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? In 1958, China embarked on the "Four Pests Campaign" that aimed to quickly eradicate flies, mosquitoes, rats, and sparrows nationwide, despite warnings from scientists that sparrows play important roles in pest control. Historians have long suspected that eradicating sparrows, by letting other pest populations grow out of control, contributed to the Great Famine in China between 1959 and 1961—the largest in human history. This paper combines newly digitized data on historical agricultural productivity in China with habitat suitability modeling methods in ecology to quantitatively test this hypothesis. We document that regions with higher "sparrow suitability" experienced significant drops in agricultural output after the Four Pests Campaign, as compared to their low-suitability counterparts, which could explain a 3.1% additional drop in rice output and a 1.5% additional decline in wheat output. We further document that the food procurement and redistribution system exacerbated the negative agricultural shock in high-sparrow suitability counties. As a consequence, we find that high-sparrow suitability counties experienced an elevated death rate of 10.4 deaths per 1,000 people during the Great Famine relative to the low-suitability counties, even though there were no systematic differences between the two before 1958. These effects are driven by yield reductions for above-ground crops, which are more vulnerable to pest outbreaks, and farmers tried to mitigate pest risks by switching to below-ground crops. When China removed sparrows from the "four pests" list in 1960 and started to reboot the sparrow population, agricultural productivity gradually recovered, while the change in crop choices persisted.

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

-Chinese anti-sparrow poem

1 Introduction

Scientists, politicians, and popular media have argued 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)—agricultural systems in particular as they are strongly connected with their surrounding ecosystems (Foley et al. 2011; Mendenhall et al. 2014). While the potentially catastrophic costs of such tail events have been theoretically established in environmental economics (Weitzman 2009), empirical evidence is scarce beyond various anecdotal speculations and artistic expressions. The rarity of "ecosystem collapses", the difficulty in clearly tracing their triggers, and the lack of granular data, all contribute to this empirical knowledge gap.

In this paper, we study one of the most catastrophic ecosystem collapses in history, the 1958 "Four Pests Campaign" (FPC) in China, which successfully drove sparrows to local extinction within two years. The key contribution this paper makes is to provide evidence for how this local extinction event played a role in causing the Great Famine—as previously hypothesized by environmental historians (Harrell 2021)—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). As part of the FPC, which aimed to improve agricultural productivity and public health, the central government 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 (Chen and Wang 2021).

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 got differentially affected by the FPC, relative to their low-suitability counterparts. We find that, sparrow suitability score was orthogonal to agricultural production and demographic trends prior to the FPC; but after the start of the FPC, the high-suitability counties experienced significant reductions in agricultural output. The high-suitability counties also 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 could account for xx% of the total yield reduction during the Great Famine and was thus responsible for xx million lives lost.

Further analysis reveals that 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 in particular). In contrast, the yield of below-ground crops, such as sweet potatoes, actually increased during the same period—likely reflecting farmers' substitutions across crops to mitigate pest risks induced by the FPC. In addition to crop switching, we also observe another margin of adjustment made by farmers in the form of more pesticide applications following sparrow killings, albeit these results are noisier and more suggestive.

In 1960, three years after the initiation of the FPC, and having killed 1.9 billion sparrows nationwide, the central government realized its mistake and removed sparrows from the list of the four pests, replacing it with bedbugs. Given that sparrows were locally extinct in most parts of the country, to reboot sparrow population, the central government had to import 200,000 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.

Our findings are robust to controlling for a series of other concurrent events and institutional features, such as the procurement quota and price of different crops, the reduction of livestock animals and production of iron and steel during the Great Leap Forward, the

popularization of fertilizers and other agricultural mechanics, as well as the eradication of the other three species on the FPC list. Taken together, our findings echo the conjectures proposed in historical research that the eradication of sparrows was an important contributing factor to the largest famine in human history.

This paper speaks to three strands of literature. First, it adds to a recent and growing body of work in environmental economics studying the role of species in production functions of interest. Recent papers have documented how sudden and unexpected die-offs of trees, bats, amphibians, and vultures can impact human mortality (Frank 2021; Frank and Sudarshan 2023; Jones and McDermott 2018; Springborn et al. 2022). These results complement additional work that uses quasi-experimental methods to quantify the economic benefits of well-functioning ecosystems (Raynor et al. 2021). While the theoretical and policy discussions have particularly stressed the potentially catastrophic costs associated with infra-marginal events such as ecosystem collapses, most of the existing literature has focused on relatively marginal ecological shocks. Our analysis, in addition to quantifying the direct benefits that specific species provide (Solow et al. 1993; Weitzman 1992; 1998), makes new contributions to the literature by providing among the first rigorous evidence on the degree to which large, infra-marginal disruptions to ecosystems can have dire consequences for humans (Cardinale et al. 2012; Jenkins 2003).

Second, our findings shed new light on the determinants of the Great Famine in China. A large body of literature has investigated various political economic determinants of the 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 the Chinese government officially refers to the Great Famine as "Three Years of Natural Disaster" and many historians have suspected that the elimination of sparrows contributed to these disasters and thus the famine, 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 the hypothesis long discussed by historians, that the intentional disruptions of the ecosystem was another substantial contributing factor to the famine. In addition, our findings also support that of (Meng et al. 2015), in showing that the procurement quota failed to adjust according to FPC-induced output losses until 1961, highlighting the rigidity of the procurement system as a driver of the famine.

Third, and more broadly, our findings also add new evidence to the perils of over-centralization and campaign-style policy initiatives, which could distort well-intended policies and cause disastrous policy outcomes (Kornai 1960; Nove 1971; He et al. 2020). 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 infra-marginal shock without sufficient *ex ante* learning through trial and error. Having experienced various such infra-marginal policy failures 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; Zhang and Xie 2017; Wang and Yang 2023).[1]

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 document the economic impacts of sparrow eradication. Section 6 discusses the demographic consequences of sparrow eradication. Section 7 concludes.

[1] That being said, to this day, China's tradition of campaign-style policy initiatives keeps trying to find its way back under strong political centralization. A recent example is the controversial "Zero-COVID" policy, which was indeed compared by many to the Sparrow Eradication Campaign: https://www.nytimes.com/2022/04/13/business/china-covid-zero-shanghai.html?_ga=2.9695221.1169382538.1698090875-1031234641.1698090875.

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 making up a decade-plan to help accelerate agricultural development and collectivization between 1956 and 1967. In the process drafting that plan, Chairman Mao Zedong received feedback from farmers that sparrows consume grains and thus hurt agricultural production. Mao therefore decided to include sparrows, together with flies, mosquitoes, and rats in the list of the "four pests", which should be eliminated nationwide within seven years.[2]

Among the "four 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, etc., and these insects actually constitute more than 80% of their diet. Therefore, when the FPC included sparrows in their list of eradication, there was widespread oppositions 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 sparrows. 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 oppositions, Mao decided to go along with his plan to quickly eradicate sparrows nationwide.

[2] National Agricultural Development Outline from 1956 to 1967 (Draft)

In late 1957, the "Great Leap Forward" was formally kicked off, which also represented the start of the FPC. Between March 1958 and May 1958, Mao repeatedly emphasized the importance of eradicating sparrows in multiple meetings, which got widely covered by national and local media outlets, and encouraged many local governments to set up "special operation teams" for sparrow eradication.[3] In enforcement, the local teams mobilized millions of state employees and citizen volunteers to systematically destroy sparrow nests, broke sparrow eggs, and killed 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.[4]

Within two years, the campaign effectively depleted the sparrow population: it is estimated that 200 million to 2 billion sparrows were killed in 1958 and 1959, pushing the species to near extinction within China. Anecdotally, it has been reported insects became widespread following the eradication of sparrows: in 1959, the rural areas reported a xx% increase in insect outbreaks, and many major cities in China saw their trees turning bald as the leaves got eaten by insects.[5]

By the end of 1959, seeing the widespread surges in insect outbreaks, a large number of prominent scientists have again voiced their strong oppositions to the the sparrow eradication movements. 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

[3] Sparrow is the most notable target among the four pests, which also made it the priority in local eradication efforts.

[4] 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 of entering 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

[5] cite here

the costs and benefits of sparrows, and established a team of scientists investigating this issue. Finally, in March 1960, Mao decided that "we should stop killing sparrows, and we can replace sparrows with bedbugs", which got legalized in April 1960. However, by this point, sparrows were already functionally extinct in China. And in order to re-populate them, China had to import 200,000 sparrows from the USSR in 1960.[6]

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 15 to 55 million.[7] According to estimates of (Cao 2005), during the Great Famine, the most stricken provinces were Anhui (18% dead), Chongqing (15%), Sichuan (13%), Guizhou (11%) and Hunan (8%).

There are two main schools of thoughts 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 productivity decline between 1959 and 1962 (...), and economists have examined various potential explanations to such backlash. (Lin 1990) points out that when the agricultural communes stopped allowing farmers to freely exit in 1958, a free-riding prisoner's dilemma emerged, which paralyzed agricultural production. (Chen and Lan 2017) show that the collectivization of agriculture also led peasants to slaughter household draft animals to keep the meat and hide, which reduced the input for agricultural production in the subsequent years.

In contrast, another more recent line of work has also pointed out that, production-based explanations alone are insufficient in explaining the magnitude of the famine, and one must also combine them with severe distortions in the distribution of agricultural output. 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

[6] Source:
[7] Source:

to the needed rural areas. Specifically, (Li and Yang 2005) suggest that the procurement quota was excessive. (Meng et al. 2015) show that in addition to the excessiveness, the rigidity of the agricultural procurement system played key roles in causing the famine. (Li and Kasahara 2020) find that grain exporting during the famine period also worsened the situation. Evidence has also been documented that political and cultural factors contributed to the distrbutional 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 hypothesis for famine origin has received much attention in qualitative discussions, but is yet to be examined rigorously.

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 switched out sparrows with bed bugs after China decided to buy 200,000 sparrows from the Soviet Union to replenish its sparrow population.

