5, we discuss the empirical results, including the agricultural impacts of sparrow eradication, the responses from farmers and governments at the time, and the eventual demographic consequences. Section 6 evaluates the robustness of our findings and benchmarks them against simulations of a simple ecological model of predator–prey population dynamics. Section 7 concludes.

2 Background

In this section, we introduce the background of the Four Pests Campaign, and the subsequent Great Famine between 1959 and 1961.

2.1 The Four Pests Campaign

In 1955, China was formulating a decade-long plan to help accelerate agricultural development and collectivization between 1956 and 1967. In the process of drafting that plan, the Chairman of the Communist Party of China, Mao Zedong, received feedback from farmers

[3] Having experienced various such failures following the implementation of drastic policies under central planning, after 1978, China's leadership decided to move away from campaign-based policy initiatives and towards gradual policy experimentation, an institutional feature that later became the pillar of policy making in China (Heilmann 2008; Xie and Xie 2017; Wang and Yang 2023).

that sparrows consume grains and damage agricultural production. Mao therefore decided to include sparrows, alongside flies, mosquitoes, and rats, in the list of the “four pests,” which should be eliminated nationwide within seven years.[4]

Three of the targeted pests—flies, mosquitoes, and rats—were included because they spread diseases and were considered public health threats, so there was relatively little controversy about eradicating them. However, sparrows were included because they eat grains, but as pointed out by biologists, sparrows are also the natural enemies of many grain-eating insects, such as locusts, rice borer, rice planthopper, among others. The share that insects make up in the diet of sparrows changes throughout the year. In winter, when house sparrows tend to not migrate, sparrows mostly feed on grain and other agricultural products. During the spring and summer months, insects constitute a large share of their diet, as high as 70-80% for fledgling sparrows (Yu et al. 2007). As a result, when the FPC included sparrows in their list of eradication, there was widespread opposition from scientists in China.

Most notably, Zhu Xi, a renowned biologist from the Chinese Academy of Sciences, voiced his opposition citing the historical episode of the Prussian king Frederick the Great trying to eliminate sparrows in 1744, but ended up with pest outbreaks and had to import sparrows from other countries to repopulate them. Zhu also analyzed examples of various cities in the US and Australia importing sparrows to help pest control, and warned Mao that more research is needed before deciding on the overall cost and benefit of sparrows. However, despite the opposition, Mao decided to go along with his plan to quickly eradicate sparrows nationwide.[5]

In late 1957, the “Great Leap Forward” formally kicked off, which also marked the start of the FPC. From March to May in 1958, Mao repeatedly emphasized the importance of eradicating sparrows in multiple meetings, which got widely covered by national and local media outlets. In addition to Mao’s personal push, being the easiest target among the four

[4] National Agricultural Development Outline from 1956 to 1967 (Draft). See the following for more details: https://searchworks.stanford.edu/view/43324. Accessed 2/22/2024.

[5] Source: https://chinadigitaltimes.net/chinese/322533.html. Accessed 2/2/2024.

pests also made sparrows the priority in local eradication efforts. Many local governments set up "special operation teams" for sparrow eradication, which mobilized millions of state employees and citizen volunteers to systematically destroy sparrow nests, break sparrow eggs, and kill sparrow chicks. In addition, in many regions, people also targeted sparrows flying in the sky by directly shooting them with slingshots, or by hitting noisy pots and pans to prevent them from resting in their nests, with the goal of causing them to drop dead from exhaustion (Cheng 1963; Harrell 2021).[6]

Within two years, the campaign effectively depleted the sparrow population: it is estimated that approximately two billion sparrows were killed between 1958 and 1959, pushing the species to near extinction within China. Anecdotally, it was also reported that insects became widespread following the eradication of sparrows. In 1959, the rural areas experienced a salient increase in insect outbreaks, and many major cities in China saw their trees turning bald as the leaves got eaten by insects.[7]

By the end of 1959, seeing the widespread surges in insect outbreaks, a large number of prominent scientists again voiced their strong opposition to the sparrow eradication movement. In November 1959, the party secretary of the Chinese Academy of Sciences (CAS), Zhang Jinfu, wrote a report titled "Report to the Chairman Regarding the Costs and Benefits of Sparrows," which provided detailed data on the dietary composition of sparrows, as well as extensive scientific findings in foreign literature. This report was read by Mao, and forwarded to all scientists at the CAS. The CAS later held two conferences discussing the costs and benefits of sparrows, and established a team of scientists to further investigate this matter. Finally, in March 1960, Mao decided that "we should stop killing sparrows, and we can replace sparrows with bedbugs in the FPC list," which was formally enacted in April

[6] Some sparrows found a refuge in the extraterritorial premises of various diplomatic missions in China. The personnel of the Polish embassy in Beijing denied the Chinese request to enter the premises of the embassy to scare away the sparrows who were hiding there, and as a result the embassy was surrounded by people with drums. After two days of constant drumming, the Poles had to use shovels to clear the embassy of dead sparrows. See: https://wyborcza.pl/1,75248,140878.html?disableRedirects=true. Accessed 2/2/2024.

[7] Source: https://chinadigitaltimes.net/chinese/322533.html. Accessed 2/2/2024.

1960. However, by this point, sparrows were already functionally extinct in China. In order to re-populate the species, China was reported to have to import 250,000 sparrows from the USSR in the 1960s.[8] The FPC posters from 1958 vs. 1960 depict how sparrows were initially included, but later excluded, from the list of the four pests (Figure 1).

Figure 1: Recognizing the Error of Exterminating the Sparrow

(a) Four Pests Campaign Poster 1958 (b) Four Pests Campaign Poster 1960

Notes: The posters show the transition from 1958 to 1960 in the composition of the four pests. The 1960 campaign replaced sparrows with bed bugs after China stopped sparrow killing and decided to import 250,000 sparrows from the Soviet Union to replenish its sparrow population.

[8] While difficult to find a formal validation of this purchase, it appears in books written about the era (page 177 of Žižek (2022)), and was referenced in popular writing about the end of the eradication campaign: https://www.thelondoner.ca/news/local-news/a-tale-of-sparrows. Accessed 2/22/2024.

2.2 The Great Famine

Between 1959 and 1961, China experienced what is generally believed to be the largest famine in human history, with an estimated death toll of 16.5 to 45 million (Meng et al. 2015; Smil 1999; Yao 1999). To place this in greater context, the World Peace Foundation's historic famine database reports a central estimate of the death toll of 36 million people, ranking the Great Famine as the highest death toll across famines recorded in the data starting as far back as 1876 (World Peace Foundation 2025). This estimate is an order of magnitude higher than the other largest recorded famines. According to estimates by Cao (2005), during the Great Famine, the most stricken provinces were Anhui (18% death rate), Chongqing (15%), Sichuan (13%), Guizhou (11%) and Hunan (8%).

There are two main schools of thought in terms of explaining the root causes of the Great Famine. The first considers agricultural output during this period. As shown in Figure 3a, China maintained robust growth in agricultural output in the years leading up to the Great Famine, but then experienced four consecutive years of dramatic productivity decline between 1959 and 1962, and economists have examined various potential explanations for that reversal. Lin (1990) points out that when the agricultural communes stopped allowing farmers to freely exist in 1958, a prisoner's dilemma with free-riding incentives emerged, which paralyzed agricultural production. Chen and Lan (2017) show that the collectivization of agriculture also led peasants to slaughter household draft animals to consume the meat, which reduced the input for agricultural production in the subsequent years.

In contrast, another more recent line of work has pointed out that production-based explanations alone are insufficient to explain the magnitude of the famine, and one must also combine them with severe distortions in the distribution of agricultural output—in agreement with the point raised by Sen (1981) regarding distribution failures as a necessary condition to generate severe famines. Consistent with this view, as shown in Figure 3b, the excessive death rate was the highest in 1960, and partially recovered in 1961, when the central government started sending grains to the rural areas in need.

Local inequality in food availability is considered to be a critical driver of the Great Famine. Specifically, Li and Yang (2005) suggest that the procurement quota—the amount of agricultural produce that was collected from the county and redistributed—was excessive. Meng et al. (2015) show that in addition to the excessiveness, the rigidity of the agricultural procurement system played a key role in causing the famine. Li and Kasahara (2020) find that grain exporting during the famine period worsened the situation. Evidence has also documented that political and cultural factors contributed to the distributional distortions (Chen and Kung 2011; Cao et al. 2022).

The Chinese government officially referred to the Great Famine as the "Three Years of Natural Disasters." Later research has shown no sudden and abnormal changes in basic weather conditions between 1959 and 1961, which partially contradicts the official narrative. That being said, historians have long suspected that the Four Pests Campaign, by eradicating sparrows and destabilizing the ecosystem, also contributed to the drop in agricultural output and hence the famine (Shapiro 1999; Dikötter 2010; Becker 1998; MacFarquhar and Fairbank 1987; Manning and Wemheuer 2011; Yang 2012). This version of production-based explanation of famine origin received much attention in qualitative discussions, but rigorous empirical evidence remains limited.

3 Sparrow Suitability, Agricultural Production and Population Data

The empirical analysis aims to examine whether eradicating sparrows during the 1958-1960 FPC played a meaningful role in the conditions that resulted in the Great Famine. To do so, we need data sources that allow us to define exposure to the sparrow eradication shock, measure agricultural production, and summarize total mortality. In this section, we briefly summarize the core data sets used in the analysis: (i) sparrow suitability scores derived from a habitat suitability model; (ii) previously used as well as newly digitized crop production data; and (iii) population levels and all-cause mortality counts. We summarize the key variables in Table 1, map cross-sectional variation in sparrow suitability in Figure 2, and plot national-level trends for agricultural production and mortality in Figure 3.

3.1 Suitability Scores

3.1.1 Sparrow Suitability Score

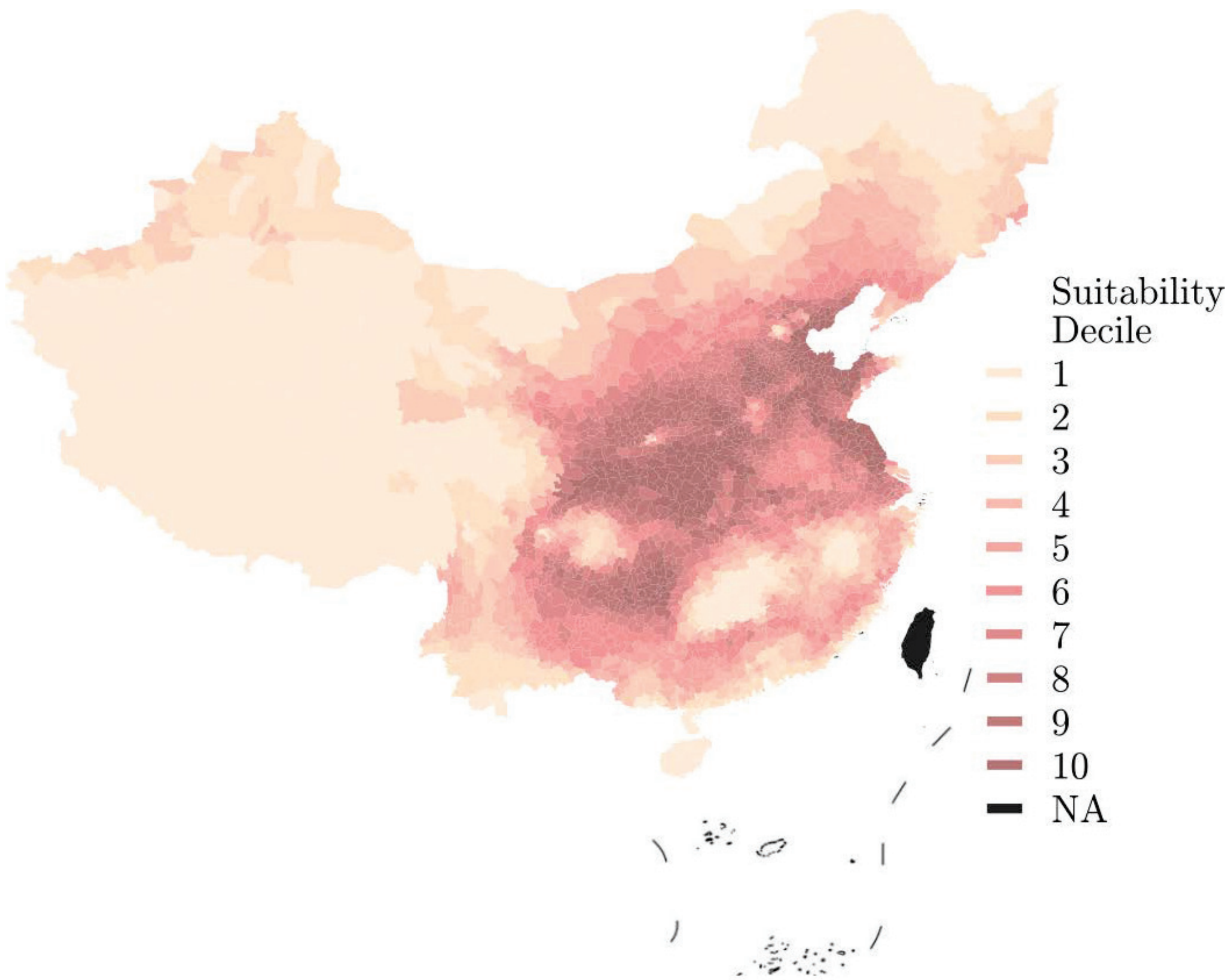
We use a proxy for sparrow population levels during our study period in the form of a habitat suitability score for each county and province. This score combines data on current observations of sparrows with the environmental features in each county to quantify the degree of habitat suitability for sparrows. Because sparrow population levels were not monitored during our study period, the sparrow suitability score provides a numerical value that is proportional to the sparrow population when it is in equilibrium. Our approach of using suitability scores in the absence of detailed wildlife population counts is similar to that used by Alsan (2015) and Frank and Sudarshan (2024). In the Online Appendix Section A.1 (Table A1 and Figure A1), we provide results from an empirical exercise that validates the agreement between habitat suitability scores for birds and scientifically collected counts of these bird species.

