Chemical Fertilizer and Migration in China*

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Abstract: This paper examines a possible connection between China's massive rural to urban migration and high chemical fertilizer use rates during the late 1980s and 1990s. Using panel data on villages in rural China (1987-2002), we find that labor out-migration and fertilizer use per hectare are positively correlated. Using 2SLS, employing the opening of a Special Economic Zone in a nearby city as an instrument, we find that village fertilizer use is linked to contemporaneous short-term out-migration of farm workers. We also examine the long-term environmental consequences of chemical fertilizer use during this period. Using OLS, we find that fertilizer use intensity is correlated with future fertilizer use rates and diminished effectiveness of fertilizer, demonstrating persistency in use patterns, and suggesting that in areas with high use of fertilizer, the land is becoming less responsive. We also demonstrate that fertilizer use within a river basin is correlated with organic forms of water pollution, suggesting that industrialization has induced pollution in China both directly and through its impact on rural labor supply.

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I. Introduction

China has long struggled to feed its population. The country is home to 22% of the world's population but only 7% of the world's arable land, leading to famine and food shortages throughout its history. However, in the 1980s, adoption of a modern agricultural input changed this dynamic entirely: chemical fertilizer. Chemical fertilizer, when used appropriately, enables farmers to increase their crop yields. The application of chemical fertilizer is also less time-intensive than manure, allowing farmers to cultivate more land with fewer workers. However, as many scholars have noted, the adoption of chemical fertilizer has not come without consequences for the country's environment (Huang and Rozelle 1995). Today, China's fertilizer use rate (kilograms per hectare) is more than twice the global average, and chemical fertilizers are responsible for the majority of the country's emission of greenhouse gasses. The organic material in these fertilizers is often blamed for the deterioration of the water quality in the country's lakes and rivers as well, which has left the majority of the country's waterways unfit for human use (World Bank 2006).

In a parallel trend, China's manufacturing industry has drawn millions of farmers out of their villages and into growing cities, migrating in search of higher wages. China's massive 'floating population' has fueled the country's industrial rise, but has left the countryside with fewer farm workers to tend to the land. While China's rural to urban migration has been hailed by many as critical to the country's rapid economic growth, the environmental consequences of this mass exodus have received less attention. In this paper, we examine a possible connection between Chinese high fertilizer use rates and the out-migration of farmers to nearby cities. We argue that as rural workers left their villagers, those remaining behind in farming areas were forced to compensate for labor scarcity by using fertilizer at very high rates of intensity.

Using village-level and household-level survey data, we examine whether there is a causal link between trends of increasing labor out-migration and fertilizer use rates.[1] Our data, gathered by China's Research Center on the Rural Economy (RCRE), provide a unique opportunity to examine this relationship, as it contains yearly information on fertilizer use and labor-out-migration from the years 1986-2002 for a panel of 318 villages that form a nationally-representative sample. Using OLS with village fixed-effects, we find that labor-outmigration is correlated with higher fertilizer use rates. Since the interpretation of these models is unclear due to plausible concerns of endogeneity of labor out-migration, we examine the relationship using 2SLS to exploit exogenous variation in out-migration driven by factors unrelated to fertilizer use. Since our data overlap with Deng Xiaoping's 1992 visit to Southern China, and the granting of special administrative rights to China's Special Economic Zones, we estimate 2SLS models where a village's distance from a zone is used as an instrument for the village's out-migration. Our results indicate that increasing out-migration is linked to higher fertilizer intensity, suggesting that the correlation between the two trends is at least in part reflecting a causal link. Furthermore, we find evidence that the relationship is dynamic: fertilizer use in a given year is predictive of fertilizer use in subsequent years and predictive of reduced effectiveness of fertilizer, suggesting that China's land may be becoming saturated and unresponsive to fertilizer.

In light of these findings, we conclude our analysis with a brief examination into the dynamics between fertilizer use rates and organic water pollution. Using long-term averages in fertilizer use rates and data collected by China's National Monitoring System in 2004, we find that areas with higher aggregate fertilizer use have higher levels of dissolved oxygen in their rivers, after controlling for the size of the river basin and rainfall. As a falsification check, we

[1] In the paper, our main results are conducted at the village level, while robustness checks are conducted at the household level. We make an exception in Table 3 (for duration of migration), where our household data is richer.

verify that industrial forms of water pollution are uncorrelated with fertilizer use. These results suggest that water pollution in China is partly driven by industrialization through the indirect effect on fertilizer use and induced demand for rural labor.