3 Sparrow Suitability, Agricultural Production & 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 eradication shock, measure agricultural production, and summarize total mortality. In the following, 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 Sparrow Suitability Score

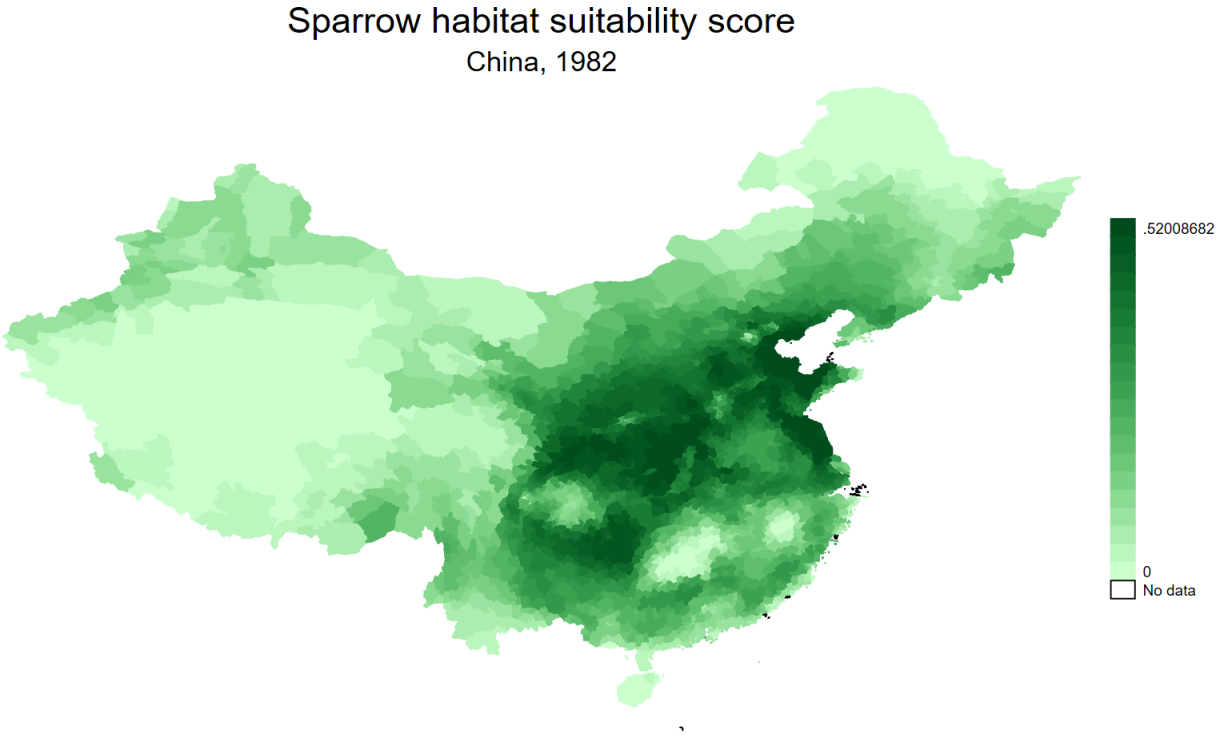
We use a proxy for sparrow population levels during our study period in the form of a habitat suitability score for each county and province. This score combines data on current observations of sparrows with the environmental features in each county to quantify the degree of habitat suitability for sparrows. 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 to using suitability scores in the absence of detailed wildlife population counts is similar to that used by (Alsan 2015) and (Frank and Sudarshan 2023). In the Online Appendix, we provide results from an empirical exercise that validates the agreement between observations of bird species, habitat suitability scores, and scientifically collected counts of those 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 elevation, temperature, and precipitation.[8] 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 area is a suitable niche for the species. In short, observing polar bears in the the Arctic landscapes would result in a high suitability score in Alaska, but not California. Similarly, observing mountain goats in high-elevation regions would result in a high suitability score across the

[8] 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.

Northern Rocky Mountains, but not across the Great Plains. 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. 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).

3.2 Agricultural Production

Our baseline county-level crop data is from China county gazetteers—the historical archives that comprehensively document the history from 1949 to 1990. Our data source comes from two sections for 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 restrict our sample to areas titled "xian" in 1990 to ensure these areas were mainly agricultural counties. Thus, all urban cities are excluded from our analysis, even if these cities provide detailed agricultural output data by crop. Second, we require the county to provide complete annual data from 1957 to 1965 for either rice or wheat, the dominant food crop grown in China. Our data sample consists of 704 rural counties; among them, 356 counties contain rice, mostly in southern China, and 432 counties contain wheat production, mostly in northern China.

The county-level crop output data are an unbalanced panel, and we test whether the distribution of missing values is related to the sparrow suitability. In the Online Appendix Table A1, we report an analysis that examines whether the reporting patterns of rice and wheat are correlated with sparrow suitability. We find no evidence for the timing of reporting or having non-missing values before and after the FPC to be correlated with sparrow suitability. However, at the extensive margin, high-suitability counties are more likely to report wheat output and less likely to report rice output.

We also obtain province-level data from various data 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 statistics with retrospective data revisions rather than data based on raw county-level archives.

3.3 Mortality and Population Data

We obtain demographic data to quantify the linkage between sparrow killing and the subsequent Great Famine. The county-level fertility and mortality rates are from Li and Kasahara 2020 as the dependent variables to evaluate the disaster consequences in the subsequent Great Famine. We complement the county-level data with province-level population data from Meng et al. 2015. Figure XX correlates the average mortality of county-level mortality and the provincial mortality rate. Death rates from these two data sources are strongly correlated at XX%. XX province experienced the largest death rate, and XX province was least affected by the Great Famine.

3.4 Other Supplementary Data

We further collect other actual sparrow-killing data to validate that our sparrow suitability score does capture the ecological shock variations of sparrow eradication. The number of sparrows killed is only found at the province level and reported in the mainstream provincial newspapers, such as the Beijing Daily, which is the official organization of the Beijing Municipal Party Committee. The "Four Pest Campaign" was a significant event in the agricultural sector during the Great Leap Forward period, and most party newspapers provide detailed tracking records of the progress and the number of sparrows killed.

With a sharp decline in sparrows, pesticides can be used as an alternative for pest control and substitute the role of sparrows in agricultural production. We further manually collect the data on the sales volume of chemical pesticides from the provincial-level Cooperative Society publications, agricultural statistical data, and national economic statistical data, such as the *Cooperative Society Publication of Liaoning Province* and the *Agricultural Economic Statistical Data of Zhejiang Province, 1949-1985.* Appendix Figure A1 plots the total quantity of pesticide usage and the grain yield from 1954 to 1965. Pesticide usage first jumped in 1958—one year before the significant drop in grain output. Pesticide usage remained unusually high till 1961 when agricultural productivity started to recover.

We further manually collect the crop price data from the following two sources: *Compilation of National Grain Price Statistics 1950-1980* published by the Ministry of Commerce of the People's Republic of China in 1981, and *Compilation of National Agricultural Product Price Statistics, 1950-1979*, published by Planning Bureau of the Ministry of Agriculture of the People's Republic of China in 1980. These crop prices are used for public procurement—an official price the government dictates to facilitate exchanges among local governments under the planned economy.

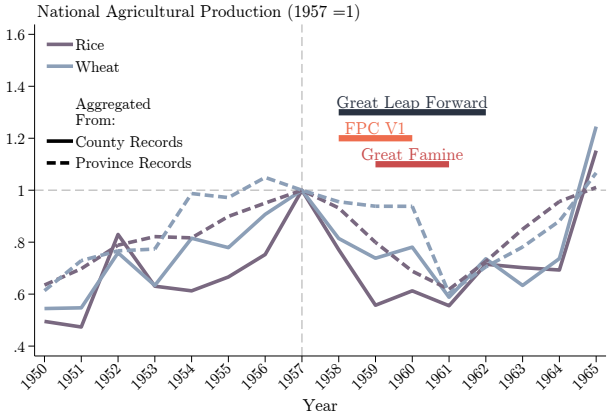
Centrally controlled redistribution of food is consequential in this setting as Meng et al. (2015) argued that procurement rigidity played an important factor in the Great Famine. To examine the relationship between procurement and sparrow suitability, we also obtain the annual county-level crop procurement data, as collected by Li and Kasahara (2020), and compute the share of the crop being procured as a metric for policy rigidity in the planned economy. These data also allow us to examine how government policy reacted to food shortages and subsequent famine.

3.5 Data Description

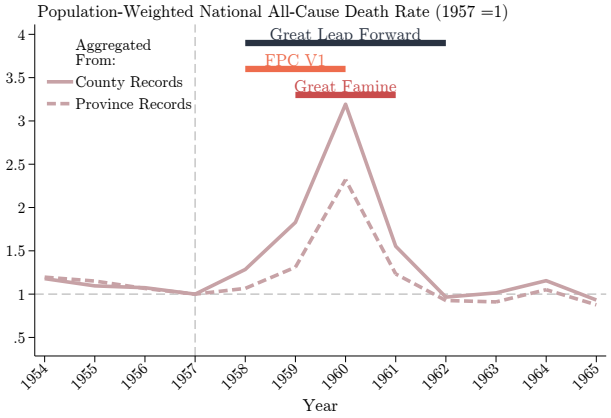
During our sample period of 1954 to 1965, China saw growth in grain production alongside a reduction in the all-cause death rate up until 1958, at which point the trend reversed. In Figure 3, we plot the total production of rice and wheat, aggregated from either the county records or the provincial records, as well as the population-weighted all-cause death rate. We normalize each time series relative to 1957, the year before the launch of the Great Leap Forward 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. 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 1961, mean mortality levels doubled or tripled relative to 1957 levels, according to the provincial or county records, respectively.

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 gazetteers. 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.

We summarize the key variables of sparrow suitability 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 1965 are similar across both groups. 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 eight-fold, from 0.51 to 4.1, during the 1958 to 1961 period, which we can reject the null hypothesis of zero difference at the 1% significance

level. Differences in the production of rice or wheat and procurement maintained the same signs and roughly the same magnitudes in the 1958 to 1961 period as in the 1954 to 1957 period.