We calculate the sparrow suitability score using the BIOCLIM model, which has been widely used since its introduction in 1984 (Booth et al. 2014). The model combines data on the presence of a species, which we obtain from eBird records, and local bioclimatic variables such as soil type, elevation, temperature, and precipitation.[9] The presence data and environmental data allow BIOCLIM to construct the convex hull of environmental conditions that appear to be beneficial for the presence of the species, which then gets projected back into geographic space to calculate suitability scores. The higher the score, the more likely the

[9] eBird is an online database of bird observations providing real-time data about bird distribution and abundance. Because eBird relies on self-reported observations of birds by citizen scientists instead of a scientifically designed monitoring protocol, we cannot simply use the mean number of sparrow records in eBird to infer habitat suitability. Habitat suitability models, such as BIOCLIM, are designed to overcome the inherent sampling biases in such species presence data.

area is a suitable niche for the species. For example, observing polar bears in the the Arctic landscapes would result in a high suitability score in Alaska, but not California. Similarly, observing beavers in wetlands would result in a high suitability score in Florida but not in Arizona. We plot the mean sparrow suitability score we obtain from the BIOCLIM model in Figure 2, and use it to assign county-level exposure to the treatment—the eradication of the sparrows.

Figure 2: Spatial Distribution of the BIOCLIM-Derived Sparrow Suitability Score



Notes: We obtain sparrow suitability for each county using the BIOCLIM Habitat Suitability Model (HSM). See text for more details.

It is important to note that suitability scores characterize the theoretical ecological niche a species can occupy—how well a species can survive in that environment—but other factors such as dispersion, competition with other species, and predators affect the ability of a species to occupy the niche.[10] In the case of birds and contiguous habitats, dispersion is not considered to be a limiting factor to their occupancy. For sparrows, food availability and environmental conditions are of higher importance than competition with other birds and the presence of predators (Repasky and Schluter 1994).

3.1.2 Crop Suitability Score

For the main crop types that we focus on in this paper (rice, wheat, and sweet potatoes), we also obtain corresponding crop suitability scores from version 4.0 of the Food and Agriculture Organization Global Agro-Ecological Zones database (Fischer et al. 2021). We choose the no-irrigation suitability scores, and use alternative measures for robustness checks that we detail in the results section.

A potential threat to our research design is that sparrow suitability might be correlated with crop suitability, in which case our estimates might also partially capture the potentially larger impacts of the GLF in regions with higher crop suitability. We address this concern in several different ways. First, in all our main regressions, we directly control for the interactions between crop suitability scores and year dummies, which isolates the impacts of sparrow eradication from potential heterogeneous responses to the GLF by regions with different levels of crop suitability. Second, we explicitly examine the relationships between sparrow suitability and crop suitability scores. In Online Appendix Figure A2, we show that they turn out to be not highly correlated with each other—conditional on crop suitability, there is still substantial variation left in sparrow suitability.

Furthermore, in Online Appendix Table A3, we investigate which environmental conditions can most strongly predict each type of suitability score. We find that the variables that are the strongest predictors for sparrow suitability do not act as strong predictors for crop

[10] Dispersion is important as it allows a species to arrive and occupy the niche. This is not considered a binding constraints for flight-capable birds. Competition with other species can prevent a species from occupying its theoretical niche. We do not know of species who can competitively exclude sparrows.

suitabilities, which explains the lack of strong correlation between their suitability scores.

3.2 Agricultural Production

Our baseline county-level crop data is from China's county gazetteers—the historical archives compiled by local gentries, which comprehensively document local socio-economic conditions and significant events separately from the official statistics.

In the 1950s and 1960s, China's official socio-economic statistics were collected through a top-down system, in which the central government elicited statistics from the provincial governments, who in turn elicited numbers from the county governments. Under the planned economy system, the numbers collected from this top-down system can be systematically distorted as the county and provincial governments were trying to meet the national targets. It is widely believed that these manipulated official economic numbers misguided policymakers, which contributed to the famine (Yang 2012).

In contrast, the county gazetteer data we digitize is from historical archives compiled and published in the 1990s.[11] Each county designates a county gazetteer committee consisting of local experts to organize historical archives, document important events (e.g., natural disasters, political events), and validate the county's statistics at their best endeavors.

A main advantage of the gazetteer data is its higher reliability compared to official statistics at the time. There are two reasons for this. First, gazetteers were published under no political pressure, as they only reported historical data; for example, publication in 1992 typically only includes data from 1949 to 1985; thus, the data released in the gazetteers are unlikely to be intentionally distorted by the local government officials. Second, the gazetteer committee corrected some data errors and made the statistics as precise as possible, particularly regarding the data reported during the radical political events, such as the Great Leap Forward and the Cultural Revolution. As discussed in Section 3.5, this is also consis-

[11] There have been two waves of gazetteer publication since the establishment of the People of Republic China: the first-wave gazetteer publication was in the 1990s, covering historical archives from 1949 to 1985 or later years depending on the actual publication date. The second-wave gazetteer publication happened in the 2010s, further updating the data till the late 2000s.

tent with the fact that the county gazetteer data indicate larger crop yield declines during the famine, relative to the provincial data, even after the provincial statistics got adjusted retrospectively by the government for misreporting.

Our data was digitized from two sections of each gazetteer: total agricultural output and total arable land from the *Economy* section and the crop-specific cultivated area and output by crop from the *Agriculture* section. First, we restricted our sample to areas titled "Xian" (county) in 1990 to ensure these areas were mainly agricultural counties. Thus, all urban jurisdictions are excluded from our analysis, even if some of these cities also provided agricultural output data. Second, to be included in our sample, we require a county to provide annual data from 1954 to 1965 for either rice or wheat, the two dominant food crops grown in China. Our eventual sample consists of 610 rural counties; among them, 421 counties grow rice, mostly in southern China, and 495 counties grow wheat, mostly in northern China, where 309 counties reported growing both rice and wheat.

The county-level crop output data is an unbalanced panel. In the Online Appendix, Section A.2, we further discuss the potential data selection issue. Online Appendix Table A2 examines whether the rice and wheat reporting patterns are correlated with the suitability of the sparrow. We find no evidence that the timing of reporting or having non-missing values before and after the FPC is correlated with sparrow suitability. Consistent with the higher suitability scores observed in northern China, high-sparrow suitability counties are more likely to report wheat output and less likely to report rice output.

We also obtain province-level data from various sources. The provincial crop data from 1950 to 1980 is obtained from the National Bureau of Statistics of China. The provincial data does not necessarily match the county-level data in gazetteers, as each provincial government puts together aggregate official statistics with retrospective data revisions, rather than data based on raw archives from the county gazetteers.

3.3 Mortality and Population Data

We obtain demographic data to quantify the link between sparrow killing and the subsequent Great Famine. The county-level fertility and mortality rates are digitized from the county gazetteers by Li and Kasahara (2020), which we use as dependent variables to quantify mortality rates in the subsequent Great Famine. We complement county-level data with provincial-level population data from Meng et al. (2015). In Online Appendix Figure A3, we correlate the average mortality of province-level and county-level death rates. Death rates from these two data sources are strongly correlated at 53% in 1960, which is not meaningfully different than the correlation from 1954 to 1965 (57%). While, in general, county-level death rates can be double that of the provinces they are in, once we take population-weighted means of the county-level death rates in 1960, the coefficient from the regression of the province-level death rate on the population-weighted mean is 0.996, reflecting almost perfect agreement between the two.

3.4 Other Supplementary Data

We also collect additional data on reported sparrow killings, pesticide use, and procurement for food redistribution. Some provincial governments self-reported sparrow-killing data during the FPC, which we can use to validate that our sparrow suitability score does capture meaningful variations in sparrow eradication. The number of sparrows killed is usually reported in mainstream provincial newspapers, such as the Beijing Daily, which is the mouthpiece of the Beijing Municipal Party Committee. The FPC was an integral part of the Great Leap Forward, so some party newspapers provided detailed records of its progress, including reported sparrow killings in each province, with the caveat that bureaucrats might had incentives to systematically over-report these numbers.

With a sharp decline in biological pest control by sparrows, farmers could have increased their use of pesticides as a mitigation—substituting for the role of sparrows in agricultural production. However, supply of pesticides was limited at the time, and there was no market mechanism that could allocate them efficiently to where they were needed the most. Even if farmers were able to substitute for the loss of biological pest control, then our results can be interpreted as a lower bound for the effects of biological pest control loss. We collect additional data on the sales volume of chemical pesticides from provincial Agricultural Cooperative Society publications.[12] In Online Appendix Figure A4, we plot the total quantity of pesticide usage and the grain yield from 1954 to 1965. Pesticide usage first jumped in 1958—after the start of the FPC and before the significant drop in grain yield. Pesticide usage remained unusually high until 1961, after which both sparrow population and agricultural productivity started to recover.

Centrally controlled procurement of food is consequential in this setting, as pointed out by Meng et al. (2015). To examine the relationship between food procurement and sparrow suitability, we also obtain the annual county-level crop procurement data, as collected by Li and Kasahara (2020), and compute the share of the crop being procured as a metric for the fiscal burden faced by each county. These data allow us to examine how government procurement policy reacted to the negative productivity shocks during the GLF.

Ideally, we would also be able to measure the intensities of various types of pest outbreaks in different locations over time. However, despite rich qualitative media discussions on increased pest issues after the FPC, this information was not systematically recorded in the county gazetteers in the 1950s and 1960s. In fact, accurately tracking pest outbreaks remains challenging even in the context of 21st century high income countries. For example, farmers in the United States do not have access to real-time data on crop pest densities in their vicinity, and have to rely on simple pest traps to monitor conditions. Those are not centralized into a single database. Even in cases of highly harmful invasive species such as the spotted lanternfly (a planthopper species), data are at best available on their presence and whether populations have managed to establish in a county, but not on their popu-

[12] For example, the *Cooperative Society Publication of Liaoning Province* and the *Agricultural Economic Statistical Data of Zhejiang Province, 1949-1985*

lation levels.[13] Similarly, despite large investments by the Food Agriculture Organization, monitoring of locust outbreaks remains a challenge, where the detection of locust swarms has improved since 2000, yet the densities of those swarms remains largely unreported. In short, even with modern technology, collecting and reporting data on insect outbreaks is a challenge—making it unsurprising that we lack detailed data on crop pest outbreaks in China from 1958 to 1960.

3.5 Secular Trends & Summary Statistics

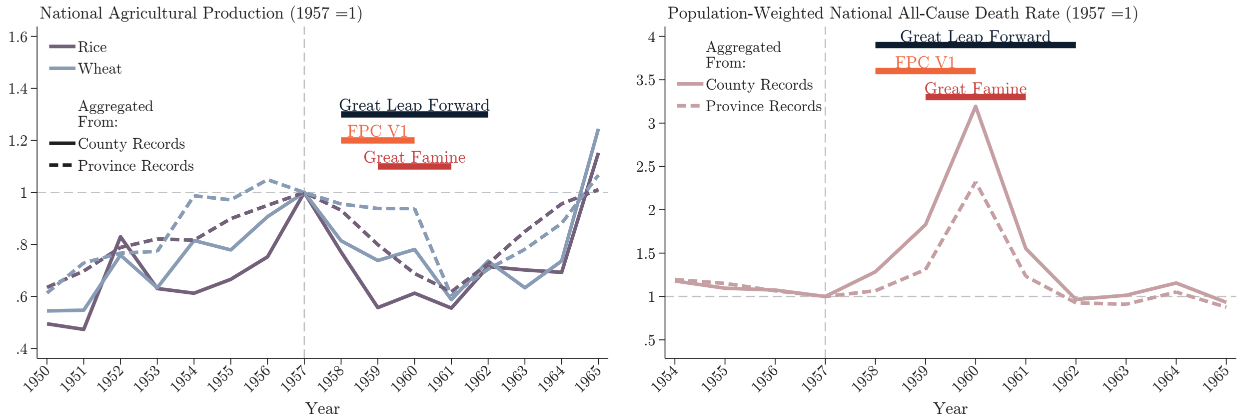
During our sample period of 1954 to 1965, China first saw consistent growth in grain production alongside reduction in all-cause death rate up until 1958, after which both trends were reversed. In Figure 3 panel (a), we plot the total production of rice and wheat, aggregated from either the county records or the provincial records. Similarly, in panel (b), we plot the population-weighted all-cause death rate, aggregated from either the county records or the provincial records. We normalize each time series relative to 1957, the year before the launch of the GLF and the FPC. We observe that by 1957, rice and wheat production had doubled relative to its 1950 baseline levels; however, those declined back to their 1951-1952 levels during 1959-1961. The fact that the (unofficial) county gazetteer data indicates larger yield declines is consistent with potential data manipulation in the official provincial statistics. China also saw a steady improvement in public health, as observed by the declining all-cause death rate from 1954 to 1957. During the peak of the Great Famine in 1960, mean mortality levels doubled or tripled relative to 1957 levels, according to the provincial or county records, respectively.

Even though our research design does not require that counties are fully balanced on observable and unobservable characteristics, it is helpful to examine the balance of key characteristics before and after the FPC. We summarize the key variables of sparrow suitability

[13] A noticeable exception is that only in the case of the spongy moth, an important forest defoliating insect, did the government invest in centralizing data on pest densities as part of its *Slow the Spread* efforts.