Our results suggest that China and other developing countries which face rapid industrialization should recognize the pressure farmers face to achieve high yields in a world with fewer available farm hands. While recent media attention has focused on the more dramatic effects of chemical treatment of crops, such as exploding watermelons (Watts 2011), our results suggest that the needs of China's manufacturing sector have generated a more pernicious environmental problem: excessive chemical fertilizer. Future policy initiatives aimed at curbing high fertilizer use should be targeted at villages with labor shortages, or other contexts in which farmers are under duress to guarantee high yields.

The paper is organized as follows. Section II provides background information on fertilizer use in China and examines the factors which have led to a substantial increase in both fertilizer consumption and rural to urban migration in China. Section III presents our data on fertilizer, special economic zones, and water quality measures. In Section IV, we present our empirical results. We conclude in Section V with a brief discussion of the policy implications of our findings.

II. Background

A. Rising Rates of Chemical Fertilizer Use

The unique combination of China's large population and limited arable land has generated intense pressure on Chinese farmers to exploit chemical fertilizers. Without access to new arable land, the primary option for meeting increasing food production is by improving crop yields through chemical fertilizer use (Zhu and Chen 2002).[2] Since applying chemical fertilizer is less time-intensive than organic fertilizers, such as manure, they also helped the country cope with rising out-migration of rural laborers. By 1985, China's nitrogen fertilizer consumption became the highest in the world, and by 2000, the country was responsible for roughly 30 per cent of the world's consumption of nitrogen fertilizer (Ju et al. 2004).

Chemical fertilizer use has increasingly displaced the use of organic fertilizer, which is safer for the environment but produce less consistent results (Zhu and Chen 2002). As a result, excessive mineral nitrogen fertilization has become common in most major grain producing regions of China since the late 1980s, and for cash crops in China since the 1990s (Ju et al. 2004). One estimate indicates it would be possible to decrease the nitrogen application rate by 30-60% while maintaining the same crop yield (Ju et al. 2009). Fertilizer has also been implicated directly by scientists in China's surface water pollution, severe land acidity, and increasing emission of greenhouse gasses (Liu et al. 2010). Zhang et al. (1996) demonstrate that the rapid increase of nitrogen fertilizer in recent years is the primary explanation for the increase in nitrate content in groundwater in northern China. Xing and Yan (1999) reveal that the rapid increase in nitrous oxide emissions is largely due to the increase in nitrogen fertilizer use.

Chemical fertilizer use has undoubtedly changed rural China, but scholarship has focused on both the benefits and costs of fertilizer use. In terms of its benefits, chemical fertilizer has been identified as a significant contributor to agricultural growth in China (Lin 1992; Fan and Pardy 1997; Huang and Rozelle 1996; Yu and Zhao 2009).[3] However, chemical fertilizer's benefit was not fully maximized, as wealthier eastern provinces have used excessive amounts

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[2] China has on average 0.10 hectares per capita of arable land versus the world average of 0.23 hectares per capita (Zhu and Chen 2002).
[3] Fan and Pardy (1997) found that 21.7 percent of agricultural growth from 1965-1993 in China was contributed by fertilizer inputs.

while the western regions have faced shortages (Ju et al. 2004). Today, there is widespread acknowledgement that farmers are using fertilizer at dangerously high rates – and that the large consumption of chemical fertilizers has already significantly reduced the usability of surface water sources in China (Zhu and Chen 2002). Accomplishing the dual objective of limiting excessive fertilizer in order to minimize environmental impact, while expanding access for appropriate use, will be an important challenge facing both Chinese policy makers and farmers.