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	.0395	.194	.155	492
	(.0264)	(.0772)	(.00496)	
Population[1]	3.93	3.51	-.421	5,685
	(5.33)	(4.56)	(.134)	
Rice Output, 1954-1957[2]	6,550	5,007	-1,543	916
	(12,978)	(5,753)	(671)	
Wheat Output, 1954-1957[2]	758	1,648	890	1,123
	(1,273)	(2,589)	(116)	
Procurement Rate, 1954-1957[2]	.255	.221	-.0342	1,361
	(.122)	(.0983)	(.00625)	
All-Cause Death Rate, 1954-1957[3]	11.7	12.2	.507	1,720
	(4.3)	(4.83)	(.221)	
Rice Output, 1958-1961[2]	5,765	3,895	-1,870	879
	(12,061)	(4,499)	(618)	
Wheat Output, 1958-1961[2]	685	1,348	663	1,058
	(1,123)	(1,740)	(88)	
Procurement Rate, 1958-1961[2]	.327	.298	-.029	1,379
	(.149)	(.126)	(.00764)	
All-Cause Death Rate, 1958-1961[3]	18.1	22.2	4.11	1,695
	(15.4)	(20.7)	(.877)	

Notes: Counties with non-missing rice or wheat data in both pre- and post-1958. Robust standard errors are 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

4.1 Descriptive Evidence on Sparrow Killings & Key Outcomes

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

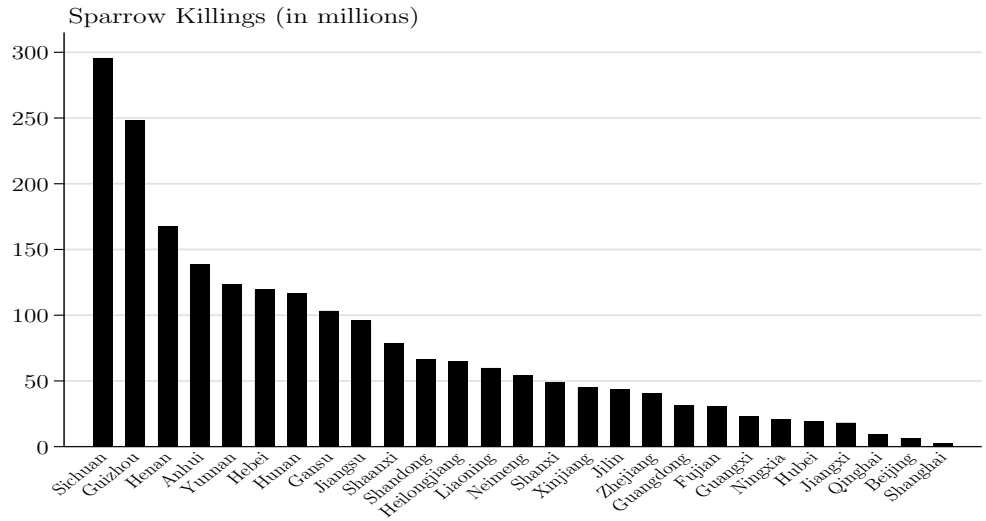
We first document that in addition to the variation in sparrow suitability (Figure 2), provinces also reported different numbers of total sparrows killed (Figure 4a). An important step in evaluating the province-level data, and our own calculations of the sparrow suitability score, is to compare the 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 or 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 to validate that the sparrow suitability metric acts as a 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).[9]

The province-level correlations are helpful in providing suggestive evidence that aligns with the hypothesis put forward by environmental historians: The campaign to eradicate sparrows played an important role in the conditions that led to the Great Famine. We avoid

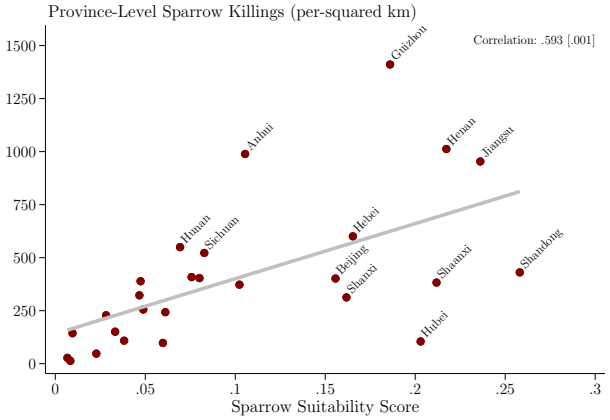
[9] We treat 1958 as a buffer year and omit it from the calculations in Figures 4c-4e.

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

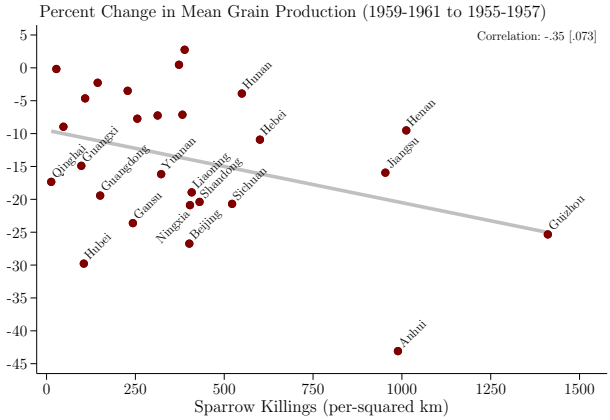
(a) Number of Reported Sparrow Killings by Province



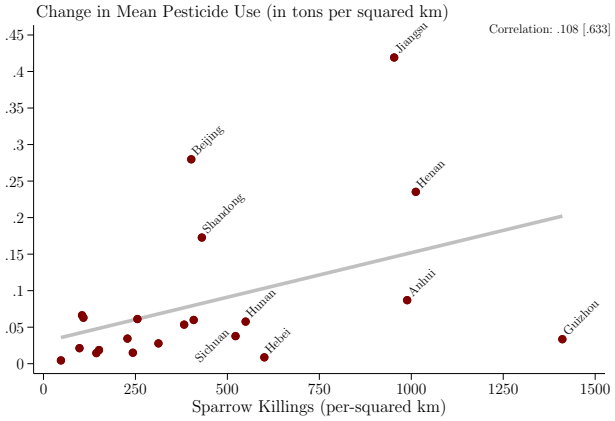
(b) Sparrow Killings VS. Sparrow Suitability



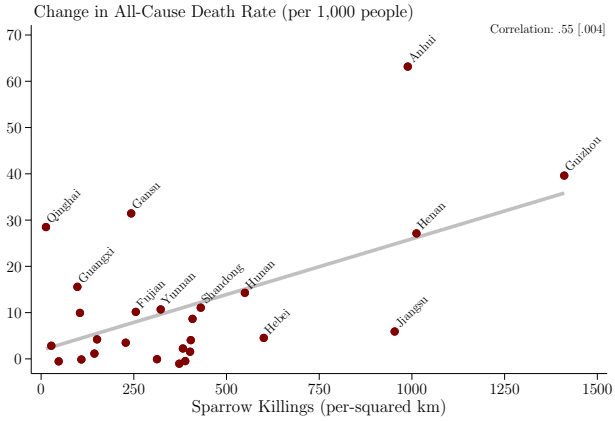
(c) Grain Production VS. Sparrow Killings



(d) Pesticide Use VS. Sparrow Killings



(e) All-Cause Mortality VS. Sparrow Killings



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 (1.4,37.3).

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 the 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 sparrow habitat suitability, then that would confound the relationship between the outcomes of interest and sparrow eradication.

Our approach 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 provinces, between counties with higher and lower sparrow suitability scores. This comparison for the main outcomes, as well as with other outcomes that were targeted by the Great Leap Forward, will better allow us to separately identify the role of sparrow eradication, while disentangling the role of other ongoing policies at the time.

4.2 Econometric Specification

Our main empirical analyses are conducted at the county-year level. We will adopt a shift-share design, exploiting variations 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, which is pre-determined and thus unaffected by political movements.

Specifically, for each county i, we calculate its sparrow suitability index $Suitability_i$, following the procedure discussed in Section 3. We then estimate the following shift-share specification:

$$Y_{ct} = \sum_{\tau \neq 1957} \beta_\tau Suitability_c \cdot \mathbb{1}\{t = \tau\} + \phi_c + \lambda_t + \varepsilon_{ct} \quad (1)$$

Where Y_{ct} is the outcome of interest in county c in year t. We interact the sparrow suitability index, $Suitability_i$—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. In the Appendix, we also report results that adjust the standard errors for both serial correlation and spatial correlation.

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.

In addition to verifying 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 examine the correlations between sparrow suitability index and a rich set of pre-1958 county characteristics (Table X), as well as the impacts of sparrow suitability index on the

enforcement of other national policies during the GLF (Table Y). As we can see, there is little evidence that the sparrow suitability index is systematically correlated with other political economic factors that would generate breaks in trends after 1958. In subsequent regressions, we will also further control for local steel production as a proxy for local "zealousness" in pushing the GLF policies.

5 Economic Impacts

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.

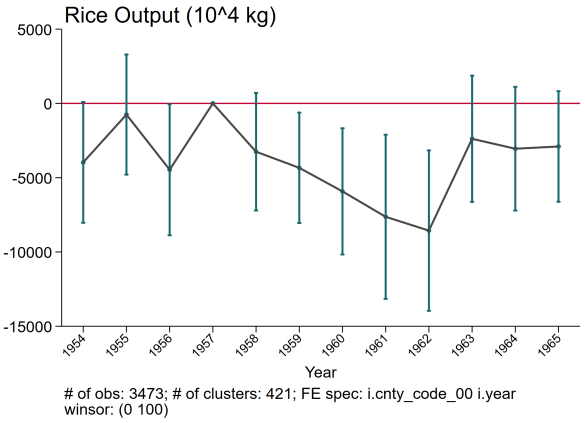
5.1 Grain Output

In Figure 5, we plot the event study coefficients obtained from estimating Equation 1, for the output of two key grain crops: rice and wheat. As can be seen, for both crops, local sparrow suitability scores appeared to be orthogonal to the pre-1958 trends in production, which gives us additional confidence in the validity of our research design. 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, coinciding with the re-population of sparrows after the FPC.

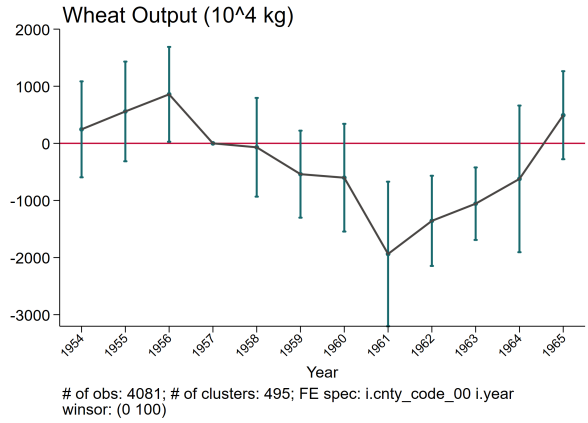
Taken together, these empirical patterns are consistent with our interpretation that, counties more suitable for sparrow habitation got affected more by the eradication of sparrows and became more vulnerable to locust and other pest outbreaks, which negatively affected their agricultural production. By re-populating sparrows after 1961, agricultural production in these affected counties gradually returned back to normal.

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

(a) Rice Production



(b) Wheat Production



Notes: Coefficients and 95% CIs for the estimation specification in Equation (1). 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.