Figure 3: National Trends in Agricultural Production and Mortality

(a) Agricultural Production (b) Mortality



Notes: Aggregating data to the yearly level from either the provincial records or the county gazetteer data. We use the unbalanced panel to aggregate the data and normalize the time series for each variable relative to 1957. We highlight the duration of the Great Leap Forward, the Four Pest Campaign (FPC) in its first version, which included sparrows and the Great Famine. Panel (a) plots rice and wheat production from 1950 to 1965, and Panel (b) plots the population-weighted national all-cause death rate from 1954 to 1965.

score and population levels across below- and above-median suitability score in Table 1. As expected, the mean suitability score is much higher, by an order of magnitude, in the above median suitability score counties. Mean population levels from 1954 to 1957 are slightly higher in low-sparrow suitability counties, but similar in magnitude. We also compare baseline levels, from 1954 to 1957, of rice output, wheat output, procurement rate, and all-cause mortality. There are lower levels of rice production and higher levels of wheat production in the above-median suitability counties. The procurement rate in the above-median suitability counties is three percentage points lower, relative to a base of about 22-25%.

We observe a sharp widening in the mortality differential between the above- and below-median suitability counties between the two time periods of interest. The above-median suitability counties have 0.51 deaths per 1,000 people more than the below-median counties, for which we can reject the null hypothesis of a zero difference at the 5% significance level. That difference in the death rate increases six-fold, from 0.53 to 3.24, during the 1958 to 1961 period, which we can reject the null hypothesis of zero difference at the 1% significance level. During 1958-1961, we also observe a widening gap in rice yield and a shrinking gap in wheat yield, both consistent with agricultural production in the high-suitability counties being impacted more during the famine.

Table 1.
Differences in Observables Before & During the Four Pest Campaign

	(1)	(2)	(3)	(4)
	Group Means		Δ:(2)-(1)	N
Sparrow Suitability	*Low*	*High*		
Sparrow Suitability Score	.0392	.195	.156	691
	(.0262)	(.0773)	(.00418)	
Population, 1954-1957[1]	3.03	2.82	-.213	8,292
	(2.99)	(2.27)	(.0599)	
Rice Output, 1954-1957[2]	6,043	5,580	-464	901
	(11,918)	(10,028)	(737)	
Wheat Output, 1954-1957[2]	903	1,473	570	1,100
	(2,144)	(1,797)	(125)	
Procurement Rate, 1954-1957[2]	.255	.215	-.0397	1,878
	(.123)	(.0977)	(.00535)	
All-Cause Death Rate, 1954-1957[3]	11.8	12.3	.532	2,364
	(4.5)	(4.71)	(.191)	
Rice Output, 1958-1961[2]	5,281	4,152	-1,129	873
	(10,924)	(6,052)	(600)	
Wheat Output, 1958-1961[2]	770	1,224	454	1,054
	(1,673)	(1,385)	(98.8)	
Procurement Rate, 1958-1961[2]	.324	.292	-.0314	1,903
	(.148)	(.124)	(.00645)	
All-Cause Death Rate, 1958-1961[3]	17.9	21.2	3.24	2,338
	(15)	(19.6)	(.714)	

Notes: Counties with non-missing rice or wheat data in both pre- and post-1958. Robust standard errors in parentheses.
1: In 100,000s.
2: In 10,000s kg.
3: Per-1,000 People.

4 The Sudden Extirpation of Sparrows as a Natural Experiment

In this section we first present descriptive evidence at the level of the province, summarizing the correlations between sparrow suitability, reported sparrow-killing levels, and outcomes such as: grain production, pesticide use, and all-cause mortality. We then proceed to describe the use of the sparrow suitability score in our econometric framework using the county-level data.

4.1 Descriptive Evidence on Sparrow Killings & Key Outcomes

To motivate the subsequent econometric analysis, in this section, we document a series of province-level correlational patterns, which help shed light on the relationships between sparrow suitability, sparrow eradication, and the Great Famine.

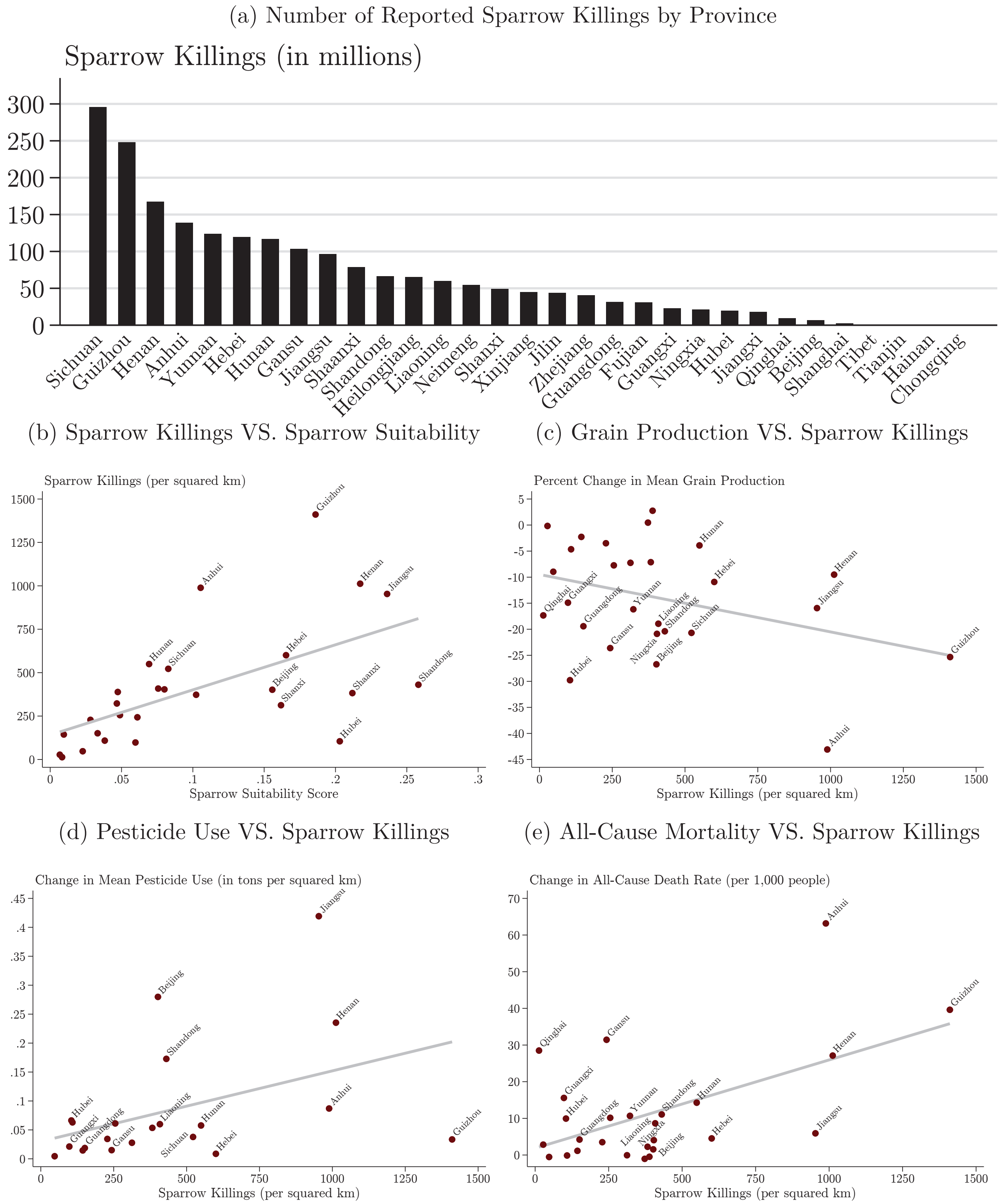
We first note that in addition to the variation in sparrow suitability (Figure 2), different provinces also reported vastly different numbers of total sparrows killed (Figure 4a). An important step in evaluating the province-level data, and our own calculations of the sparrow suitability score, is to compare the correlation between sparrow killings and suitability. In Figure 4b, we report a noisy, yet positive, correlation between the sparrow suitability score and the reported number of sparrows killed, normalized by area. The fact that we observe a low number of reported sparrow killings per square km where the suitability score is low is reassuring—provinces did not all report a uniformly high level of sparrow killings that was independent of habitat suitability for sparrows. Similarly, we observe that, at least on average, provinces that reported a high number of sparrows killed are also those for which we calculate a high sparrow suitability score. Combined, we find that the correlation in Figure 4b helps validate that the sparrow suitability metric acts as a useful proxy for baseline levels of sparrow populations. In addition, higher sparrow killings are correlated with lower grain production, higher pesticide use, and higher death rates in the immediate post-sparrow eradication campaign (1959 to 1961) relative to the preceding years (1955 to 1957) (Figures 4c-4e).[14] It is worth noting that if misreporting was severe in this context, we might have expected to see a positive—instead of negative—correlation between grain production and sparrow killings, as provinces would have had incentives to exaggerate reporting of both, leading to a spurious correlation.

The province-level correlations help provide suggestive evidence that aligns with the hypothesis put forward by environmental historians: the campaign to eradicate sparrows contributed to the Great Famine. We avoid interpreting the empirical findings we discuss above as causal evidence because, especially at the level of the province, a key cause for concern is that local governments could have had other political motivations, which could have caused them to enthusiastically implement not only the sparrow eradication campaign, but also many other potentially harmful policy campaigns in this era. Those additional Great Leap Forward policies could also have contributed to the conditions that led to and exacerbated the famine. If the adoption of those additional policies was systematically correlated with the effort put into sparrow eradication, that would confound the relationship between the outcomes of interest and sparrow eradication.

Our baseline research design instead leverages the local exposure to the eradication shock—the combination of the baseline suitability and the sudden local extinction event—with the local agricultural production and mortality data. The empirical strategy, discussed below, uses more fine-scaled spatial variation at the level of the county to compare within geographic clusters, between counties with higher and lower sparrow suitability scores. This comparison will better allow us to separately identify the role of sparrow eradication, holding constant other ongoing policies at the time.

[14] We treat 1958 as a buffer year and omit it from the calculations in Figures 4c-4e.

Figure 4: Province-Level Correlations Between Sparrow Killings & Outcomes



Notes: Summary of descriptive statistics of province-level statistics. Changes in panels (c)-(e) are for 1959-1961 relative to 1955-1957. Panel (d) excludes Shanghai for easier visual inspection as it has an outlier value of (372.7, 1.4).

4.2 Econometric Specification

Our main empirical analyses are conducted at the county-year level. We implement a difference-in-differences design, exploiting variation in each county's innate suitability for sparrow habitation, and compare how high- vs. low-suitability counties differed in agricultural and demographic outcomes, before and after the initiation of the FPC.

Specifically, for each county c, we calculate its sparrow suitability index $Suitability_c$, following the procedure discussed in Section 3. We then estimate the following specification:

$$Y_{ct} = \sum_{\tau \neq 1957} \beta_\tau Suitability_c \times \mathbb{1}\{t = \tau\} + \phi_c + \lambda_t + \varepsilon_{ct} \tag{1}$$

where Y_{ct} is the outcome of interest in county c in year t. We interact the sparrow suitability index, $Suitability_c$—either as a dummy for having an above median score, or as the continuous score—with year dummies. The parameters of interest are the β_τ coefficients that capture the dynamic response of the outcome to the impulse of the sparrow eradication, relative to 1957, which is the omitted category.

We account for time-invariant factors and pooled shocks by including ϕ_c and λ_t, which are county and year fixed effects, respectively. County fixed effects absorb factors that affect baseline agricultural productivity such as soil conditions, local crop pest composition, and climatology. Year fixed effects absorb pooled shocks such as extreme weather events, technological improvements, and structural transformation trends. In robustness tests, we allow the year fixed effects to vary at sub-national levels. Any unobserved heterogeneity is captured by the error term, ε_{ct}. The standard errors are clustered at the county level. The Online Appendix, Section A.6, further discusses spatial correlation (Figures A5-A7) and reports standard errors adjusted for spatial correlation—verifying that we are not underestimating the standard errors by clustering at the county level.

Our identifying assumption is that, in the absence of the FPC, local sparrow suitability index should have been orthogonal to the trajectories of agricultural production and demographic change. Therefore, in the event studies for the outcomes of interest, we expect β_τ to be statistically indistinguishable from zero before the onset of the FPC.

Even with parallel trends prior to the FPC, one additional potential confounder is that sparrow suitability might be systematically correlated with certain regional features, such as political zealousness in enforcing central policies, or levels of social capital, that could trigger differential responses to the national campaigns during the Great Leap Forward, and thereby generating breaks in trends after 1958. To investigate this possibility, we will directly examine the correlations between the sparrow suitability index and a set of province-level variables that capture other GLF policies that were ongoing during the FPC.

5 Economic & Demographic Consequences of Sparrow Eradication

In this section, we follow the baseline econometric specifications, as laid out in Equation 1, to investigate the economic impacts of sparrow eradication. In Section 5.1, we document the impacts of sparrow eradication on agricultural output. In Section 5.2, we examine the farmers' responses to sparrow eradication. In Section 5.3, we show how the government procurement policies responded to the sparrow-induced agricultural productivity loss. In Section 5.4, we examine the impacts on mortality and fertility. In Section 5.5, we combine the estimation results in a series of back-of-the-envelope calculations to quantify the contribution of the sparrow eradication to the agricultural loss and mortality.