B. Special Economic Zones and Rural to Urban Migration

The Special Economic Zone experiment began soon after Deng Xiaoping's 1978 policy statement in which he argued for greater economic liberalization, and more interaction with firms from overseas. These zones were envisioned as small laboratories to explore the economic potential of a further opening of China's economy. Four cities were chosen for SEZ status, in which they were able to operate with administrative autonomy from the provincial government, and were allowed tax exemptions for foreign firms. The SEZ's were strategically located in coastal areas close to islands with capitalist economies, including Xiamen (near Taiwan), Zhuhai (near Macao), and the most successful SEZ, Shenzhen, which capitalized on its proximity to Hong Kong. The SEZ's were successful at attracting foreign investment and cheap migrant labor from nearby provinces almost immediately (Yeung 2009; Giles and Yoo 2007).

During the late 1980s, however, many policymakers in China felt that the country's entry into the world economy was proceeding too slowly. Some believed that China's reform efforts were stagnating and wanted to develop faster, yet met resistance from conservative elements of the country who wished to maintain the status quo. Deng Xiaoping's famous visit to the South in 1992 was intended to promote reform policies, and embolden those who wished to continue China's move to capitalism. In the wake of Deng's visit, Free Trade Zones were established in several other coastal cities, including Shanghai's highly-successful Putong Economic Zone. Important administrative reforms were enacted in the original Special Economic Zones, including the upgrade of Shenzhen's government to sub-provincial administrative. Today, millions of migrants are living in cities outside of their original *hukou* and in destination cities such as Shenzhen. The massive exodus from rural areas has generated a major population shift, with rural areas left empty and cities teeming with masses of people.

The connection between these two trends: surging out-migration from rural areas and into cities, and high fertilizer intensity, is examined in our empirical work. In the next section, we present our data on villages and their fertilizer use and migration patterns.

III. Data

Our primary data source is a set of village- and household-level surveys conducted by China's Research Center on the Rural Economy (RCRE). These surveys are the primary instrument by which the Chinese government gathers information on changes in farming practices among households across China's massive rural population.[4] The surveys are nationally representative, and sample 337 villages across China's 31 provinces. Our sample covers 1986-2002.[5] The data are panel, allowing for comparison between the same villages over time. In each village, between 40 and 120 households are randomly chosen to complete the household

[4] The best available English language discussion of the RCRE surveys complete with comparison to other cross sectional and panel data sources from China can be found in Dwayne et al. (2005).

[5] Budget shortfalls prevented collection in 1992 and 1994 and there was no information for fertilizer use in 1986.It is important to note that not all variables are available for all years since there have been three different versions of the household and village survey instruments: one for the years 1986 to 1991, one for 1993 and a third from1995 through 2002. For example, fertilizer information is only available at the village level for the years 1986-1991 and available at the household level for the years 1993-2002. In order to have fertilizer information for all of the years, we took the mean average of fertilizer use per household and multiplied it by the number of households in the village. Recognizing that this might induce a bias to size, we ran additional robustness checks by aggregating the data according to the amount of land in a given village. Results are available from the authors upon request.

component and the village component is completed by an administrative representative of the village.

The RCRE sampling procedure is designed to include villages that are similar to the province's composition by restricting sampling to a set of counties that mirror the province's composition. While the original sample includes all 31 provinces, we exclude four provinces in the Western part of the China, where migration for geographical reasons is less prevalent and for which data are less reliable: Neimenggu (Inner Mongolia), Xizang (Tibet), Qinghai, and Xinjiang. We also are forced to delete observations that contain outliers and duplicated values, which results in a final data set for our analysis on migration and fertilizer use containing 27 provinces and 318 villages for the years 1987-1991, 1993, and 1995-2002. The RCRE survey was not conducted in 1992 or 1994.

Our RCRE data are then matched using GIS to several other datasets. We merge the RCRE to weather station data from the *World Meteorological Association* to account for variation in rainfall and its impact on our variables of interest. We also assigned to each village its distance from all major cities (or prefecture), where our interest is in tracking whether the village is within a specified distance of a Special Economic Zone. Our data on Special Economic Zones were catalogued by the authors from publicly-available sources online, and are available for download.[6] We record for each special zone the year in which it was established, the special privileges associated with the zone, and the county in which it is located, and the distance of each zone from other counties. We record a village's distance from each county, and so we can record whether it was within any number of kilometers of one of three different types of zones: Special Economic Zones (SEZ), Free Trade Zones (FTZ), and Export Processing Zones (EPZ).