Table 2 quantifies the patterns observed in Figure 5. In Panel A Column 1, we see that counties with higher sparrow suitability scores experienced a large and significant drop in rice output during the FPC, compared to periods before and after. Quantitatively, a 1 S.D. increase in sparrow suitability score is associated with an 18416.7 ton drop[10] in rice production during the FPC. In Column 2, we control for the dynamic impacts of baseline population (i.e., average population between 1954 and 1957 interacted with year FE); in Column 3, we restrict the comparison to be within each region-year cluster; in Column 4, we further control for local steel production, which is a proxy for local "political zealousness" during the GLF. As can be seen, our findings are robust across these different specifications.

Panel B replicates the findings on rice output with wheat, and the results are qualitatively consistent across all specifications. Our estimates indicate that, during the period of sparrow eradication, a 1 S.D. increase in sparrow suitability score is associated with a 3168.6 ton reduction in wheat output.

As a placebo test, in Appendix Table AX, we run the same regressions using the suitability

[10] 1 S.D. increase in suitability*$(\beta_{1959} + \beta_{1960} + \beta_{1961})$

scores for other species, including those on the FPC list, and those not. None of the other scores show similar empirical patterns when they are used to regress against agricultural output.

Table 2: Effects on Rice and Wheat Output

(a) Effects on Rice Output

	(1) Rice b/se	(2) Rice b/se	(3) Rice b/se	(4) Rice b/se	(5) Rice b/se
sparrow_1954	-3969.4	-2054.4	-5210.9*	-6659.5	-3423.1
	(2466.197)	(2137.260)	(2832.814)	(5161.172)	(4810.885)
sparrow_1955	-751.0	171.9	-709.1	3296.0	1712.5
	(2452.443)	(2381.847)	(2735.318)	(4469.897)	(4108.223)
sparrow_1956	-4461.4*	-2929.9	-5283.9	-5314.2	-3689.1
	(2677.663)	(2500.059)	(3252.442)	(4560.244)	(3145.453)
sparrow_1958	-3252.8	-190.8	-3554.7	-1403.5	-492.2
	(2401.615)	(1988.449)	(2745.829)	(3719.448)	(3396.845)
sparrow_1959	-4336.0*	-2985.9	-3108.6	-4927.0	-3269.2
	(2254.698)	(1945.216)	(2581.871)	(3159.317)	(2274.594)
sparrow_1960	-5923.1**	-4634.9**	-4298.3	-7648.6**	-6332.5***
	(2576.801)	(1855.483)	(2996.967)	(3193.023)	(2267.326)
sparrow_1961	-7632.6**	-5861.2**	-6329.7*	-8592.5**	-7010.9**
	(3351.421)	(2832.360)	(3800.207)	(4138.508)	(3017.843)
sparrow_1962	-8562.7***	-6271.3**	-8333.6**	-8971.9*	-8002.9**
	(3275.335)	(2862.843)	(3846.106)	(4707.055)	(3950.749)
sparrow_1963	-2382.7	-1665.1	-879.3	-4322.1	-2830.8
	(2576.809)	(2577.591)	(2933.111)	(3909.848)	(3341.569)
sparrow_1964	-3049.2	-3141.7	-2243.1	-5591.1	-4255.3
	(2526.646)	(2564.218)	(2872.615)	(3915.435)	(3256.973)
sparrow_1965	-2899.9	-4855.9***	-2175.7	-6660.8**	-4730.8**
	(2257.405)	(1664.914)	(2038.308)	(2602.353)	(2181.598)
Time Window	1954-1965	1954-1965	1954-1965	1954-1965	1954-1965
Pop#Year	N	Y	N	Y	Y
Steel	N	N	N	Y	Y
Crop Suit	N	N	N	N	Y
Year FE	Y	Y	N	Y	Y
County FE	Y	Y	Y	Y	Y
Region#Year FE	N	N	Y	N	N
R-squared	0.890	0.899	0.895	0.884	0.889
Obs.	3473	2712	3473	1720	1720

(b) Effects on Wheat Output

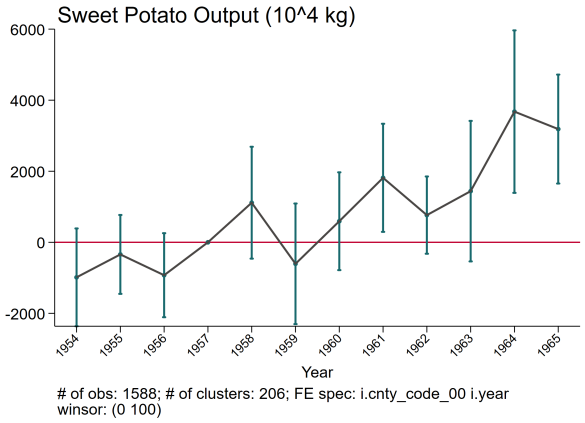
	(1) Wheat b/se	(2) Wheat b/se	(3) Wheat b/se	(4) Wheat b/se	(5) Wheat b/se
sparrow_1954	245.3	274.9	462.4	7.905	58.00
	(509.738)	(386.197)	(587.297)	(562.314)	(553.000)
sparrow_1955	558.7	226.3	367.0	-14.57	-129.3
	(529.603)	(410.356)	(497.806)	(607.998)	(608.129)
sparrow_1956	858.3*	859.4	492.4	549.2	769.2
	(503.749)	(583.940)	(469.434)	(820.255)	(741.056)
sparrow_1958	-69.08	130.8	-328.2	-194.7	-428.4
	(524.452)	(578.975)	(460.877)	(900.061)	(859.303)
sparrow_1959	-539.8	-579.2	-525.3	-695.2	-654.0
	(462.265)	(388.032)	(431.205)	(523.162)	(527.321)
sparrow_1960	-601.5	-565.3	-417.6	-694.2	-706.1
	(572.177)	(522.023)	(573.087)	(560.766)	(557.949)
sparrow_1961	-1937.0**	-1325.5*	-1648.4**	-1354.2	-1471.1*
	(767.942)	(705.813)	(772.793)	(859.750)	(859.174)
sparrow_1962	-1357.0***	-1270.8***	-1372.5***	-1328.1**	-1304.4**
	(479.208)	(470.447)	(478.775)	(550.189)	(551.284)
sparrow_1963	-1056.7***	-1052.2***	-950.9***	-1132.2**	-1153.4**
	(385.289)	(393.521)	(337.007)	(527.375)	(519.434)
sparrow_1964	-622.3	-384.3	-543.9	-455.9	-618.4
	(779.091)	(869.052)	(882.475)	(1061.473)	(1054.696)
sparrow_1965	492.6	233.7	555.0	-9.943	31.06
	(467.606)	(451.015)	(461.992)	(609.618)	(596.326)
Time Window	1954-1965	1954-1965	1954-1965	1954-1965	1954-1965
Pop#Year	N	Y	N	Y	Y
Steel	N	N	N	Y	Y
Crop Suit	N	N	N	N	Y
Year FE	Y	Y	N	Y	Y
County FE	Y	Y	Y	Y	Y
Region#Year FE	N	N	Y	N	N
R-squared	0.901	0.878	0.905	0.853	0.855
Obs.	4081	3290	4081	2248	2248

5.2 Farmers' Adjustments

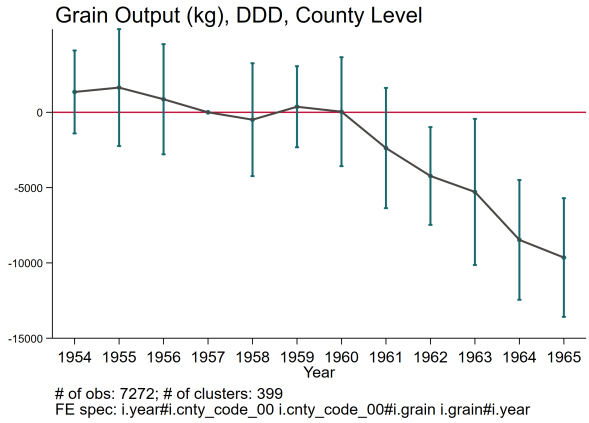
In Figure 6 Panel A, we repeat the same analyses for sweet potatoes, and find *opposite* effects to rice and wheat throughout all specifications: the event study coefficients demonstrate a re-assuring flat pre-trend, and then a large and persistent *increase* in crop output after 1958. This indicates that, counties more suitable for sparrow habitation experienced significant spikes in the production of sweet potatoes during the FPC, and the results still remain salient in the post-1961 period.

Figure 6: Effects on Sweet Potato Output at County Level

(a) Sweet Potato Production



(b) Grain Output, DDD



Notes:

Such empirical patterns are consistent with the biological features of these different crops. Because sweet potatoes grow below the ground, compared to above-ground crops like rice and wheat, they are less vulnerable to pest outbreaks, in particular locust outbreaks that were the main threat to agricultural production throughout Chinese history. As a result, in the absence of the pest control functions historically provided by sparrows, rice/wheat farmers would become more willing to switch to growing sweet potatoes to hedge themselves against future pest outbreaks. Such switch in crop choice appears persistent even after the re-population of sparrows, which can be potentially rationalized by either a fixed cost of crop switching or shock-induced learning (about the benefits of growing sweet potatoes).

Figure 6 Panel B presents a "triple difference" analysis, benchmarking the growth in sweet potatoes against the decline in rice and wheat, 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.

Table 3 quantifies the graphical patterns documented in Figure 6a, following the same

specifications used in Table 2. Our estimates indicate that, a 1 S.D. increase in sparrow suitability score explains an 1855.1 ton increase in sweet potato production, in both the short run and the long run. The fact that high-suitability counties keep producing more sweet potatoes in the long run, combined with the fact that rice/wheat production in these counties return to normal in the long run, suggests that the passive adoption of sweet potatoes during a time of crisis might have long-run benefits to these counties, who suffered the most in the short run due to sparrow eradication.

5.3 Government Responses

As documented by (Meng et al. 2015), during the GLF, in addition to declines in agricultural output, 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 regions more affected by the FPC, which helps shed light on whether/how the FPC would play a role in the formation of the Great Famine.

As shown in Figure 7, the total amount of crop procurement was indeed rigid, and barely responded to the negative production shocks in the high-suitability counties until after 1961. As a result, the effective procurement rate (procurement divided by output) actually went up for the high-suitability counties during the FPC, which echoes the patterns found by (2015). After 1960, both the procurement amount and the effective procurement rate started to catch up with the lost production 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 (...).

Taking stock, our results indicate that the eradication of sparrows hurt crop yields in counties with high sparrow suitability scores between 1959 and 1962, while the procurement of crops in these areas did not adjust accordingly until 1961. As a result, 1961 was likely a particularly difficult year for the high-suitability counties – yield had been falling signifi-

cantly, while procurement remained high. We examine this hypothesis explicitly in Section 6.