5.1 Grain Output Declined Following the FPC

In Figure 5, we plot the event study coefficients we obtaine from estimating Equation 1, for the outputs of two key grain crops: rice and wheat. For rice, we do not observe a systematically different evolution of production in the years leading up to the FPC between sparrow-suitable and non-suitable counties. For wheat, we observe a nosily estimated minor growth in wheat production in sparrow-suitable counties prior to 1958. For both outcomes, we fail to see a downward pre-trend in treatment relative to control counties, which gives us additional confidence in the validity of our research design. In contrast, after 1958, when the sparrow eradication began, we see salient drops in rice and wheat output, which later gradually recovered in the post-1961 era. We observe a sharp decline in total grain production (rice or wheat) when defining treatment as the continuous sparrow suitability score, or when defining it in a binary manner—above-median sparrow suitability.

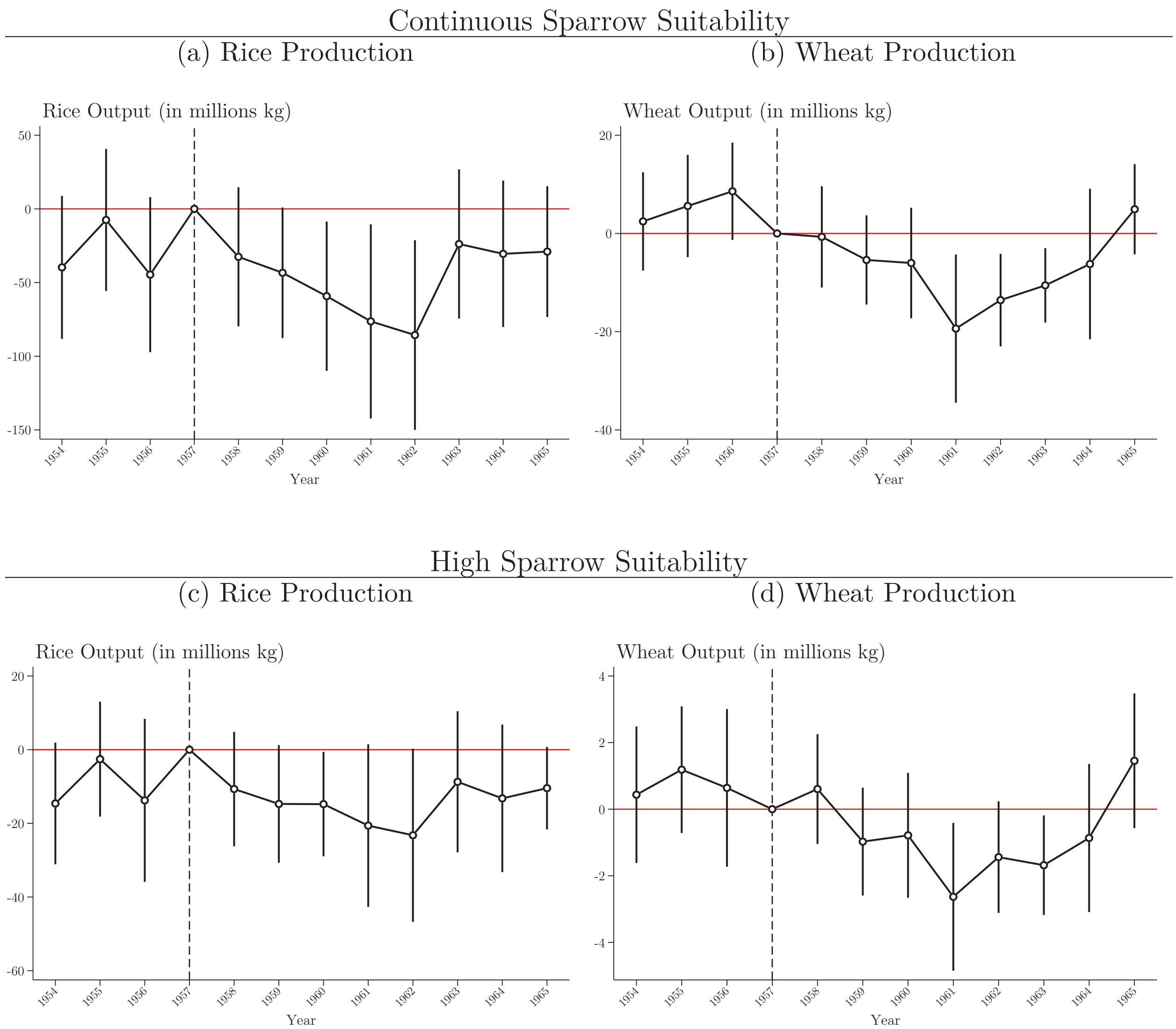
Taken together, these empirical patterns are consistent with our interpretation that counties more suitable for sparrow habitation were affected more by the eradication of sparrows. As a result, these counties became more vulnerable to locusts, planthoppers, and other pest outbreaks, which negatively affected their agricultural production. By removing sparrows from the FPC, and allowing them to repopulate after 1961, agricultural production in these affected counties gradually returned to their baseline levels.

The event study results are somewhat imprecisely estimated, with several of the 95% confidence intervals including zero; however, when we pool the treatment effects for 1958 to 1961, and 1962 to 1965, we recover more precisely estimated treatment effects. In Table 2, we summarize the patterns observed in Figure 5.[15] When we use the continuous suitability score (CSS), we see that counties with higher sparrow suitability scores experienced a large and significant drop in rice and wheat output during the FPC, compared to 1954 to 1957 (Panel A, columns 1 to 6).

To place the magnitudes in context, a one standard deviation increase in CSS results in a 3,129 or 1,145 metric tons decline in total rice or wheat output from 1958 to 1961 (Panel A, columns 1 and 4). Relative to the mean levels in the sample, these reflect declines of 5.3% and 8.7%, respectively. Alternatively, the difference in rice or wheat output between counties that have CSS values at the 75th percentile versus the 25th percentile is 4,886 or 1,787 metric tons, respectively. In addition, if we compare the counties that have a CSS that

[15] Online Appendix Table A4 reports the results weighted by baseline population.

Figure 5: Effects on Rice and Wheat Output at County Level



Notes: Coefficients and 95% CIs for the estimation specification in Equation (1). Panels (a) and (b) interact the continuous sparrow suitability score with year dummies, while panels (c) and (d) interact the dummy for above-median sparrow suitability (high sparrow suitability) with the year dummies. Each regression includes county and year fixed effects. Samples include all unbalanced counties with at least one year of non-missing data for rice and wheat before and after the onset of the FPC. Standard errors are clustered at the county level.

is above the median—hereafter, High Sparrow Suitability (HSS)—we find that rice or wheat declined in the HSS counties by 8,130 or 1,460 metric tons relative to their below-median counterparts (Panel B, columns 1 and 4). For both the CSS and HSS, we find that output was still meaningfully lower from 1962 to 1965, relative to 1954 to 1957, as the recovery of output towards baseline levels occurred around 1964 and 1965.

We continue to recover coefficients of similar magnitude and precision when we control for the dynamic impacts of baseline population—average population between 1954 and 1957 interacted with year fixed effects (columns 2 and 5). The results are also robust to including crop suitability interacted with year fixed effects (columns 3 and 6), indicating that the findings are not confounded by the sparrow suitability index picking up variations in the crop suitability indices.

One potential concern is that the campaign targeted four pests, yet we are focusing our attention on just one—sparrows. We do so for three reasons. First, sparrows were the primary target during our sample period, which is why the FPC is also referred to by many as the "sparrow eradication campaign." Second, sparrows were the only species included with agricultural production as the justification, while the other species were included due to public health reasons. If the eradication of flies, mosquitoes, and rats did improve public health, we would expect that to increase agricultural productivity. Similarly, even though rats were targeted for their role in spreading infectious diseases, rats can also cause agricultural damage by feeding on grain crops. Yet their eradication, if successful, would have led to higher agricultural production, and not lower production as we observe in the high-sparrow suitable areas. Third, controlling for the suitability of the other pests is complicated by the fact that all the pests targeted by the campaign are generalist species and can thrive in many habitats. This means that the same environmental conditions that predict high suitability for sparrows, tend to do so for the other pests as well. In addition, in the case of sparrows, there is one dominant species, the house sparrow, but in the case of the other pests, there are five fly species, five mosquito species, and two rat species—resulting in 12 additional covariates that are highly correlated with sparrow suitability.

Table 2
Effects on Rice and Wheat Output

	Rice Output			Wheat Output		
Panel A. Continous Suitability Score						
	(1)	(2)	(3)	(4)	(5)	(6)
CSS×1958-1961	-32.12**	-24.09**	-40.27***	-11.75***	-8.98**	-10.83***
	(14.79)	(11.39)	(13.71)	(3.65)	(3.54)	(3.63)
CSS×1962-1965	-21.61	-30.92**	-21.19	-9.68***	-8.87***	-9.69***
	(15.20)	(12.95)	(15.70)	(3.44)	(3.22)	(3.43)
R^2	0.89	0.90	0.89	0.90	0.88	0.90
Dep. Var. Mean	59.54	55.28	59.54	13.22	11.41	13.22
N	3,473	2,712	3,473	4,081	3,290	4,081
Clusters	421	336	421	495	407	495
Panel B. High Suitability Score						
	(1)	(2)	(3)	(4)	(5)	(6)
HSS×1958-1961	-8.13**	-9.05***	-7.77**	-1.46**	-1.07	-1.29*
	(3.45)	(2.93)	(3.31)	(0.70)	(0.79)	(0.70)
HSS×1962-1965	-7.01*	-9.34**	-7.06*	-1.03*	-1.60***	-1.07*
	(4.06)	(4.22)	(4.12)	(0.61)	(0.60)	(0.61)
R^2	0.89	0.90	0.89	0.90	0.88	0.90
Dep. Var. Mean	59.54	55.28	59.54	13.22	11.41	13.22
N	3,473	2,712	3,473	4,081	3,290	4,081
Clusters	421	336	421	495	407	495
Baseline Population-by-Year FE	N	Y	N	N	Y	N
Crop Suitability-by-Year FE	N	N	Y	N	N	Y

Notes: Estimation results from Equation 1 for the main sample spanning 1954 to 1965. Each regression includes county and year fixed effects. Standard errors are clustered at the county level.

5.2 Farmers' Adjustments

Farmers were limited in their ability to make adjustments in response to a potential increase in crop pest pressure for several reasons. First, most crop planting decisions were centrally planned, especially for grains such as rice and wheat. One notable exception to this was that after 1960, farmers were allowed to plant sweet potatoes for subsistence purposes (Meng et al. 2015). Second, other beneficial inputs such as pesticides and fertilizers were centrally distributed as opposed to purchased by farmers—preventing farmers from flexibly increasing inputs. Finally, migration and labor allocations were rigidly managed through the Hukou system (Yang 2012).

We begin examining potential adaptation by estimating whether there was a differential adoption of sweet potatoes in the counties that are more suitable for sparrows. It is important to note that grain crops such as rice and wheat are above-ground crops, while sweet potatoes are (root) below-ground crops. This feature makes sweet potatoes potentially less susceptible to an above-ground crop pest infestation—in particular locust outbreaks that were the main threat to agricultural production throughout Chinese history—the type that sparrows is believed to have played a key role in preventing (Mullié 2009; Sharma and Sharma 2017). It is documented in historical accounts that after 1960, the Chinese central government started allowing farmers to grow sweet potatoes on "private plots (*Zi Liu Di*)," in order to cope with the famine (Yang 2012).

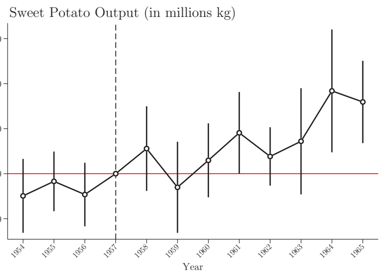
In Figures 6a and 6d, we report the coefficients from the estimation of Equation (1) for total sweet potato production, and find *opposite* effects to rice and wheat. The event study coefficients demonstrate a reassuring flat pre-trend, and then a large and persistent *increase* in crop output after 1960—when sweet potato planting was allowed for self-consumption. This indicates that counties more suitable for sparrow habitation experienced significant spikes in the production of sweet potatoes following the FPC, which persisted even as rice and wheat crops returned to baseline levels. It is important to note, however, that our sample size for counties with sweet potato data is smaller—206 counties relative to 421 and 495 counties for rice and wheat.