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[6] These data are available for download at the author's website, matched to China's 2000 census data at the 4-digit and 6-digit levels. http://demog.berkeley.edu/~ebenstei/research/fertilizer/datafiles/all_economic_zones_citygb.dta .

We also merge our village-level data with data from the Hydro1k project, a suite of products produced by the United States Geological Survey that contain a Digital Elevation Model (DEM) for China, recording the boundaries of the country's main river basins. A river basin, or drainage basin, is an area for which rainfall and presumably fertilizer run-off would be shared. We merge our village-level data with water quality measures taken from China's national water monitoring system (2004), provided by the World Bank (2006). The data contain water quality readings for 484 geographic points across China's nine river systems. In our empirical analysis, we examine the statistical relationship between average water quality readings across the monitoring stations and the long-term average of fertilizer use rates within the river basin.[7]

Summary stats of the data are presented in Table 1.[8] Our sample comprises 3,808 observations with each observation representing a village's information for a given year. It is worth noting that several of these variables are recorded at the village level, and fertilizer use is generated at the village level by aggregating across households. We present the mean, standard deviation, min, max, and number observations for the variables used in our regressions. Our data reflect wide variation in fertilizer use patterns across our sample, with the average village consuming roughly 200,000 kilograms of fertilizer, and a standard deviation exceeding 350,000 kilograms. To eliminate skew in the data, we analyze the logarithm of fertilizer use. Our primary interest, however, is in fertilizer use rates, which is the ratio of fertilizer use to a village's total arable land, and so our main outcome variable is the log of fertilizer use per hectare. Our average for this measure in our data is 7.08, with a standard deviation of 1.02. The remainder of the table is devoted to reporting summary statistics for the fertilizer rate, total farm labor, total, labor out-migration, arable land, total sown areas, fertilizer productivity, total grain produced, fertilizer

[7] For more information on this data set, see Ebenstein (2011).
[8] Our summary stats at the household level are summarized in Appendix Table 1.

price index, rainfall, and two measures of water quality.[9] Our two water quality measures are dissolved oxygen and mercury, with the former being associated with organic sources of pollution (such as nitrogen-based fertilizers) and the latter more commonly associated with forms of industrial waste.

IV. Empirical Results

A. Relationship between Fertilizer Use and Labor Out-Migration

In Table 2, we present our results examining the correlation between contemporaneous fertilizer use-rates and labor out-migration. In each column, we regress a village's annual log fertilizer rate on the village's aggregate number of labor out-migration (persons). A village's log fertilizer rate is defined as total fertilizer use (kilograms) divided by arable land (hectares). Columns (2) through (6) introduce a rich set of controls for the size of the village workforce, the amount of land sown in a village, rainfall in millimeters, and year and village fixed effects.

The results show a positive and statistically significant relationship between the log fertilizer rate and labor out-migration. As shown in column (1), an increase in labor migration by 100 migrants is associated with an increase in a 17.2 percentage point increase in the fertilizer use rate per hectare. Relative to a village average of roughly 100 migrants per village, doubling out-migration is therefore associated with a 17.2 percentage point increase in the intensity of fertilizer use. Columns (2-6) indicate that the correlation between fertilizer use and out-migration is robust to the inclusion of various controls, though the relationship is weaker after accounting for covariates by village, such as total laborers in the village, total sown areas in hectares, rainfall, and year and village fixed effects. However, the relationship remains statistically significant at the 1% or 5% level in all specifications, suggesting that in years where a village has more labor-outmigration, it also uses fertilizer at a higher intensity.

[9] Price index data is only available from 1995 and onwards, resulting in fewer observations.