5.4 Robustness

We examine the robustness of our baseline findings in several ways.

One potential concern is the representativeness of our baseline county sample. Since official statistics were widely known to be severely exaggerated in that period (...), we rely on decentralized information independently documented in the county gazetteers, which has been shown to be more accurate (...). However, the county gazetteers were only available intermittently in xx counties (xx%), 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 alleviates concerns that the county-level results are driven by it incomplete coverage.[11]

Second, in addition to aggregating the analysis to the provincial level, we also repeat the county-level analysis with only a balanced panel.[12] As shown in Appendix Table A3, compared to estimates using the unbalanced panel, restricting the sample to be balanced between 1955 and 1962 has no substantial influence on the baseline empirical patterns. This is reassuring that our findings are indeed driven by the treatment effect of sparrow eradication, instead of endogenous entry and exit of counties in our baseline sample.

One might also worry about potential outliers in the historical data, especially given

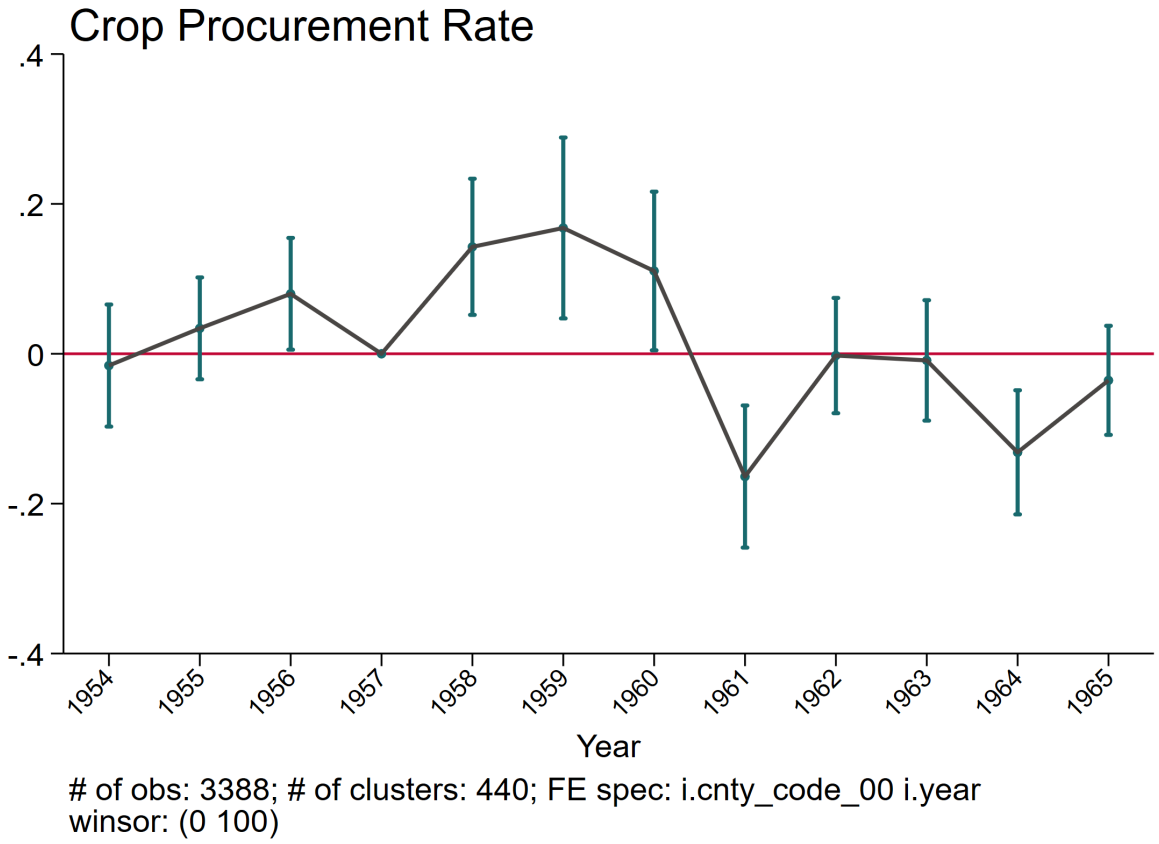
[11] While it is certainly possible that the provincial official statistics may have been manipulated, it is wort noting that such politically motivated mis-reporting would likely be systematically inflated for both crop yields and sparrow killings, thereby generating a spurious positive correlation between the two, rather the negative relationship observed in our data.

[12] 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.

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 Appendix Table A4, we re-run the baseline regressions using winsorized samples at [1%,99%], [2.5%,97.5%], and [5%,95%], respectively. As can be seen, the baseline empirical patterns are highly robust to these different samples, indicating that the main results are not driven by outliers.

We also investigate whether our findings are sensitive to the definition of the key explanatory variable — the sparrow suitability index. As reported in Appendix Table A5, if instead of using a continuous measure of sparrow suitability, we use a binary measure of whether a county's suitability score is above the national median, all the main findings remain.

Figure 7: Effects on Procurement Rate at County Level



Notes:

Table 3: Effects on Sweet Potato Output

	(1)	(2)	(3)	(4)	(5)
	Sweet Potato	Sweet Potato	Sweet Potato	Sweet Potato	Sweet Potato
	b/se	b/se	b/se	b/se	b/se
sparrow_1954	-986.4	-273.9	-823.9	-1627.1	-1219.8
	(832.827)	(515.602)	(913.628)	(1515.202)	(1380.121)
sparrow_1955	-341.3	284.3	-360.0	-401.2	-174.0
	(671.859)	(561.165)	(701.991)	(1005.301)	(947.943)
sparrow_1956	-926.4	25.18	-768.1	-189.2	83.46
	(715.751)	(563.440)	(815.261)	(1281.217)	(1266.934)
sparrow_1958	1114.2	1124.9*	965.2	255.7	220.8
	(953.031)	(641.331)	(1120.524)	(850.071)	(802.345)
sparrow_1959	-605.6	-1115.0*	-520.7	-276.4	-296.1
	(1027.008)	(664.401)	(1168.717)	(584.082)	(583.231)
sparrow_1960	592.9	-935.9	921.5	-1443.4	-1458.4*
	(832.921)	(866.526)	(923.591)	(977.197)	(845.289)
sparrow_1961	1814.9*	381.0	2277.3**	66.12	-258.9
	(920.860)	(816.655)	(1068.560)	(858.238)	(776.104)
sparrow_1962	765.2	145.2	756.2	333.6	-114.3
	(658.060)	(488.534)	(689.333)	(666.944)	(618.506)
sparrow_1963	1439.2	-88.34	1468.2	194.9	143.7
	(1196.726)	(564.330)	(1388.785)	(728.050)	(680.279)
sparrow_1964	3678.0***	1761.1***	3911.0***	1962.1**	1599.4**
	(1383.935)	(629.866)	(1476.414)	(796.323)	(797.095)
sparrow_1965	3186.9***	2220.3***	3279.9***	2390.1***	1614.0**
	(927.829)	(511.949)	(1072.363)	(764.204)	(732.808)
Time Window	1954-1965	1954-1965	1954-1965	1954-1965	1954-1965
Pop#Year	N	Y	N	Y	Y
Steel	N	N	N	Y	Y
Crop Suit	N	N	N	N	Y
Year FE	Y	Y	N	Y	Y
County FE	Y	Y	Y	Y	Y
Region#Year FE	N	N	Y	N	N
R-squared	0.856	0.877	0.865	0.864	0.867
Obs.	1588	1219	1571	690	690

6 Demographic Impacts

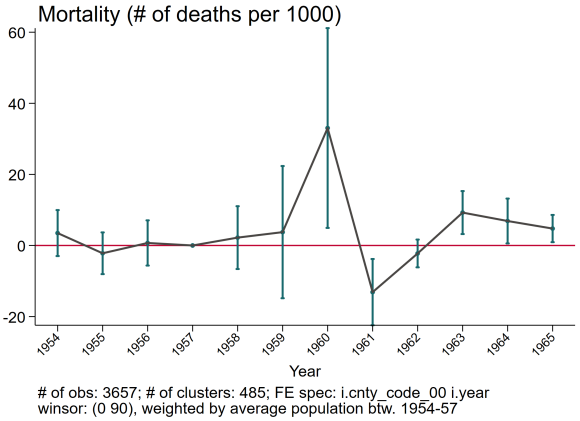
In this section, we investigate the demographic impacts of the eradication of sparrows, and conduct a back of the envelope calculation to evaluate the aggregate contribution of the FPC to the Great Famine. All the demographic analyses are weighted by the pre-1957 population of each county.

6.1 Mortality and Fertility Rates

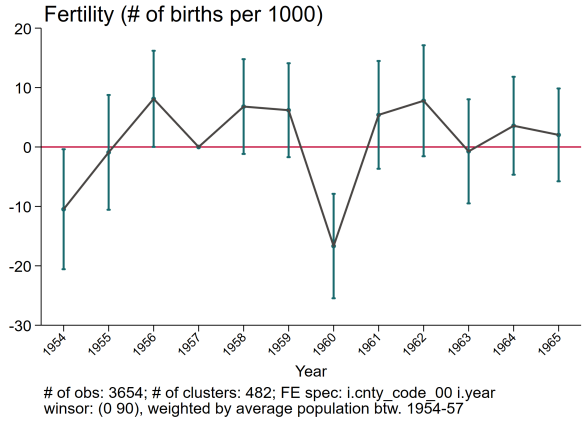
Figure 8 plots the event study coefficients on how sparrow eradication affected mortality and fertility rates. In Panel A, we show that sparrow suitability score was uncorrelated with the trend in mortality rate until 1960, but in 1961, high-suitability counties saw a large and significant spike in death rate, which returned back to normal again in the subsequent years. 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.

Figure 8: Effects on Population at County Level

(a) Mortality



(b) Fertility



Notes:

In Panel B, 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 (...). As expected, the pattern appears to be

the mirror image of that in Panel A: birth rate is strongly negatively correlated with sparrow suitability score in 1961, but not in the years before or after.

Table 4 quantifies these graphical patterns. Our estimates indicate that, a 1 S.D. increase in sparrow suitability score was associated with an extra 0.34% increase mortality rate, and an additional 0.17%% reduction in fertility rate, in 1960. Like what we did in Section 5.4, we investigate the robustness of these findings with respect to keeping a balanced panel, removing outliers, and using a binary definition of sparrow suitability. As shown in Appendix Tables A6 to A8, the demographic results, like the agricultural results, are insensitive to these alternative specifications.