These observed empirical patterns are consistent with the different susceptibility of the below- versus above-ground features we described above. We interpret these findings as

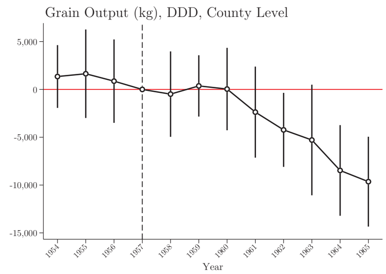
Figure 6: Effects on Sweet Potato Output and Crop Sown Area at County Level

Continuous Sparrow Suitability

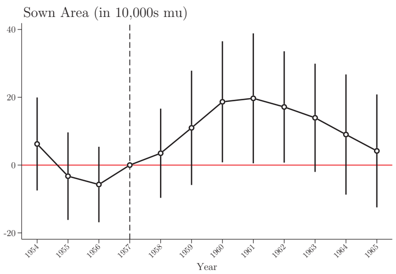
(a) Sweet Potato Production



(b) Grain Output, DDD

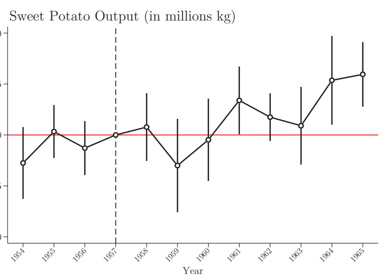


(c) Crop Sown Area

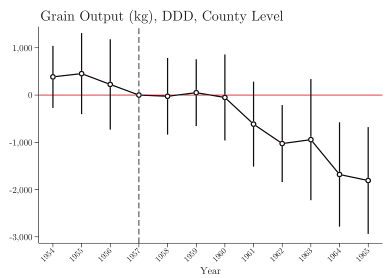


High Sparrow Suitability

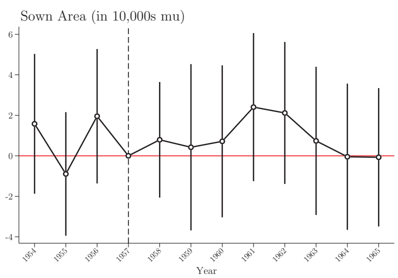
(d) Sweet Potato Production



(e) Grain Output, DDD



(f) Crop Sown Area



Notes: Coefficients and 95% CIs for the estimation specification in Equation (1). Panels (a)-(c) interact the continuous sparrow suitability score with year dummies, while panels (d)-(f) interact the dummy for above-median sparrow suitability (high sparrow suitability) with the year dummies. Each regression includes county and year fixed effects. Samples include all unbalanced counties with at least one year of non-missing data for rice and wheat before and after the onset of the FPC. Standard errors are clustered at the county level.

suggestive evidence that, in the absence of the biological provision of pest control functions, historically provided by sparrows, farmers of rice and wheat crops would become more willing to switch or increase their sweet potato cultivation to hedge themselves against future pest outbreaks. Such a switch in crop choice in the more sparrow-suitable counties appears persistent even after the removal of sparrows from the FPC, which can be rationalized by either a fixed cost of crop switching or shock-induced learning (about the benefits of growing sweet potatoes).[16]

The cultivation of sweet potatoes is a time-varying outcome that could account for other

[16] Sweet potatoes were not introduced to China until the mid-seventeenth century, when farmers had been growing rice and wheat for centuries and did not fully adopt this new crop (Jia 2014). A negative shock to rice and wheat yields such as the FPC could have induced farmers to learn more about the returns to growing sweet potatoes.

factors that affect rice and wheat production—for example, drought conditions. We estimate a triple-differences specification by using a sample of rice, wheat, and sweet potato, where the comparison between rice/wheat vs. sweet potato provides the third dimension of "difference." In Figures 6b and 6e, we report the coefficients for the triple-interaction of sparrow suitability (continuous or dummy for above-median), rice or wheat crops, and year dummies. Effectively, this specification benchmarks the decline in rice and wheat against the growth in sweet potatoes, across counties with different levels of sparrow suitability score, before and after the FPC. The results again reveal that, after the start of sparrow eradication, counties more affected by sparrow eradication shifted from relying on rice and wheat to relying on sweet potatoes, creating a clear divergence in crop choices that persisted even after the end of the FPC.

One potential way farmers could have increased production is to increase the amount of land area under cultivation, especially given that "private plots (*Zi Liu Di*)" for sweet potatoes became allowed at the time. However, one challenge to that could have been that labor reallocation from rural villages led to the abandonment of agricultural lands, leading to reduced total agricultural output. If sparrow-suitable counties systematically reduced the sown area more than non-suitable counties then this presents a threat to our identification strategy as it offers an alternative explanation to the decline in output. In Figures 6c and 6f, we report imprecisely estimated *increases* in sown area in the sparrow-suitable counties. We interpret this result as the data on sown area not being consistent with the notion that grain output fell in sparrow-suitable counties because of a sharp reduction in cultivated land for agricultural production. In other words, using sown area as a proxy for rural labor, we do not find evidence that supports a differential reallocation of rural labor away from sparrow-suitable counties relative to non-suitable counties.

In Table 3, we summarize the graphical patterns documented in Figure 6, following the same specifications used in Table 2. Our estimates indicate that a one standard deviation increase in the sparrow suitability score resulted in an increase of 1,263 and 2,732 metric tons of sweet potato production during the periods of 1958-1961 and 1962-1965 (Panel A, column 1). The fact that sparrow-suitable counties keep producing more sweet potatoes in the long run, combined with the fact that rice or wheat production in these counties returned to baseline by 1965, suggests that the passive adoption of sweet potatoes during a time of crisis might have long-run benefits to these counties, who suffered most during the famine. As expected, in Panel B of Table 3, we fail to recover an estimate for sweet potato production increasing in the HSS counties from 1958 to 1961, but we recover meaningful and precisely estimated spikes in production from 1962 to 1965. Finally, when using either the CSS or HSS, we always fail to detect statistically significant changes in crop sown area, and can reject meaningful declines in sown area.

5.3 Government Responses

As documented by Meng et al. (2015), during the GLF, in addition to declines in agricultural output, the rigid procurement standard also played a key role in generating regional food shortages and thereby causing the famine. Guided by this insight, we formally examine whether the government was able to adjust procurement requirements in the regions that were more affected by the FPC, which helps shed light on whether, and through what potential mechanisms, the FPC would play a role in the formation of the Great Famine.

Our analysis demonstrates that the rigid crop procurement rule further exacerbated the negative agricultural production shock. We report the coefficients for the event study estimation for the procurement rate and amount in Figure 7, where we observe a spike during the years of the FPC with sharp reversal in 1961. When high-suitability counties experienced a negative output shock after sparrow eradication, they woefully got assigned even higher procurement amounts, which was likely driven by the central government's working assumption for the FPC—that sparrow eradication would boost agricultural productivity, rather than reducing it (Zhao and Su 2011). For example, in 1960, when China's Vice Premier Tan Zhenlin discussed the FPC—despite a long list of prominent scientists arguing other-

Table 3
Effects on Sweet Potato Output and Crop Sown Area

	Sweet Potato Output			Crop Sown Area		
Panel A. Continous Suitability Score						
	(1)	(2)	(3)	(4)	(5)	(6)
CSS×1958-1961	12.97*	-0.87	6.19	14.03*	10.26	13.85*
	(7.75)	(5.72)	(7.50)	(8.18)	(7.64)	(7.93)
CSS×1962-1965	28.05***	11.02***	20.11**	11.59	7.45	11.55
	(10.27)	(3.92)	(8.48)	(8.39)	(7.43)	(8.16)
R^2	0.85	0.87	0.86	0.98	0.98	0.98
Dep. Var. Mean	17.02	14.11	17.02	85.15	82.89	85.15
N	1,588	1,219	1,588	3,741	3,345	3,741
Clusters	206	164	206	459	417	459
Panel B. High Suitability Score						
	(1)	(2)	(3)	(4)	(5)	(6)
HSS×1958-1961	1.09	-1.26	-0.29	0.49	0.12	0.39
	(1.45)	(1.36)	(1.50)	(1.79)	(1.56)	(1.77)
HSS×1962-1965	4.46***	2.07**	2.88**	0.10	-0.55	0.05
	(1.60)	(0.87)	(1.28)	(1.93)	(1.63)	(1.91)
R^2	0.85	0.88	0.86	0.98	0.98	0.98
Dep. Var. Mean	17.02	14.11	17.02	85.15	82.89	85.15
N	1,588	1,219	1,588	3,741	3,345	3,741
Clusters	206	164	206	459	417	459
Baseline Population-by-Year FE	N	Y	N	N	Y	N
Crop Suitability-by-Year FE	N	N	Y	N	N	Y

Notes: Estimation results from Equation 1 for the main sample spanning 1954 to 1965. Each regression includes county and year fixed effects. Standard errors are clustered at the county level.

wise—he remarked, "*the achievement of the FPC is more than clear; sparrows have mostly been eradicated, crop yield has been growing steadily, we have already greatly alleviated the negative impacts of sparrows on agricultural production.*"[17] This maladaptation further reduced local available food supplies, which were now being procured and redistributed, in the exact location that already experienced a negative production shock.

Since crop yield and procurement amount moved in such opposite directions, the effective procurement rate (procurement divided by output) went up substantially for the high-suitability counties during the FPC, which echoes the patterns documented by Meng et al. (2015), in which more productive counties saw larger declines in food availability. After 1960, both the procurement amount and the effective procurement rate started to catch up with the lower yields in high-suitability counties, consistent with the historical background documented in the Great Famine literature—the Chinese government realized the severity of the famine after 1960, and adjusted its procurement policies accordingly (Yang 2012).

Taking stock, our results indicate that the eradication of sparrows reduced crop yields in counties with high sparrow suitability scores between 1958 and 1961, while grain procurement in these areas did not adjust accordingly until 1961. As a result, 1960 was likely a particularly difficult year for the high-suitability counties—yield had already fallen significantly, while procurement amount further went up. We examine this hypothesis explicitly in the following section.

5.4 Mortality and Fertility Rates

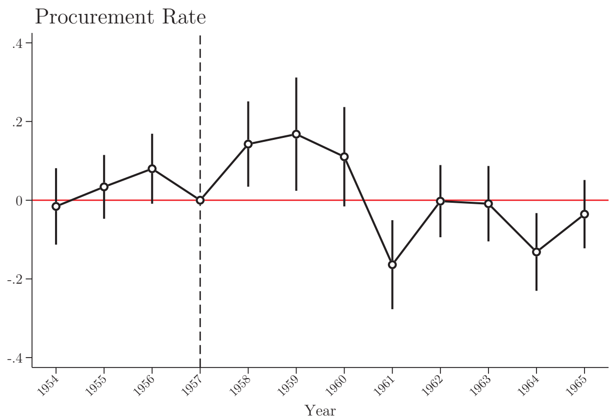
In this section, we investigate the demographic impacts of the eradication of sparrows. Our key hypothesis is that because sparrow-suitable counties experienced both a decline in agricultural production, and, at the same time, were required to deliver more of their diminished food surplus for purposes of redistribution, they were likely to experience a higher degree of food shortages. If so, this should reflect in more severe mortality outcomes in these coun-

[17] Source: https://www.gov.cn/test/2006-02/27/content_212502.htm. Accessed June 6, 2025.

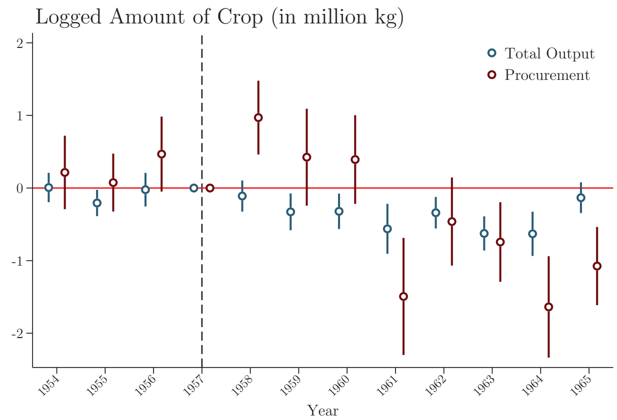
Figure 7: Examining the Role of the Procurement Policy

Continuous Sparrow Suitability

(a) Procurement Rate

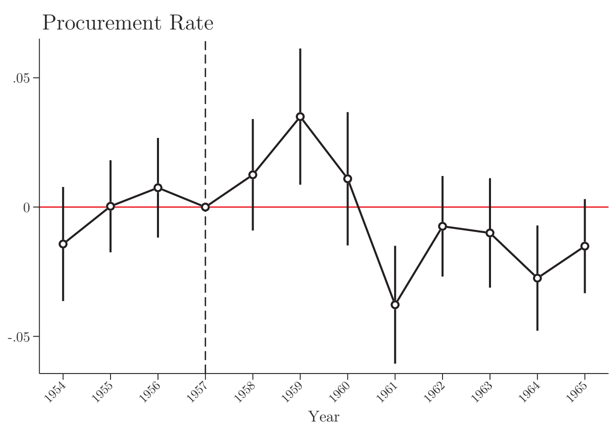


(b) Numerator and Denominator

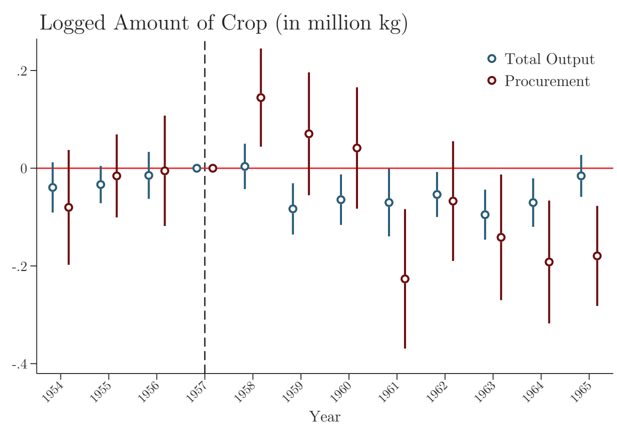


High Sparrow Suitability

(c) Procurement Rate



(d) Numerator and Denominator



Notes: Coefficients and 95% CIs for the estimation specification in Equation (1). Panels (a) and (b) interact the continuous sparrow suitability score with year dummies, while panels (c) and (d) interact the dummy for above-median sparrow suitability (high sparrow suitability) with the year dummies. In panels (a) and (c), we plot the procurement rate (amount procured for redistribution relative to total local production), while in panels (b) and (d), we separately examine the logged amount in the numerator or denominator in the procurement rate. Each regression includes county and year fixed effects. Samples include all unbalanced counties with at least one year of non-missing data for rice and wheat before and after the onset of the FPC. Standard errors are clustered at the county level.

ties. Throughout the demographic analysis, all regressions are weighted by the pre-1957 population of each county.[18]

There was no systematic difference in mortality or fertility trends between sparrow-suitable or non-suitable counties before the FPC, but during the peak of the Great Famine, sparrow-suitable counties experienced a meaningful differential shock to these outcomes. In Figure 8, we plot the event study coefficients from Equation (1) for either the all-cause death rate or the birth rate, per 1,000 people. For the all-cause death rate, we observe no difference in how sparrow-suitable counties were trending relative to the sparrow-unsuitable counties in the pre-FPC years—when using either the continuous or dummy version of the treatment variable (Figure 8a or 8c). For both versions of the treatment variable, we observe a sharp spike in mortality in 1960, the peak of the Great Famine. The timing of this effect is highly consistent with the relative timelines of agricultural shock and delayed procurement adjustment, as discussed in Section 5.3. When using the above-median sparrow suitability treatment definition (Figure 8c), we observe that the high sparrow suitability counties started to diverge from the low sparrow suitability counties in 1958.