In the household data, we are able to observe the duration of absence for short-term migrants and able to complement our results in Table 2. In Table 3, we report that the shorter-term migrants have the largest impact on fertilizer use at their original household. In particular, a short work spell outside of the village is associated with a .04 percentage point increase in the intensity of fertilizer use. For migrants who leave for 180 days, each day of absence is only associated with .02 percentage point increase in the intensity of fertilizer use. Among migrants who are gone 300 days, they have a marginal impact on fertilizer use. However, the statistical significance of the relationship between the duration of migration and the intensity of fertilizer use is strongest among medium term migrants (120-300 days). This is consistent with an interpretation that once a household member leaves for an extended period, the household takes their absence into account in future planting decisions, but in the short and medium run, and especially for brief absences, it appears the household compensates for the worker's absence with the application of chemical fertilizer. This is logical as chemical fertilizer is less time-intensive to apply than manure.

We present Figure 1 as a graphical analogue to these results, which indicates that regions of China with greater labor-outmigration have been characterized by higher fertilizer intensity rates. The correlation, however, suggests very little in terms of a causal link between the two trends. It may be that fertilizer use increases labor productivity and *allows* a village to send its labor to nearby cities for manufacturing employment. In this scenario, higher labor-outmigration in areas with higher fertilizer use is a consequence of fertilizer adoption, rather than a causal factor in explaining its rise. A second reasonable concern is that places with less access to fertilizer are poorer, and therefore less likely to have sons fit for city employment. In such a circumstance, the correlation between fertilizer use and out-migration will be driven by unobserved variation in the suitability of village workers for city employment, should they leave farming.

In Table 4, we present results estimating the relationship between fertilizer use and labor out-migration using the presence of a nearby economic zone as an instrument for labor out-migration. Our identification strategy is to compare villages near and not near economic zones, and their respective changes in fertilizer and out-migration averages in a 2 X 2 set-up, where 'Treated' villages are those within 500 kilometers of one of the three types of Special Economic Zones. Due to data limitations, we collapse our sample into long-term averages before and after 1992, the year in which Deng Xiaoping visited southern cities and they received expanded administrative privileges. We contend that being near a special economic zone after 1992 should not be correlated with differential rates of change in the technology associated with fertilizer, and should only affect fertilizer use if there is an impact on outmigration of labor-outmigration.

As shown in Panel A, column (1), villages that are near Special Economic Zones have larger increases in out-migration than other villages in the sample. In particular, the long-term average of out-migration is raised by 58 persons per year among villages within 500 kilometers of a zone relative to those not within that distance, and the estimate is statistically significant at the 1% level. Columns (2-5) indicate that the correlation between labor out-migration and a nearby SEZ is robust to the inclusion of various controls, though the relationship is weaker after accounting for covariates by village, such as total laborers in the village, total sown areas in hectares, and village fixed effects. However, the relationship remains statistically significant at the 1% or 5% level in all specifications, suggesting that places near a special economic zone experience more labor out-migration.

Our 2SLS results are shown in Panel B, where we estimate the relationship between fertilizer intensity and fitted values for out-migration using the variation associated with being near a special economic zone. Our results indicate a significant correlation link between out-migration and a village's fertilizer use rate. As shown in column (1), an additional out-migrant is associated with a .869 percentage point increase in the fertilizer use rate respectively. Columns (2-5) indicate that the correlation between out-migration and a village's fertilizer use rate is robust to the inclusion of controls. These results are consistent with a posited causal link existing between the observed patterns of higher fertilizer use in villages with more labor-outmigration, whereby Special Economic Zones induce out-migration of rural laborers, and their absence from villages is correlated with higher fertilizer use rates.

We interpret this as evidence that a direct link exists between the two trends, and that labor-outmigration induces the farmers who remain in the villages to use more chemical fertilizer. The results suggest that when rural labor left for the cities, the remaining farmers switched from natural fertilizers, such as manure, to chemical fertilizers in light of the time-saving properties of using the latter.

Our 2SLS models in Table 4 relied on a binary treatment of whether villages were "sufficiently" close to a Special Economic Zone to be affected, and we chose this arbitrarily to be 500 kilometers. In Table 5, we investigate the sensitivity of our results to this choice, using instead 100, 200, 300, and 400 kilometer distances to generate the binary variable. As shown in Table 5, the results are remarkably robust to our choice of distance, as the table reflects both our first stage results and 2SLS estimates are similar across the distance measures. The one exception is a 100km rule, which may lead to too few villages being identified as "close" to a zone, and weaken the IV strategy.