Table 4: Effects on Population

(a) Effects on Mortality

	(1) Mortality b/se	(2) Mortality b/se	(3) Mortality b/se	(4) Mortality b/se
sparrow_1954	3.491	4.698	-0.340	4.167
	(3.925)	(3.794)	(4.237)	(4.687)
sparrow_1955	-2.193	-0.736	0.0795	-3.669
	(3.559)	(4.067)	(4.937)	(5.245)
sparrow_1956	0.709	2.600	-3.013	-0.834
	(3.858)	(3.970)	(5.068)	(4.943)
sparrow_1958	2.212	4.097	-2.171	3.574
	(5.361)	(5.591)	(5.616)	(7.038)
sparrow_1959	3.752	5.142	4.802	6.061
	(11.286)	(12.041)	(10.713)	(4.870)
sparrow_1960	33.05*	37.09**	33.56	53.40***
	(17.053)	(18.357)	(22.639)	(20.107)
sparrow_1961	-13.12**	-12.13**	-15.84**	-4.470
	(5.653)	(5.727)	(6.140)	(6.379)
sparrow_1962	-2.245	-2.430	-3.013	-4.593
	(2.369)	(2.333)	(2.559)	(3.096)
sparrow_1963	9.257**	10.16**	9.680*	4.309
	(3.670)	(4.098)	(5.141)	(5.885)
sparrow_1964	6.887*	7.144*	9.607*	-1.299
	(3.828)	(4.216)	(5.496)	(5.644)
sparrow_1965	4.758**	3.957*	4.504*	-0.0403
	(2.325)	(2.251)	(2.361)	(3.339)
Time Window	1954-1965	1954-1965	1954-1965	1954-1965
Pop#Year	No	Yes	No	Yes
Steel	No	No	No	Yes
Year FE	Yes	Yes	No	Yes
County FE	Yes	Yes	Yes	Yes
Region#Year FE	No	No	Yes	No
R-squared	0.462	0.463	0.608	0.461
Obs.	3657	3657	3657	2505

(b) Effects on Fertility

	(1) Fertility b/se	(2) Fertility b/se	(3) Fertility b/se	(4) Fertility b/se
sparrow_1954	-10.48*	-11.34*	5.765	-22.08***
	(6.125)	(6.178)	(6.647)	(7.928)
sparrow_1955	-0.909	-3.381	8.805	-4.049
	(5.859)	(5.930)	(5.625)	(8.142)
sparrow_1956	8.103*	8.453*	9.467*	2.923
	(4.907)	(4.787)	(5.734)	(5.962)
sparrow_1958	6.800	5.987	10.04	6.712
	(4.837)	(4.859)	(6.098)	(6.797)
sparrow_1959	6.188	5.334	5.889	11.24*
	(4.796)	(4.723)	(5.434)	(6.168)
sparrow_1960	-16.68***	-19.29***	-11.49**	-20.48***
	(5.333)	(5.326)	(4.723)	(5.665)
sparrow_1961	5.401	4.192	9.478*	3.871
	(5.503)	(5.473)	(5.373)	(6.299)
sparrow_1962	7.777	6.769	8.710	3.959
	(5.667)	(5.523)	(7.434)	(6.442)
sparrow_1963	-0.737	-1.786	4.168	8.609
	(5.315)	(5.166)	(5.521)	(5.688)
sparrow_1964	3.571	1.831	9.686**	9.256*
	(5.000)	(5.109)	(4.728)	(4.845)
sparrow_1965	2.032	1.750	3.942	3.150
	(4.740)	(4.917)	(4.167)	(5.597)
Time Window	1954-1965	1954-1965	1954-1965	1954-1965
Pop#Year	No	Yes	No	Yes
Steel	No	No	No	Yes
Year FE	Yes	Yes	No	Yes
County FE	Yes	Yes	Yes	Yes
Region#Year FE	No	No	Yes	No
R-squared	0.684	0.685	0.764	0.705
Obs.	3654	3654	3654	2506

It is worth noting that, while sparrow eradication caused the largest reductions in crop yields in 1961, the main demographic consequences only existed in 1960, which again echoes (2015) by highlighting the central role of procurement rules in causing the famine. To put it in another way, it is unlikely that the eradication of sparrows alone would have caused the documented demographic changes, had there not been a lack of flexibility in the procurement rules prior to 1960.

6.2 Back of the Envelope Calculation

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, 46,595,385 (8,016,822) tons of lost rice (wheat) can be attributed to the eradication of sparrows,[13] which is 17.63% of the baseline national crop yield, and accounts for 39.7% of the lost output during the Great Famine. According to our demographic estimates, sparrow eradication led to the loss of 1,890,124 lives, and reduced fertility counts by 397,450.[14] This is equivalent to 0.297% of the total national population, and 6.27% of the total death count during the Great Famine.

7 Conclusions

We document a large reduction in grain production and a spike in all-cause mortality, in the years leading to and during the events of the Great Famine, in Chinese counties with high sparrow suitability following the successful campaign to eradicate them from 1958 to 1960. We provide important empirical validation to a long-standing, yet understudied, environ-

[13] lost crop caused by sparrow killing = sum of suitability scores of all the counties $*(\beta_{1959}+\beta_{1960}+\beta_{1961})$. total lost crop = sum of estimated crop output btw. 1959 and 1961 - actual crop output btw. 1959 and 1961. Coefficient times score, then sums up across all counties

[14] loss of lives = $\sum_{provinces} suitability_p * (pop_{1959} * \beta_{1959} + pop_{1960} * \beta_{1960} + pop_{1961} * \beta_{1961})$. Coefficient times score, then sums up across all counties

mental history hypothesis regarding the conditions that played a role in causing the Great Famine in China. These results demonstrate that while ecosystem collapses are rare, their consequences can be catastrophic when they do occur. In recent years, countries have largely avoided driving species towards local extinction, yet due to habitat loss, climate change, and over-exploitation, many species are becoming either functionally or locally extinct. As our findings demonstrate, losses of species that play important roles in production functions that affect human well-being can have dire consequences.

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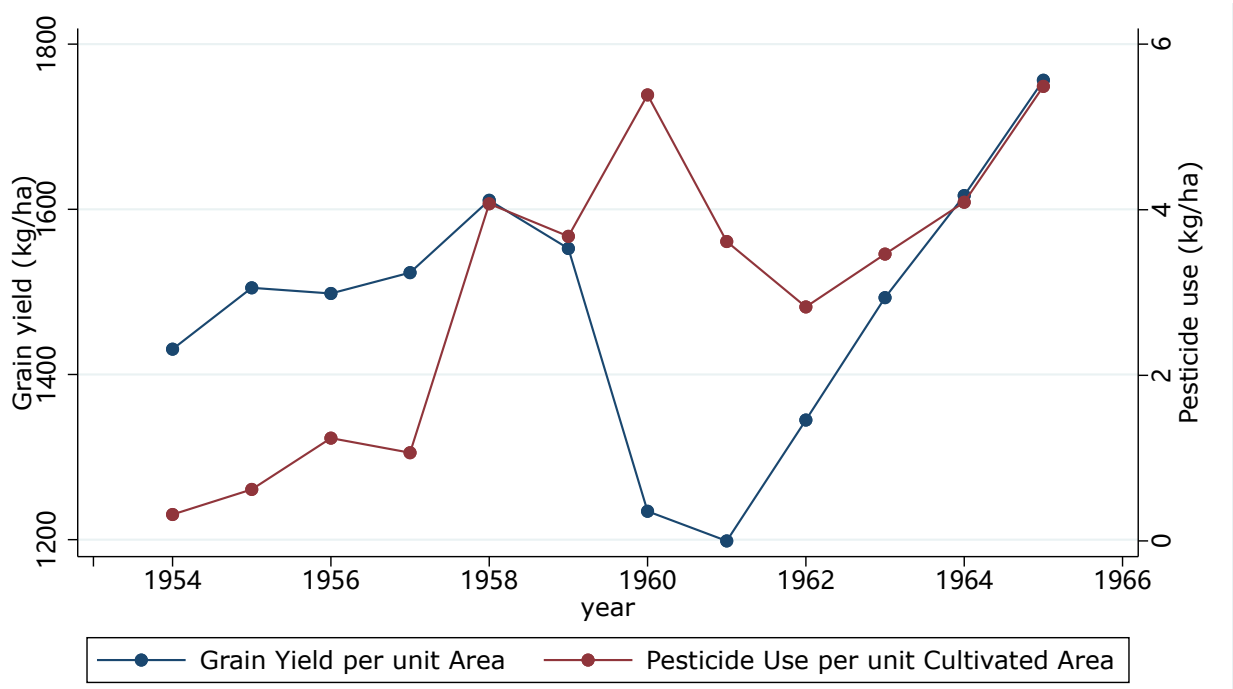
Appendix

A Additional Results

A.1 Examining Data Reporting & Correlation With Sparrow Suitability

As we mention in the data section of the main text, after we drop large counties from the data, we have 492 out of the 704 counties (70%) that report at least rice or wheat in both 1954 to 1957 and 1958 to 1965. However, most counties fail to report rice or wheat data every year. Here, we examine whether the missing data patterns are correlated with the sparrow suitability score. We reports results for linear probability models where the outcomes are either: (i) non-missing value in year t for rice or wheat, (ii) ever reporting rice or wheat, or (iii) having data for either rice or wheat in both pre- and post-FPC periods. In Table A1, we report results using both the continuous sparrow suitability score and the above-median suitability dummy variable. We find that the timing of missing data is not correlated with sparrow suitability; however, high sparrow suitability counties are less likely to report rice output and are more likely to report wheat output. Finally, we fail to detect any correlation between having non-missing rice or wheat data in both pre- post-FPC periods and sparrow suitability.

Figure A1: National Trends in Agricultural Production & Pesticide Use



(a) National Trend: Grain Yield and Pesticide Use

Notes: *This figure should show aggregate production levels of different crops that are affected by pests that sparrows eat (solid lines) and those that they don't eat (dashed lines), with a different color for each crop. In addition, one line for total population. Also, one line for total pesticide use. Every line should be indexed relative to the base year of the data. We should shade the years of 1958-1960 and 1959-1961 as the four pest campaign years and the great famine years.*

Table A1: Summarizing Rice & Wheat Data Reporting Patterns

Non-Missing	At t				Ever				Pre/Post	
	Rice		Wheat		Rice		Wheat		Rice or Wheat	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Suitability	-0.006		0.109		-0.761		0.529		-0.060	
	(0.211)		(0.181)		(0.186)		(0.186)		(0.178)	
Suitability (H)		0.003		0.015		-0.126		0.098		-0.007
		(0.039)		(0.036)		(0.038)		(0.037)		(0.035)
$\overline{Y}$	0.65	0.65	0.66	0.66	0.51	0.51	0.61	0.61	0.70	0.70
R^2	0.05	0.05	0.04	0.04	0.02	0.02	0.01	0.01	0.00	0.00
N	4,272	4,272	5,184	5,184	704	704	704	704	704	704
Clusters	356	356	432	432	704	704	704	704	704	704

Notes: Estimation results for linear probability models as a function of sparrow suitability (continuous score of above-median score). In columns 1 to 4 the oucome is whether the crop (rice or wheat) is not missing in a specific year. In columns 5 to 8 the outcome is whether the county ever has a non-missing value. In columns 9 and 10 the outcome is whether the county has non-missiong data for rice *or* wheat in the pre- *and* post-FPC periods (during 1954-1957 and 1958-1965).