The magnitudes of the mortality effects are meaningful, even against the backdrop of the calamity of the Great Famine. For example, in 1960, a one standard deviation difference in the sparrow suitability score resulted in 3.3 additional deaths per 1,000 people. Alternatively, the difference in mortality in 1960 between a county with a sparrow suitability score at the 75th to the 25th percentile level is 5.1 additional deaths per 1,000 people. The high sparrow suitability counties (above-median suitability) had 13.14 additional deaths per 1,000 people in 1960, relative to the low sparrow suitability counties. These reflect relative differences of 9.6%, 15%, and 38.9%, respectively, relative to the mean all-cause death rate in 1960 of 33.9 deaths per 1,000 people.[19]

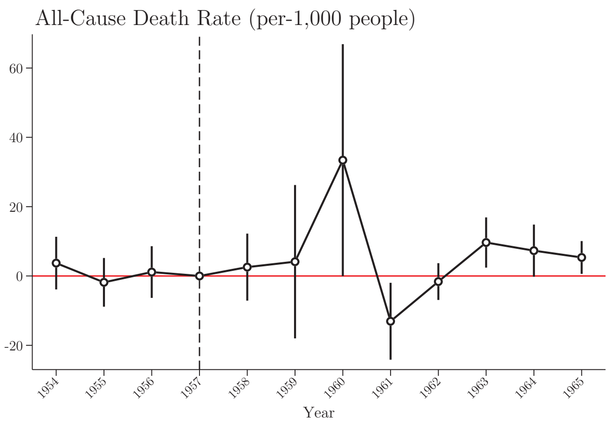
[18] To allow for comparison between the previous unweighted results and results reported here, we present population-weighted results in Table 4, and unweighted results in Online Appendix Table A5.

[19] The mean all-cause death rate in 1960 is masking considerable heterogeneity. The 10th, 25th, 75th, and 90th percentile values for the all-cause death rate in 1960 were: 9.7, 13.6, 52.7, and 70.4 deaths per 1,000 people.

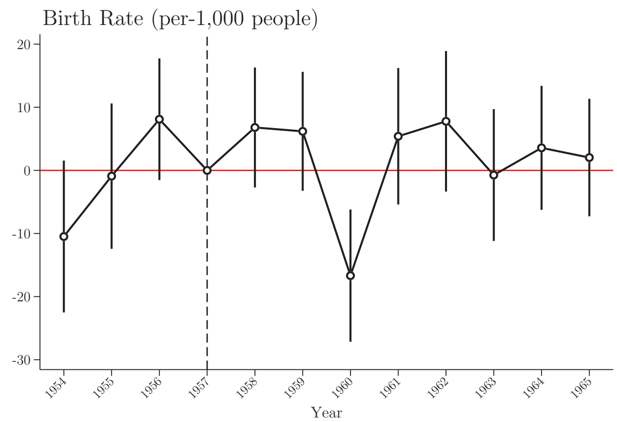
Figure 8: Effects on Population at County Level

Continuous Sparrow Suitability

(a) Mortality

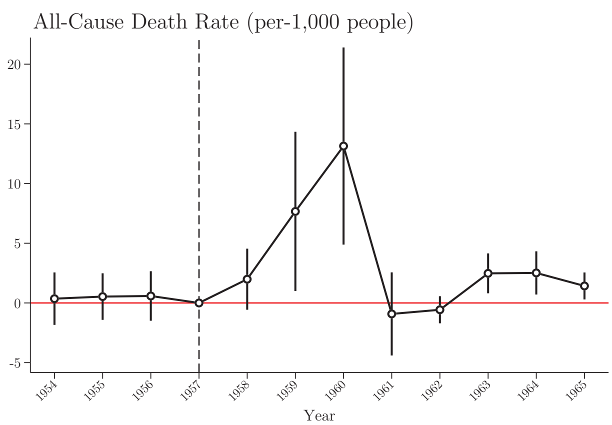


(b) Fertility

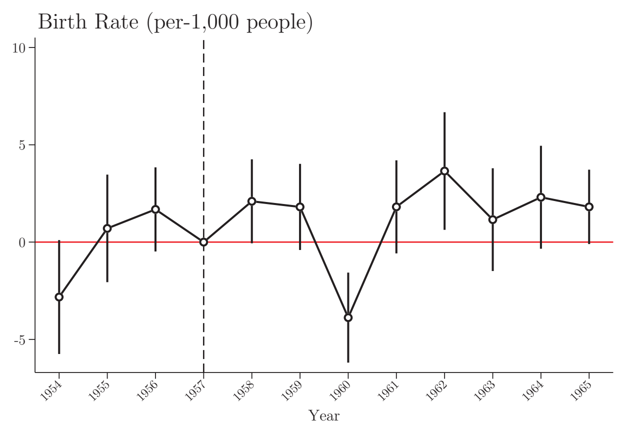


High Sparrow Suitability

(c) Mortality



(d) Fertility



Notes: Coefficients and 95% CIs for the estimation specification in Equation (1). Panels (a) and (b) interact the continuous sparrow suitability score with year dummies, while panels (c) and (d) interact the dummy for above-median sparrow suitability (high sparrow suitability) with the year dummies. Each regression includes county and year fixed effects. Samples include all unbalanced counties with at least one year of non-missing data for rice and wheat before and after the onset of the FPC. Standard errors are clustered at the county level.

Higher mortality is one demographic dimension through which counties could have experienced the severe negative effects of the Great Famine, while fertility is another important dimension we examine. In Figures 8b and 8d, we repeat the same exercise for fertility rate, motivated by previous findings in the literature showing that the Great Famine consisted of not only death counts but also foregone births in the corresponding cohorts (Ashton et al. 1992). As expected, the pattern appears to be the mirror image of that in mortality results: the birth rate is strongly negatively correlated with the sparrow suitability score in 1960, but not in the years before or after.

In Table 4, we summarize the patterns we report in Figure 8.[20] Because the events of the Great Famine were so heavily concentrated during the peak in 1960, we recover a positive but imprecisely estimated coefficient when we pool 1958 to 1961 together, using the CSS (Panel A, columns 1 to 3). When we use the HSS, we recover precisely estimated increases in mortality over the 1958-1961 period of 5.1 additional deaths per 1,000 people (Panel B, column 1). While our pooled estimates for fertility from 1958 to 1961 smooth out the sharp negative effect in 1960 we observe in Figures 8b and 8d, we observe a precisely estimated *increase* in the birth rate following the FPC, during 1962 to 1965. We find that the birth rate was 2.2 births per 1,000 people higher in the HSS counties (Panel B, column 4). This is consistent with delayed fertility decisions and with fertility choices that seek to compensate for mortality shocks (Nobles et al. 2015; Eckstein et al. 1984).

It is worth noting that while sparrow-suitable counties experienced the largest reductions in rice production in 1960-1961, and in wheat production in 1961, the main demographic consequences were heavily concentrated in 1960, which echoes Meng et al. (2015) by highlighting the central role of procurement rules in driving the famine. In fact, we observe that sparrow-suitable counties experienced the biggest differential change to the procurement rate in 1960 (Figures 7a and 7c). To put it in another way, it is unlikely that the eradication of sparrows alone would have caused all the documented demographic changes, had there not

[20] Online Appendix Table A5 reports the same sets of regression with equal-weighted rather than population-weighted.

Table 4
Effects on Death and Birth Rate

	Death Rate			Birth Rate		
Panel A. Continous Suitability Score						
	(1)	(2)	(3)	(4)	(5)	(6)
CSS×1958-1961	5.49	6.14	0.46	0.52	-0.16	-0.21
	(7.89)	(8.06)	(7.58)	(3.61)	(3.48)	(3.70)
CSS×1962-1965	4.28*	2.91	3.05	3.12	2.76	-0.10
	(2.25)	(2.22)	(2.30)	(4.02)	(4.05)	(3.68)
R^2	0.45	0.46	0.48	0.68	0.68	0.70
Dep. Var. Mean	14.65	14.65	14.65	31.63	31.63	31.63
N	3,699	3,699	3,699	3,654	3,654	3,654
Clusters	486	486	486	482	482	482
Panel B. High Suitability Score						
	(1)	(2)	(3)	(4)	(5)	(6)
HSS×1958-1961	5.10**	5.44**	4.17*	0.31	0.14	0.14
	(2.18)	(2.37)	(2.17)	(0.79)	(0.80)	(0.81)
HSS×1962-1965	1.00*	0.73	0.74	2.16**	2.15**	1.58*
	(0.51)	(0.49)	(0.54)	(0.91)	(0.97)	(0.86)
R^2	0.46	0.46	0.48	0.68	0.68	0.70
Dep. Var. Mean	14.65	14.65	14.65	31.63	31.63	31.63
N	3,699	3,699	3,699	3,654	3,654	3,654
Clusters	486	486	486	482	482	482
Baseline Population-by-Year FE	N	Y	N	N	Y	N
Crop Suitability-by-Year FE	N	N	Y	N	N	Y

Notes: Estimation results from Equation 1 for the main sample spanning 1954 to 1965. Each regression is weighted by the mean population between 1954 and 1957. Each regression includes county and year fixed effects. Standard errors are clustered at the county level.

been such misguided procurement rules prior to 1960.

5.5 Back-of-the-Envelope Calculation

In this section, we evaluate the aggregate contribution of the FPC to the Great Famine. Linking the estimates for agricultural and demographic impacts, and imposing linearity assumptions on these effects, we can conduct back-of-the-envelope calculations on the extent to which the eradication of sparrows contributed to the Great Famine.

Specifically, according to our agricultural estimates, 23,169,473 (3,844,525) tons of lost rice (wheat) can be attributed to the eradication of sparrows, which is 8.72% of the baseline national crop yield, and accounts for 19.64% of the lost output during the Great Famine.[21] According to our demographic estimates, sparrow eradication led to the loss of 1,954,169 lives, and reduced fertility counts by 397,368.[22] This is equivalent to 0.307% of the total national population, and 6.49% of the total death count during the Great Famine.

In Online Appendix Tables A6 and A7, we redo these calculations using different versions of baseline point estimates and under different functional form assumptions, and present the most "aggressive" vs. "conservative" findings. As the results suggest, while the calculated impacts of sparrow eradication do vary across specifications and functional forms, the main quantitative message remains robust—sparrow eradication was accountable for a substantial amount of agricultural output loss and excessive deaths during the Great Famine.

[21] We calculate the lost crop caused by sparrow killing as the sum of products across counties of the suitability scores, which is weighted by the percentage of a certain crop production out of the total output of all crops, multiplied by the event study coefficients for 1959, 1960, and 1961. We calculate the total lost crop as the difference in the sum of the estimated crop output between 1959 and 1961 and the actual crop output between 1959 and 1961.

[22] We calculate the total loss of lives in a similar way to the crop losses. We take the sum of products of the suitability scores times the all-cause death rate event study coefficients for 1959, 1960, and 1961, multiplied by the county's population. We then divide that sum by the total number of deaths across all counties. We repeat this process for fertility.

6 Robustness Checks and Ecological Validation

In Section 6.1, we assess the robustness of our baseline findings. In Section 6.2, we benchmark the econometric results against simulations of a simple ecological model of predator–prey population dynamics.

6.1 Robustness & Threats to Internal Validity

We examine the robustness of our baseline findings to a variety of changes to the regression specification, or additional sample restrictions. One potential concern is the representativeness of our baseline county sample. Since official statistics were widely known to be severely exaggerated in that period (Chen and Kung 2011), we rely on decentralized information independently documented in the county gazetteers, which is believed to be more accurate (Alesina et al. 2020). However, the county gazetteers were only available intermittently in 898 counties, reflecting 58.6% of the total number of agricultural counties at the time, raising questions about possible sample selection issues across regions and over time. We address these concerns in two ways.

First, as discussed in Section 4, when regressing official agricultural output numbers against official numbers of sparrow killings at the provincial level, this balanced panel shows a pattern consistent with our county-level analysis: provinces reported to have killed more sparrows during the FPC also experienced sudden losses in agricultural output during this period. This aggregated balanced panel thus helps alleviate concerns that the county-level results are driven by its incomplete coverage. While it is certainly possible that the provincial official statistics may have been manipulated, it is worth noting that such politically-motivated misreporting would likely be systematically inflated for both crop yields and sparrow killings, thereby generating a spurious positive correlation between the two, rather than the negative relationship observed in our data.

Second, in addition to aggregating the analysis to the provincial level, we also repeat the county-level analysis with only a balanced panel.[23] In Online Appendix Table A8, we compare estimates from the baseline specification in Equation (1) using the unbalanced panel, to the estimates we obtain when restricting the sample to be balanced between 1955 and 1962. We fail to find meaningful differences in the baseline empirical patterns. This is reassuring that our findings are indeed driven by the treatment effect of sparrow eradication, instead of potentially endogenous entry and exit of counties in our baseline sample. The results from the balanced sample complement the analysis in Online Appendix Table A2, where we do not find evidence that the timing of failing to report a value for rice or wheat is correlated with sparrow suitability.

Environmental data are often spatially clustered, and since the sparrow suitability score is a function of different environmental variables, we expect it to be spatially clustered as well (see Figure 2). One concern that arises from such spatial clustering is that the standard errors are spatially clustered, and that by clustering at the county level, we might be systematically overestimating the precision of our estimates. In Online Appendix Section A.6, we first document the distance distribution between counties, then demonstrate that when allowing standard errors to be correlated across neighboring counties, the precision of the results holds.