Table A2: Other Species

Table A3: Effects on Agriculture with Balanced Sample

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Rice	Rice	Wheat	Wheat	Sweet Potato	Sweet Potato	Proc Rate	Proc Rate
	b/se	b/se	b/se	b/se	b/se	b/se	b/se	b/se
sparrow_1955	-514.6	1668.6	528.0	811.7	-107.3	-557.9	0.0303	-0.0524
	(2444.685)	(2104.802)	(553.139)	(540.368)	(663.824)	(560.982)	(0.043)	(0.043)
sparrow_1956	-4009.0	-1006.7	982.8*	1094.0***	-878.3	-1362.6**	0.0817*	0.0111
	(2688.397)	(1029.186)	(522.017)	(403.394)	(705.871)	(547.569)	(0.047)	(0.040)
sparrow_1958	-3043.6	-810.1	-60.59	434.8	1233.1	1145.1	0.141**	0.111*
	(2370.252)	(2068.101)	(537.883)	(524.797)	(1010.059)	(1083.544)	(0.055)	(0.060)
sparrow_1959	-4105.7*	-2779.8	-553.9	-369.5	-434.5	-349.2	0.157**	0.107
	(2240.305)	(1894.400)	(475.805)	(452.318)	(1054.670)	(1194.432)	(0.073)	(0.080)
sparrow_1960	-5695.6**	-5478.1**	-614.2	-533.4	810.7	1471.0	0.103	0.0374
	(2568.231)	(2635.325)	(580.395)	(593.139)	(825.141)	(996.955)	(0.065)	(0.074)
sparrow_1961	-7463.7**	-6218.6**	-2007.8***	-1912.4**	1909.5**	2086.9	-0.168***	-0.219***
	(3305.288)	(3059.782)	(759.879)	(865.792)	(953.476)	(1284.458)	(0.059)	(0.062)
sparrow_1962	-7732.0**	-5609.4**	-1237.9***	-981.5**	843.0	1205.8	-0.00258	-0.0654
	(3205.015)	(2355.911)	(474.146)	(495.825)	(693.174)	(875.427)	(0.048)	(0.055)
Time Window	1955-1962	1955-1962	1955-1962	1955-1962	1955-1962	1955-1962	1955-1962	1955-1962
Balanced	No	Yes	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.882	0.951	0.906	0.904	0.877	0.892	0.762	0.733
Obs.	2324	1832	2713	2128	1051	816	2248	1608

Table A4: Effects on Agriculture with Winsored Sample

(a) Effects on Rice Output, Winsored

	(1) Rice b/se	(2) Rice b/se	(3) Rice b/se	(4) Rice b/se
sparrow_1954	-3969.4	-3156.8*	-2973.1*	-1434.4
	(2466.197)	(1832.766)	(1634.746)	(1006.222)
sparrow_1955	-751.0	10.26	-2187.8	-284.2
	(2452.443)	(1885.990)	(1356.440)	(973.702)
sparrow_1956	-4461.4*	-2232.7**	-1602.5*	-86.75
	(2677.663)	(952.211)	(873.794)	(762.825)
sparrow_1958	-3252.8	-1979.7	-2845.2*	-942.3
	(2401.615)	(1762.095)	(1567.592)	(811.019)
sparrow_1959	-4336.0*	-3257.6**	-3551.6**	-1659.4
	(2254.698)	(1600.706)	(1437.822)	(1019.747)
sparrow_1960	-5923.1**	-5950.9***	-6093.0***	-4039.3***
	(2576.801)	(2143.899)	(1928.240)	(1304.345)
sparrow_1961	-7632.6**	-6252.1**	-6685.3***	-3977.2**
	(3351.421)	(2589.786)	(2422.185)	(1681.512)
sparrow_1962	-8562.7***	-6360.8***	-6243.0***	-3243.9***
	(3275.335)	(1919.716)	(1766.342)	(1154.461)
sparrow_1963	-2382.7	-1118.4	-2102.0	-227.9
	(2576.809)	(1723.744)	(1428.099)	(1118.491)
sparrow_1964	-3049.2	-561.0	-3377.8**	-1496.1
	(2526.646)	(1421.111)	(1434.950)	(924.855)
sparrow_1965	-2899.9	-1782.5	-5052.2***	-3094.1***
	(2257.405)	(1959.200)	(1409.815)	(868.544)
Winsor	0-100	1-99	2.5-97.5	5-95
Time Window	1954-1965	1954-1965	1954-1965	1954-1965
Year FE	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes
R-squared	0.890	0.900	0.889	0.898
Obs.	3473	3403	3297	3118

(b) Effects on Wheat Output, Winsored

	(1) Wheat b/se	(2) Wheat b/se	(3) Wheat b/se	(4) Wheat b/se
sparrow_1954	245.3	570.7	442.0	379.7
	(509.738)	(507.075)	(346.942)	(332.654)
sparrow_1955	558.7	584.9*	625.2**	363.2
	(529.603)	(298.854)	(298.071)	(273.850)
sparrow_1956	858.3*	1332.2***	1343.5***	780.4**
	(503.749)	(373.415)	(377.417)	(302.093)
sparrow_1958	-69.08	382.9	-54.06	-26.47
	(524.452)	(469.578)	(270.855)	(278.879)
sparrow_1959	-539.8	-142.8	-214.9	-377.7
	(462.265)	(367.569)	(269.190)	(261.690)
sparrow_1960	-601.5	-261.6	116.0	120.5
	(572.177)	(469.777)	(317.772)	(291.028)
sparrow_1961	-1937.0**	-1558.4**	-987.3*	-1164.3***
	(767.942)	(707.647)	(579.747)	(319.737)
sparrow_1962	-1357.0***	-1071.4***	-532.6	-513.2**
	(479.208)	(364.752)	(337.834)	(246.069)
sparrow_1963	-1056.7***	-662.5**	-576.6**	-476.8**
	(385.289)	(265.728)	(272.257)	(238.803)
sparrow_1964	-622.3	-433.7	-801.9**	-1087.4***
	(779.091)	(734.405)	(354.873)	(241.789)
sparrow_1965	492.6	726.1*	735.1**	309.8
	(467.606)	(377.332)	(339.212)	(254.686)
Winsor	0-100	1-99	2.5-97.5	5-95
Time Window	1954-1965	1954-1965	1954-1965	1954-1965
Year FE	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes
R-squared	0.901	0.873	0.877	0.893
Obs.	4081	3996	3873	3657

(c) Effects on Sweet Potato Output, Winsored

	(1) Sweet Potato b/se	(2) Sweet Potato b/se	(3) Sweet Potato b/se	(4) Sweet Potato b/se
sparrow_1954	-986.4	-1352.5*	-1645.6**	-1248.7
	(832.827)	(801.439)	(808.683)	(773.872)
sparrow_1955	-341.3	-380.9	9.177	109.1
	(671.859)	(650.706)	(570.232)	(576.871)
sparrow_1956	-926.4	-777.3	-312.4	-133.5
	(715.751)	(661.494)	(605.335)	(609.020)
sparrow_1958	1114.2	1952.9***	1819.7**	2137.9***
	(953.031)	(718.008)	(744.395)	(759.335)
sparrow_1959	-605.6	25.88	154.6	394.0
	(1027.008)	(628.801)	(614.606)	(638.333)
sparrow_1960	592.9	494.8	272.5	373.1
	(832.921)	(818.351)	(735.306)	(700.996)
sparrow_1961	1814.9*	1159.7	1096.6	437.5
	(920.860)	(881.658)	(861.784)	(704.631)
sparrow_1962	765.2	457.1	297.5	397.8
	(658.060)	(551.830)	(552.737)	(556.672)
sparrow_1963	1439.2	406.7	439.1	655.0
	(1196.726)	(610.519)	(608.782)	(611.988)
sparrow_1964	3678.0***	2433.8***	2477.6***	2400.2***
	(1383.935)	(831.863)	(810.780)	(779.808)
sparrow_1965	3186.9***	2824.6***	2474.1***	2315.0***
	(927.829)	(784.100)	(570.661)	(556.800)
Winsor	0-100	1-99	2.5-97.5	5-95
Time Window	1954-1965	1954-1965	1954-1965	1954-1965
Year FE	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes
R-squared	0.856	0.892	0.894	0.893
Obs.	1588	1557	1504	1424

(d) Effects on Procurement Rate, Winsored

	(1) Proc Rate b/se	(2) Proc Rate b/se	(3) Proc Rate b/se	(4) Proc Rate b/se
sparrow_1954	-0.0157	-0.0280	-0.0367	-0.0209
	(0.049)	(0.046)	(0.042)	(0.041)
sparrow_1955	0.0339	-0.00222	-0.00362	-0.0241
	(0.041)	(0.041)	(0.036)	(0.037)
sparrow_1956	0.0800*	0.0517	0.0562	0.0423
	(0.045)	(0.044)	(0.041)	(0.041)
sparrow_1958	0.143***	0.177***	0.212***	0.207***
	(0.055)	(0.050)	(0.044)	(0.044)
sparrow_1959	0.168**	0.173***	0.189***	0.143**
	(0.073)	(0.067)	(0.061)	(0.056)
sparrow_1960	0.110*	0.108*	0.126**	0.122**
	(0.064)	(0.061)	(0.057)	(0.051)
sparrow_1961	-0.164***	-0.180***	-0.137***	-0.0762
	(0.058)	(0.055)	(0.050)	(0.050)
sparrow_1962	-0.00239	-0.0315	-0.0320	-0.0338
	(0.047)	(0.045)	(0.040)	(0.040)
sparrow_1963	-0.00884	-0.0363	-0.0521	-0.0645
	(0.049)	(0.048)	(0.041)	(0.040)
sparrow_1964	-0.132***	-0.169***	-0.146***	-0.167***
	(0.050)	(0.049)	(0.042)	(0.043)
sparrow_1965	-0.0355	-0.0545	-0.0445	-0.0425
	(0.044)	(0.043)	(0.039)	(0.038)
Winsor	0-100	1-99	2.5-97.5	5-95
Time Window	1954-1965	1954-1965	1954-1965	1954-1965
Year FE	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes
R-squared	0.754	0.753	0.750	0.734
Obs.	3388	3320	3214	3042

Table A5: Effects on Agriculture with Binary Explanatory Variable

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Rice	Rice	Wheat	Wheat	Sweet Potato	Sweet Potato	Proc Rate	Proc Rate
	b/se	b/se	b/se	b/se	b/se	b/se	b/se	b/se
sparrow_1954	-3969.4	-1460.9*	245.3	43.46	-986.4	-275.1	-0.0157	-0.0143
	(2466.197)	(839.555)	(509.738)	(104.287)	(832.827)	(178.852)	(0.049)	(0.011)
sparrow_1955	-751.0	-257.8	558.7	118.7	-341.3	33.51	0.0339	0.000312
	(2452.443)	(793.215)	(529.603)	(96.836)	(671.859)	(131.917)	(0.041)	(0.009)
sparrow_1956	-4461.4*	-1376.2	858.3*	64.01	-926.4	-129.1	0.0800*	0.00748
	(2677.663)	(1125.498)	(503.749)	(120.524)	(715.751)	(134.563)	(0.045)	(0.010)
sparrow_1958	-3252.8	-1068.3	-69.08	60.52	1114.2	77.16	0.143***	0.0125
	(2401.615)	(790.154)	(524.452)	(83.893)	(953.031)	(168.725)	(0.055)	(0.011)
sparrow_1959	-4336.0*	-1473.0*	-539.8	-97.39	-605.6	-300.1	0.168**	0.0350***
	(2254.698)	(811.712)	(462.265)	(82.399)	(1027.008)	(232.713)	(0.073)	(0.013)
sparrow_1960	-5923.1**	-1478.6**	-601.5	-78.57	592.9	-47.74	0.110*	0.0109
	(2576.801)	(720.911)	(572.177)	(95.441)	(832.921)	(204.891)	(0.064)	(0.013)
sparrow_1961	-7632.6**	-2061.7*	-1937.0**	-263.1**	1814.9*	339.2**	-0.164***	-0.0378***
	(3351.421)	(1122.524)	(767.942)	(112.955)	(920.860)	(168.545)	(0.058)	(0.012)
sparrow_1962	-8562.7***	-2322.8*	-1357.0***	-144.0*	765.2	174.7	-0.00239	-0.00743
	(3275.335)	(1195.731)	(479.208)	(85.233)	(658.060)	(118.789)	(0.047)	(0.010)
sparrow_1963	-2382.7	-873.3	-1056.7***	-168.2**	1439.2	90.85	-0.00884	-0.0100
	(2576.809)	(975.040)	(385.289)	(76.053)	(1196.726)	(193.594)	(0.049)	(0.011)
sparrow_1964	-3049.2	-1321.9	-622.3	-86.49	3678.0***	536.2**	-0.132***	-0.0275***
	(2526.646)	(1019.039)	(779.091)	(113.155)	(1383.935)	(220.958)	(0.050)	(0.010)
sparrow_1965	-2899.9	-1045.1*	492.6	145.3	3186.9***	594.7***	-0.0355	-0.0151
	(2257.405)	(570.420)	(467.606)	(102.963)	(927.829)	(161.044)	(0.044)	(0.009)
Time Window	1954-1965	1954-1965	1954-1965	1954-1965	1954-1965	1954-1965	1954-1965	1954-1965
Measure	continous	binary	continous	binary	continous	binary	continous	binary
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.890	0.891	0.901	0.900	0.856	0.856	0.754	0.753
Obs.	3473	3473	4081	4081	1588	1588	3388	3388

Table A6: Effects on Population with Balanced Sample

	(1) Mortality b/se	(2) Mortality b/se	(3) Fertility b/se	(4) Fertility b/se
sparrow_1955	2.523	-0.806	8.009	2.761
	(3.383)	(2.769)	(5.072)	(6.163)
sparrow_1956	2.613	4.034	15.12***	12.96**
	(3.123)	(2.730)	(4.636)	(5.158)
sparrow_1958	5.199	-1.601	9.752**	6.415
	(3.656)	(3.738)	(4.163)	(4.389)
sparrow_1959	-7.072	-17.45*	13.34***	9.074*
	(7.691)	(9.994)	(4.397)	(4.817)
sparrow_1960	26.65*	19.07	-6.217	-9.805
	(14.953)	(18.140)	(5.382)	(6.288)
sparrow_1961	-2.153	-7.037	7.959	6.494
	(5.245)	(6.505)	(5.029)	(6.352)
sparrow_1962	-0.118	-1.755	13.42***	13.26**
	(2.409)	(2.480)	(5.141)	(6.212)
Time Window	1955-1962	1955-1962	1955-1962	1955-1962
Balanced	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes
R-squared	0.488	0.464	0.632	0.583
Obs.	2446	1608	2448	1616

Table A7: Effects on Population with Winsored Sample

(a) Effects on Mortality, Winsored

	(1) Mortality b/se	(2) Mortality b/se	(3) Mortality b/se	(4) Mortality b/se
sparrow_1954	4.015	2.605	2.484	1.930
	(2.879)	(2.664)	(2.415)	(2.184)
sparrow_1955	2.180	2.193	1.792	3.785
	(2.992)	(2.930)	(2.701)	(2.562)
sparrow_1956	3.183	2.355	2.766	1.548
	(2.775)	(2.651)	(2.519)	(2.291)
sparrow_1958	3.891	2.624	3.819	3.639
	(3.373)	(3.390)	(3.422)	(3.281)
sparrow_1959	-6.700	0.855	3.614	0.0424
	(7.529)	(4.888)	(4.544)	(2.991)
sparrow_1960	27.00*	19.36**	22.88***	10.78**
	(14.875)	(9.441)	(6.938)	(4.812)
sparrow_1961	-2.650	-3.094	1.147	-0.121
	(5.129)	(4.973)	(4.658)	(3.700)
sparrow_1962	0.0886	0.0670	0.971	0.407
	(2.084)	(2.014)	(1.947)	(1.882)
sparrow_1963	11.92***	11.82***	12.06***	7.405***
	(3.064)	(2.989)	(2.905)	(1.894)
sparrow_1964	9.597***	9.395***	9.404***	8.487***
	(2.837)	(2.764)	(2.590)	(2.493)
sparrow_1965	5.061**	5.135***	5.293***	4.682**
	(1.985)	(1.934)	(1.909)	(1.840)
Winsor	0-100	1-99	2.5-97.5	5-95
Time Window	1954-1965	1954-1965	1954-1965	1954-1965
Year FE	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes
R-squared	0.438	0.495	0.472	0.457
Obs.	3733	3656	3537	3340

(b) Effects on Fertility, Winsored

	(1) Fertility b/se	(2) Fertility b/se	(3) Fertility b/se	(4) Fertility b/se
sparrow_1954	2.858	3.560	3.051	3.019
	(5.066)	(5.053)	(5.019)	(4.887)
sparrow_1955	8.839*	9.730**	8.992*	9.150**
	(5.002)	(4.591)	(4.579)	(4.469)
sparrow_1956	15.37***	16.67***	16.11***	17.79***
	(4.612)	(4.561)	(4.564)	(4.205)
sparrow_1958	10.90***	9.335**	7.470*	8.102**
	(4.166)	(4.106)	(4.014)	(3.941)
sparrow_1959	14.81***	13.89***	13.04***	12.38***
	(4.458)	(4.365)	(4.315)	(4.177)
sparrow_1960	-4.453	-3.853	-2.496	2.460
	(5.505)	(5.401)	(5.631)	(5.673)
sparrow_1961	9.633*	9.581*	8.874*	12.02**
	(5.119)	(5.018)	(5.002)	(5.013)
sparrow_1962	14.52***	13.18***	12.55***	12.35***
	(4.994)	(4.783)	(4.706)	(4.603)
sparrow_1963	7.321	7.937*	9.977**	9.054**
	(4.508)	(4.313)	(4.171)	(4.068)
sparrow_1964	9.941**	7.648*	3.863	4.154
	(4.555)	(4.507)	(4.336)	(4.340)
sparrow_1965	4.468	3.361	1.291	-1.166
	(4.663)	(4.076)	(3.944)	(3.788)
Winsor	0-100	1-99	2.5-97.5	5-95
Time Window	1954-1965	1954-1965	1954-1965	1954-1965
Year FE	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes
R-squared	0.668	0.682	0.672	0.654
Obs.	3733	3657	3539	3341

Table A8: Effects on Population with Binary Explanatory Variable

	(1) Mortality b/se	(2) Mortality b/se	(3) Fertility b/se	(4) Fertility b/se
sparrow_1954	4.015	0.267	2.858	0.256
	(2.879)	(0.814)	(5.066)	(1.205)
sparrow_1955	2.180	0.559	8.839*	2.313**
	(2.992)	(0.683)	(5.002)	(1.153)
sparrow_1956	3.183	0.341	15.37***	2.899***
	(2.775)	(0.672)	(4.612)	(0.993)
sparrow_1958	3.891	1.782**	10.90***	2.803***
	(3.373)	(0.846)	(4.166)	(0.895)
sparrow_1959	-6.700	3.823	14.81***	3.251***
	(7.529)	(2.322)	(4.458)	(0.970)
sparrow_1960	27.00*	11.27***	-4.453	-2.155**
	(14.875)	(2.884)	(5.505)	(1.084)
sparrow_1961	-2.650	1.371	9.633*	1.708
	(5.129)	(1.276)	(5.119)	(1.049)
sparrow_1962	0.0886	-0.157	14.52***	4.239***
	(2.084)	(0.454)	(4.994)	(1.067)
sparrow_1963	11.92***	2.490***	7.321	2.848***
	(3.064)	(0.537)	(4.508)	(1.036)
sparrow_1964	9.597***	2.585***	9.941**	3.900***
	(2.837)	(0.587)	(4.555)	(1.068)
sparrow_1965	5.061**	1.228***	4.468	2.703***
	(1.985)	(0.417)	(4.663)	(0.887)
Time Window	1954-1965	1954-1965	1954-1965	1954-1965
Measure	continous	binary	continous	binary
Year FE	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes
R-squared	0.438	0.448	0.668	0.671
Obs.	3733	3733	3733	3733