Another concern with our use of environmental data is that we use data from more recent years when estimating the sparrow suitability score. Because of climate change, it is possible that environmental conditions today are meaningfully different than what they were around 1960. This could threaten our identification strategy if climate change had a larger effect in sparrow-suitable areas, as it would introduce non-classical measurement error to our key treatment variable. In Online Appendix Section A.7, we examine the scope of this concern. We first document that the temperature distribution has shifted to the right over time, but verify that changes in mean annual temperatures are uncorrelated with the sparrow suitability score we calculate.

[23] To avoid dropping too many counties from the sample, for the robustness checks with balanced panels, we focus on the sample period between 1955 and 1962.

One might also worry about potential outliers in the historical data, especially given that the county gazetteers data was largely voluntarily documented by the local gentry class, without a streamlined process of quality checking. To alleviate such concerns, in Online Appendix Tables A10 and A11, we re-run the baseline regressions using truncated samples at [1%,99%], [2.5%,97.5%], and [5%,95%], respectively. Compared to the baseline untruncated sample, the key empirical patterns remain highly robust, indicating that the main results are not driven by outliers.

To further verify that the main results are not sensitive to the choice of fixed effects in the specification, especially the temporal controls, we report several variations to the baseline regression specification in Equation (1). In Online Appendix Tables A12-A25, we report—for all the outcomes, using either the CSS or HSS—the baseline event-study coefficients, along with results that include the baseline population-by-year, and the crop suitability-by-year controls. To this, we add results that also allow the year fixed effects to vary by one of three regions (east, middle, or west). In a more demanding check, we include province, of which there are 31 of, linear time trends. This change leads to similar patterns in terms of the sign of the dynamics, despite sometimes resulting in less precisely estimated coefficients.

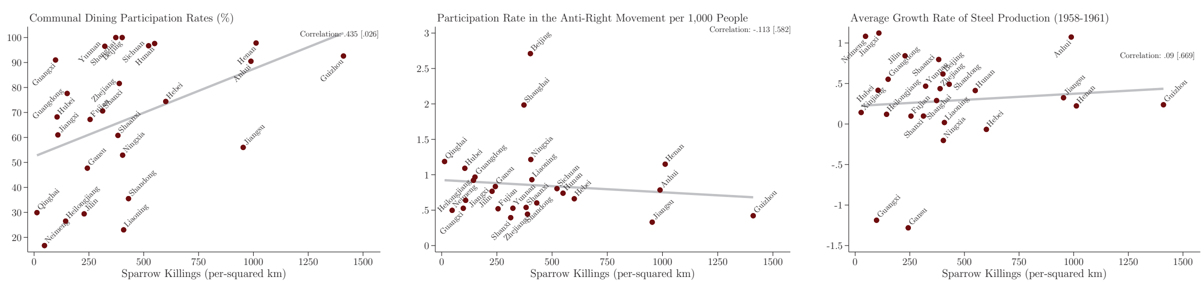
As additional time-varying controls, in Online Appendix Tables A12-A25, we also add the province-level cross-sectional covariates on communal dining, participation in the anti-rightist movement, cattle killings, and steel production growth, which we interact with year fixed effects. All four have been used in previous papers on the GLF and the Great Famine to examine the varying degree of adherence to GLF policies (Lin 1990; Lin and Yang 2000; Meng et al. 2015; Chen and Lan 2017). We also summarize the province-level correlation of these variables with the reported sparrow killings in Figure 9, where we fail to detect meaningful correlations.[24] By including the interactions of these province-level proxies for GLF "zealousness," we are allowing different dynamics at the province level to absorb more

[24] While communal dining (Figure 9a, shows a linear fit with a positive slope, it is heavily driven by just three outlier provinces. Removing just one of the three provinces in the top-right corner of the figure, greatly suppresses the positive slope of the linear fit line.

of the variation in agricultural production, as well as other outcomes. As we include more of these covariates, however, we reduce the sample size because not all of these variables are reported for all of the provinces. In the most demanding specification, where we include baseline population-by-year, crop suitability-by-year, GLF covariates-by-year, and province linear time trends, we are left with a little over half of the original sample, yet we still recover meaningful and precisely estimated treatment effects based on sparrow suitability.

Figure 9: Cross-Sectional Provincial Correlations With GLF Policies

(a) Communal Dining (b) Anti-Right Movement (c) Steel Production Growth



Notes: Province-level correlations of proxies for “zealousness” with respect to pursing other Great Leap Forward policies, and sparrow killings.

6.2 Benchmarking Agricultural Losses

To better interpret our findings on the decline in grain production, we use a predator–prey model to derive back-of-the-envelope estimates. The Lotka–Volterra model is one of the most commonly used frameworks in ecology for describing the population dynamics of two interacting species (Wangersky 1978). Our goal is not to make precise predictions of population levels but rather to highlight how a change in one species’ population can lag behind a change in the other and to illustrate the potential magnitude of their oscillations over time. Figure 10a plots the dynamics of both populations, initialized at steady state and subjected to a negative shock to the predator population. In Online Appendix Section A.8, we present the equations and steady-state of the system.

Using this model, we simulate how crop damage varies following a decline in biological pest control. We consider multiple baseline values for both the sparrow and pest populations, as well as the damage coefficient quantifying pest impacts on crops. Baseline population levels are determined by the four key model parameters: the pest birth rate, the predation rate by natural enemies (biological pest control), the predator death rate, and the conversion factor from consumed prey to new predators. In each simulation, these four parameters are sampled from uniform distributions. We also sample the pest damage coefficient from values commonly reported in the literature. These are the five system parameters.

We vary the relative reduction in biological pest control following the sparrow eradication across simulations. As noted earlier, sparrows were not the sole agents of pest control, and the campaign's targeting was imperfect: other species continued providing control, while sparrow-like birds may also have been affected. We simulate predator population shocks of 1 – 20 percent, performing 100 iterations per shock. In each iteration, we randomly sample the five system parameters. We then infer the relative change in crop damage from the resulting deviation in pest population levels from the steady state.

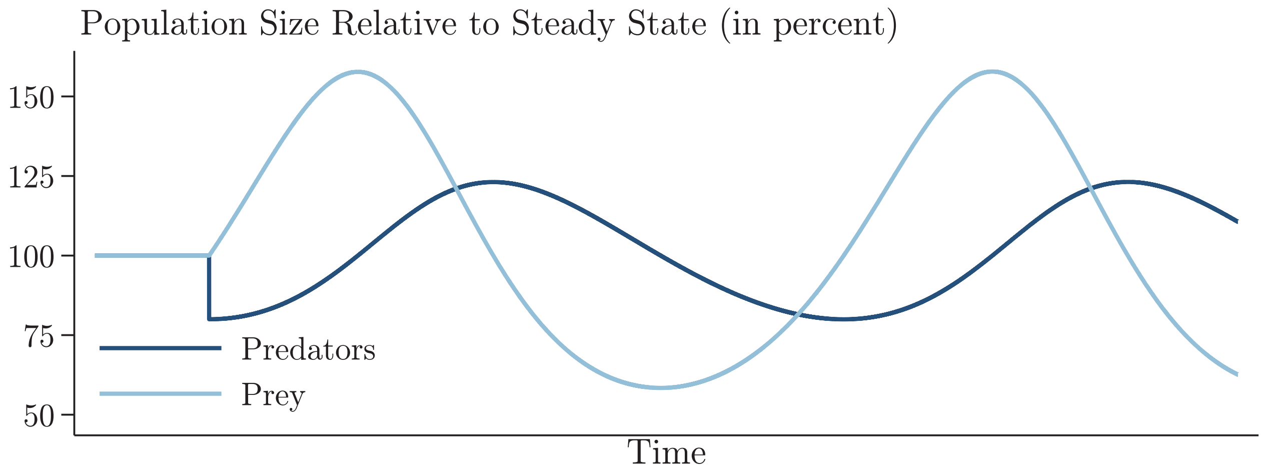
Simulation results highlight a wide range of possible crop-damage increases—up to 40 percent. In Figure 10b, we plot each trajectory of crop-pest damage following a shock to biological pest control. Although the simulation abstracts away from many important system dimensions, we find that the observed relative declines in rice and wheat fall well within the simulated damage increases. In other words, the simulations illustrate that biological pest control did not have to collapse completely after sparrows were eradicated. Even moderate losses of pest control, combined with varying degrees of pest-damage coefficients, can produce large, meaningful declines in output.

It is important to caveat the results from this simulation as it is an illustrative exercise. We place less emphasis on the exact numbers we obtain, as those are sensitive to the chosen ranges of parameter values, and the model provides a highly simplified system of only two species. That being said, we argue that the simulation offers two useful insights: (i) the reduction in biological pest control leads to larger crop pest damages due to the insects that do not get eaten, but more importantly, because the insect population increases non-linearly;

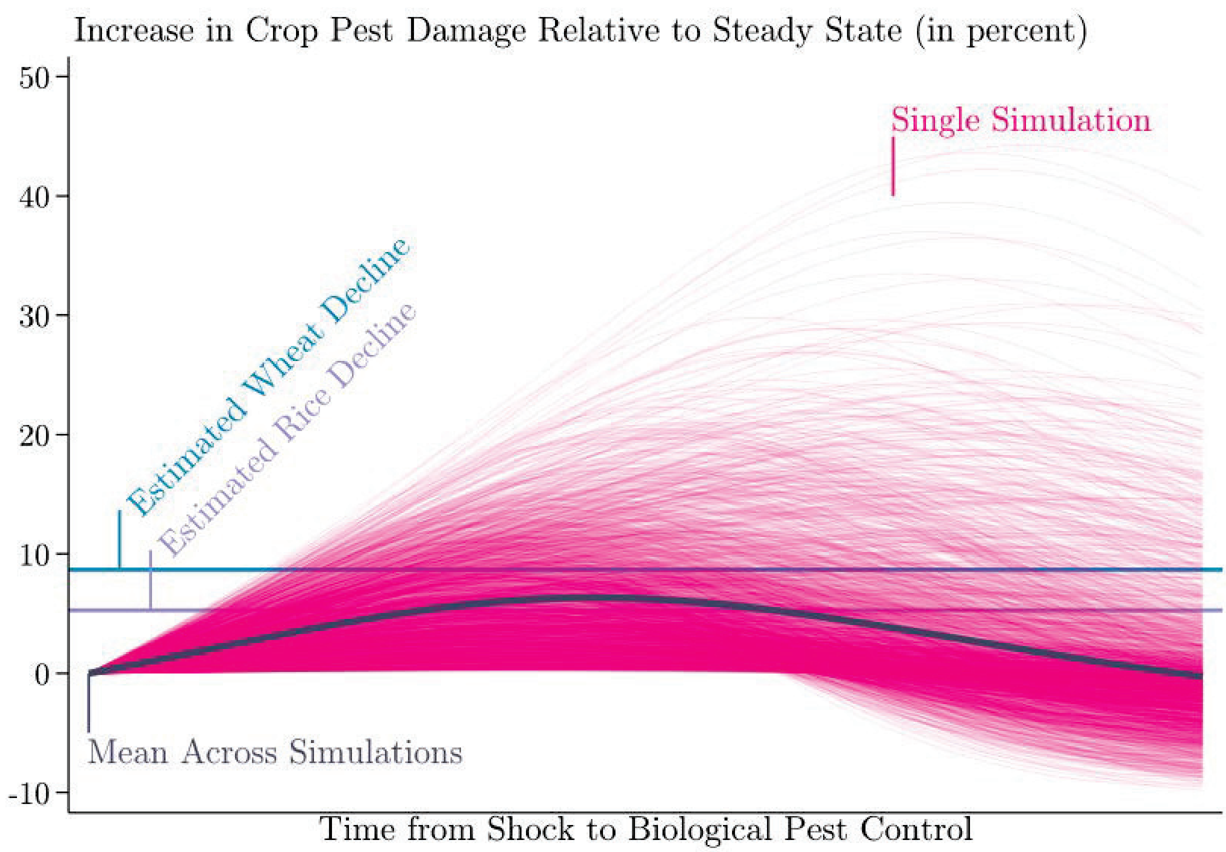
and (ii) the simulation results highlight that under a combination of parameter values, the increase in crop damages can be substantially higher, even higher by an order of magnitude than what we estimate in our analysis.

Figure 10: Benchmarking Agricultural Losses Using a Predator-Prey Simulation

(a) Schematic Predator-Prey Model Dynamics



(b) Change in Agricultural Losses Due to Crop Pests



Notes: In Panel (a), we plot the schematic dynamics of a predator-prey model. Starting with the populations of both at steady state, we sharply reduce the predator population by 20 percent. This sets in motion a cycle of changes in the population size that repeats itself unless the system is disrupted again. In Panel (b), we summarize 2,000 simulations of such a model, where the prey are the crop pests and the predators are sparrows and other species that can provide biological pest control. In the simulations, we draw at random a damage coefficient that converts the crop pest population to agricultural losses. We plot the change in the the damages from crop pests relative to the steady state as it evolves over time following the shock to the biological pest control population. We also plot our estimated declines in rice and wheat in sparrow suitable to unsuitable counties, which fall very close to the mean loss across all simulations.

7 Conclusions

Our findings confirm that counties in China with high sparrow habitation suitability experienced a marked reduction in grain production and a surge in all-cause mortality during the Great Famine, following the Four Pests Campaign of 1958–1960. This outcome offers robust empirical support for the long-held environmental history hypothesis that eradicating sparrows—a decision pursued despite widespread scientific warnings—played a significant role in exacerbating famine conditions. More broadly, it underscores how ignoring scientific advice in favor of political expediency can lead to disastrous policy outcomes. Notably, parallels to China's more recent "COVID Zero" strategy have appeared in public discourse under the moniker "Sparrow Zero," underscoring that large-scale interventions enacted without gradual experimentation and adequate scientific scrutiny risk triggering unintended, and potentially catastrophic, consequences.

From an environmental standpoint, our findings underscore the importance of preserving ecosystem stability in the face of ongoing challenges like habitat loss, climate change, and over-exploitation. Although modern governments rarely enact extermination programs on the scale of the Four Pests Campaign, many species remain at risk of local or functional extinction. Our results demonstrate that, given the intricate interdependencies within ecosystems, even localized losses of key species can severely disrupt production functions essential to human well-being. Consequently, striking a balance between societal needs and ecological sustainability requires that policymakers heed scientific insights—ensuring that short-sighted measures do not inadvertently undermine the very ecosystems upon which human survival depends.

> "You call them thieves and pillagers; but know,
> They are the winged wardens of your farms,
> Who from the cornfields drive the insidious foe,
> And from your harvests keep a hundred harms;"
>
> *-Longfellow's Birds of Killingworth*

References

Alesina, Alberto, Marlon Seror, David Y Yang, Yang You, Weihong Zeng, et al. 2020. *Persistence through revolutions.* National Bureau of Economic Research.

Alsan, Marcella. 2015. "The Effect of the TseTse Fly on African Development." *The American Economic Review* 105 (1): 382–410.

Ashton, Basil, Kenneth Hill, Alan Piazza, and Robin Zeitz. 1992. "Famine in china, 1958–61." In *The population of modern China,* 225–271. Springer.

Becker, Jasper. 1998. *Hungry Ghosts: Mao's Secret Famine.* Henry Holt / Company.

Booth, Trevor H, Henry A Nix, John R Busby, and Michael E F Hutchinson. 2014. "BIOCLIM: the first species distribution modelling package, its early applications and relevance to most current MaxEnt studies." Edited by Janet Franklin. *Diversity & Distributions* 20 (1): 1–9.

Butt, Khalid Manzoor, and Sarah Sajid. 2018. "Chinese Economy under Mao Zedong and Deng Xiaoping." *Journal of Political Studies* (Lahore Pakistan; China; Pakistan, Pakistan, Lahore) 25 (1): 169–178.

Cao, Jiarui, Yiqing Xu, and Chuanchuan Zhang. 2022. "Clans and calamity: How social capital saved lives during China's Great Famine." *Journal of Development Economics* 157 (102865).

Cao, Shuji. 2005. "The Population Death and Causes in China between 1959 and 1961." *Chinese Journal of Population Science,* no. 01, 16–30+97.

Cardinale, Bradley J, J Emmett Duffy, Andrew Gonzalez, David U Hooper, Charles Perrings, Patrick Venail, Anita Narwani, et al. 2012. "Biodiversity loss and its impact on humanity." *Nature* 486 (7401): 59–67.

Chen, Hanyi, and Xuebin Wang. 2021. "Sparrow Slaughter and Grain Yield Reduction During the Great Famine of China."

Chen, Shuo, and James Kai-sing Kung. 2011. "The Tragedy of the Nomenclature: Career Incentives and Political Radicalism during China's Great Leap Famine." *American Political Science Review* 105 (1): 27–45.

Chen, Shuo, and Xiaohuan Lan. 2017. "There Will Be Killing: Collectivization and Death of Draft Animals." *American Economic Journal: Applied Economics* 9 (4): 58–77. https://doi.org/10.1257/app.20160247. https://www.aeaweb.org/articles?id=10.1257/app.20160247.

Cheng, Tien-Hsi. 1963. "Insect Control in Mainland China." *Science* 140 (3564): 269–277.

Cooper, Gregory S, Simon Willcock, and John A Dearing. 2020. "Regime shifts occur disproportionately faster in larger ecosystems." *Nature Communications* 11 (1): 1175.

Dasgupta, Partha. 2021. *The Economics of Biodiversity: The Dasgupta Review.* Technical report.

Diamond, Jared. 2005. *Collapse: How Societies Choose to Fail or Succeed.* Penguin.

Dikötter, Frank. 2010. *Mao's Great Famine.* Walker & Company.

Eckstein, Zvi, T Paul Schultz, and Kenneth I Wolpin. 1984. "Short-run fluctuations in fertility and mortality in pre-industrial Sweden." *European Economic Review* 26 (3): 295–317.

Evenden, Matthew D. 1995. "The Laborers of Nature: Economic Ornithology and the Role of Birds as Agents of Biological Pest Control in North American Agriculture, ca. 1880–1930." *Forest and Conservation History* 39 (4): 172–183.

Fischer, G, F Nachtergaele, S Prieler, E Teixeira, G Toth, H Velthuizen, L Verelst, and D Wiberg. 2021. "Global Agro-ecological Zones (GAEZ v4.0)- Model Documentation."

Foley, Jonathan A, Navin Ramankutty, Kate A Brauman, Emily S Cassidy, James S Gerber, Matt Johnston, Nathaniel D Mueller, et al. 2011. "Solutions for a cultivated planet." *Nature* 478 (7369): 337–342.

Frank, Eyal. 2024. "The Economic Impacts of Ecosystem Disruptions: Costs From Substituting Biological Pest Control." *Science* 385:eadg0344.

Frank, Eyal, and Anant Sudarshan. 2024. "The Social Costs of Keystone Species Collapse: Evidence From The Decline of Vultures in India." *American Economic Review* 114 (10): 3007–3040.

Garcia, Karina, Elissa M Olimpi, Daniel S Karp, and David J Gonthier. 2020. "The Good, the Bad, and the Risky: Can Birds Be Incorporated as Biological Control Agents into Integrated Pest Management Programs?" *Journal of Integrated Pest Management* 11 (1).

Harrell, Stevan. 2021. "The Four Horsemen of the Ecopocalypse: the Agricultural Ecology of the Great Leap Forward." *Human Ecology* 49 (1): 7–18.

Heal, Geoffrey. 2000. "Valuing Ecosystem Services." *Ecosystems* 3 (1): 24–30.

Heilmann, Sebastian. 2008. "Policy Experimentation in China's Economic Rise." *Studies in Comparative International Development* 43:1–26. https://doi.org/10.1007/s12116-007-9014-4.

IPBES. 2019. *Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.* Edited by S Dı az, J Settele, E S Brondı zio E. S., H T Ngo, M Guèze, J Agard, A Arneth, et al. IPBES secretariat, Bonn, Germany.

Jenkins, Martin. 2003. "Prospects for biodiversity." *Science* 302 (5648): 1175–1177.

Jia, Ruixue. 2014. "Weather shocks, sweet potatoes and peasant revolts in historical China." *The Economic Journal* 124 (575): 92–118.

Jones, Benjamin A, and Shana M McDermott. 2018. "Health Impacts of Invasive Species Through an Altered Natural Environment: Assessing Air Pollution Sinks as a Causal Pathway." *Environmental & Resource Economics* 71 (1): 22–43.

Kornai, Janos. 1960. “Overcentralization in Economic Administration: A Critical Analysis Based on Experience in Hungarian Light Industry.” *Soviet Studies* 11 (4): 421–424.

Li, Bingjing, and Hiroyuki Kasahara. 2020. “Grain exports and the causes of China’s Great Famine, 1959–1961: County-level evidence.” *Journal of Development Economics* 146 (102513).

Li, Wei, and Dennis Tao Yang. 2005. “The Great Leap Forward: Anatomy of a Central Planning Disaster.” *The Journal of Political Economy* 113 (4): 840–877.

Lin, Justin Yifu. 1990. “Collectivization and China’s agricultural crisis in 1959-1961.” *The Journal of Political Economy* 98 (6): 1228–1252.

Lin, Justin Yifu, and Dennis Tao Yang. 2000. “Food Availability, Entitlements and the Chinese Famine of 1959-61.” *The Economic Journal* 110 (460): 136–158.

MacFarquhar, Roderick, and John K. Fairbank, eds. 1987. *The Great Leap Forward: 1958-1960.* Vol. 14. Cambridge University Press.

Manning, Kimberley Ens, and Felix Wemheuer, eds. 2011. *Eating Bitterness: New Perspectives on China’s Great Leap Forward and Famine.* University of British Columbia Press.

Mao, Sally Wen. 2019. “On Sparrows.” *The Kenyon Review* 41 (5): 77–93.

Marks, Robert B. 2017. *China: An environmental history.* Rowman & Littlefield.

Mendenhall, Chase D, Daniel S Karp, Christoph F J Meyer, Elizabeth A Hadly, and Gretchen C Daily. 2014. “Predicting biodiversity change and averting collapse in agricultural landscapes.” *Nature* 509 (7499): 213–217.

Meng, Xin, Nancy Qian, and Pierre Yared. 2015. “The Institutional Causes of China’s Great Famine, 1959-1961.” *The Review of Economic Studies* 82 (4 (293)): 1568–1611.

Mullié, Wim C. 2009. “Birds, locusts and grasshoppers.” In *Living on the Edge,* 202–223. KNNV Publishing.

Musiani, Marco, and Paul C Paquet. 2004. “The Practices of Wolf Persecution, Protection, and Restoration in Canada and the United States.” *Bioscience* 54 (1): 50–60.

Nobles, Jenna, Elizabeth Frankenberg, and Duncan Thomas. 2015. “The effects of mortality on fertility: population dynamics after a natural disaster.” *Demography* 52 (1): 15–38.

Nordhaus, William D. 2019. “Climate Change: The Ultimate Challenge for Economics.” *American Economic Review* 109 (6): 1991–2014. https://doi.org/10.1257/aer.109.6.1991.

Nove, Alec. 1971. “An Economic History of the U.S.S.R.” *The Journal of Economic History* 31 (2): 514–515. https://doi.org/10.1017/S002205070009135X.

O’Rourke, Kevin. 1994. “The Economic Impact of the Famine in the Short and Long Run.” *The American Economic Review* 84 (2): 309–313.

Ravallion, Martin. 1997. “Famines and Economics.” *Journal of Economic Literature* 35 (3): 1205–1242.

Raynor, Jennifer L, Corbett A Grainger, and Dominic P Parker. 2021. "Wolves make roadways safer, generating large economic returns to predator conservation." *Proceedings of the National Academy of Sciences of the United States of America* 118 (22).

Repasky, Richard R, and Dolph Schluter. 1994. "Habitat Distributions of Wintering Sparrows Along an Elevational Gradient: Tests of the Food, Predation and Microhabitat Structure Hypotheses." *The Journal of Animal Ecology* 63 (3): 569–582.

Sen, Amartya. 1981. *Poverty and Famines: An Essay on Entitlement and Deprivation.* OUP Oxford.

Shapiro, Judith. 1999. "Mao's war against nature: Politics and the environment in revolutionary China." Ph.D. dissertation, American University.

———. 2001. "Mao's war against nature." *(No Title).*

Sharma, Jyoti Trehan, and Harsh Bala Sharma. 2017. "Reflecting on the relationship between human beings and sparrows." *Journal Of Innovation For Inclusive Development* 2 (2): 86–90.

Smil, V. 1999. "China's great famine: 40 years later." *BMJ* 319 (7225): 1619–1621.

Springborn, Michael R, Joakim A Weill, Karen R Lips, Roberto Ibanez, and Aniruddha Ghosh. 2022. "Amphibian Collapses Exacerbated Malaria Outbreaks 3 in Central America." *Environmental Research Letters* 17 (104012): 1–12.

Steinfeld, Jemimah. 2018. "China's deadly science lesson: How an ill-conceived campaign against sparrows contributed to one of the worst famines in history." *Index on Censorship* 47 (3): 49–49.

Strona, Giovanni, and Kevin D Lafferty. 2016. "Environmental change makes robust ecological networks fragile." *Nature Communications* 7:12462.

Taylor, M Scott. 2011. "Buffalo Hunt: International Trade and the Virtual Extinction of the North American Bison." *The American Economic Review* 101 (7): 3162–3195.

Wang, Shaoda, and David Y. Yang. 2023. "Policy Experimentation in China: the Political Economy of Policy Learning." Revise and Resubmit, Journal of Political Economy.

Wangersky, Peter J. 1978. "Lotka-Volterra Population Models." *Annual Review of Ecology and Systematics* 9:189–218.

Weitzman, Martin L. 1998. "The Noah's ark problem." *Econometrica: Journal of the Econometric Society,* 1279–1298.

———. 2009. "On Modeling and Interpreting the Economics of Catastrophic Climate Change." *The Review of Economics and Statistics* 91 (1): 1–19.

World Peace Foundation. 2025. *Historic Famines, 1876-2024.*

Xie, Yinxi, and Yang Xie. 2017. "Machiavellian experimentation." *Journal of Comparative Economics* 45 (4): 685–711.

Yang, Jisheng. 2012. *Tombstone: The Great Chinese Famine, 1958-1962.* Translated by Stacy Mosher and Guo Jian. Farrar, Straus / Giroux.

Yao, Shujie. 1999. "A Note on the Causal Factors of China's Famine in 1959–1961." *The Journal of Political Economy* 107 (6): 1365–1369.

Yu, Hongwei, Jie Zhang, and Yingzhu Liu. 2007. "Research on the Biological Character Comparison of Sparrow and Swallow in Harbin." *Natural Science Journal of Harbin Normal University* 23 (1): 105–108.

Zhao, Sheng, and Zhiliang Su. 2011. "The Four Pest Campaign in New China." *Comtemporary Chinese History Research* 18 (5): 28–35.

Žižek, Slavoj. 2022. "A Materialist Defense Of An Idealist Subjectivity." In *Ideas and idealism in philosophy,* edited by D Gruyter, 173–192. New Studies in the History and Historiography of Philosophy. de Gruyter.