In the next section, we examine whether temporal increases in fertilizer use leads to permanently higher fertilizer use rates and reduced fertilizer effectiveness, and whether these higher levels of fertilizer use rates are associated with organic water pollution in China's lakes and rivers.

B. Long-Term Consequences of Higher Fertilizer Use Rates

In Table 6, we examine whether shocks to fertilizer use could lead to long-term higher rates of fertilizer use and whether fertilizer use leaves the land less responsive to future application. Some argue that China's soil has become inured to high fertilizer use rates, and unresponsive to "normal" levels of fertilizer. Declining effectiveness of fertilizer would be manifested in higher rates among places already using high rates of fertilizer. We present evidence consistent with this hypothesis in Table 6.

In Panel A, we present models where we examine the relationship between fertilize use in the present cropping year (period T) and the previous cropping year (period T-1). We add an increasingly rich set of controls, such as for sown land, rainfall, year fixed effects, and village fixed effects. We find that in our parsimonious specification, a 1 percent increase in fertilizer use rates in year T is associated with a .785 percent increase in next year's fertilizer use rate. The results are consistently statistically significant across all the specifications in the table, with the results being somewhat weaker as we add controls. Still, with our saturated model that includes controls for the village's remaining laborers, amount of sown land, rainfall, year fixed effects, and village effects, we still find that next year's fertilizer use is significantly predicted by behavior in the prior use.

In Panel B, we examine the relationship between fertilizer productivity in a particular cropping year (period T) and the intensity in the previous cropping year (period T-1). We focus on grain production (wheat, rice, corn), since these are the primary crops produced by the farmers in our sample. Fertilizer productivity is defined as the ratio of grain production (000s kilograms) to total fertilizer used (in kilograms). We find that in our specification, a 1 percent increase in fertilizer productivity in year T is associated with a 3.67 percent decrease in the previous year's fertilizer use rate, suggesting that following a year of high fertilizer use, the land requires more fertilizer to achieve a given yield. In combination with Panel A, this suggests that land in China is becoming less responsive to fertilizer, and to maintain current yields farmers will need to increase their use in subsequent years.

We interpret Table 6 as evidence that some villages are becoming "addicted" to fertilizer use, which may be due to natural effects of the land becoming less responsive, or that people are becoming too used to relying on chemical fertilizer due to psychological factors. It may be that risk aversion leads farmers to want to avoid the possibility of applying too little fertilizer, and are less concerned about applying too much fertilizer. Regardless of the precise mechanism, the consistent increases in fertilizer use rates have become a dangerous environmental concern. We present Figure 2 as a graphical analogue to these results, which indicates that while grain production has increased in China, fertilizer productivity has decreased. The figure indicates that the mean grain production in our sample of villages has increased from 750,000 kilograms to 875,000 kilograms from 1987 to 2002. However, fertilizer *productivity* has decreased dramatically, declining from 11 kilograms of grain per kilogram to about five kilograms of grain per kilogram. [10]

In Table 7, we examine the consequences of high fertilizer use rates on water quality across China's lakes and rivers. In Panel A, we present long-term averages for fertilizer use by village, and examine the impact on the water quality at the nearest monitoring site. In Panel B,

[10] We find that these results are also robust at the household level (Appendix Table 2).

we explore an alternative strategy where we collapse our fertilizer data by river basin, and merge this with the water quality stations within the river basin. The results are consistent across the two methods, and demonstrate that villages with higher long-term fertilizer use have higher measures of organic pollution, such as dissolved oxygen (See also Figure 3). As a falsification exercise, we examine whether fertilizer use is correlated with industrial waste products, such as mercury, and find no significant relationship.

In Panel A, column 1, we estimate that a 100 percent increase in the long-term average of fertilizer is associated with .232 increase in water units, which is measured on a 6 point scale. As a reference, the average water quality grade is 1.84, suggesting a doubling of fertilizer would raise the water grade by .232 units, raising its index of pollution by over 10%. Since water grades reflect usefulness, this could represent the difference between water being usable for drinking (grade I and grade II) versus only for swimming (grade III and above). As expected, controlling for rainfall in column 2 reduces the size of the coefficient slightly, since rainfall mitigates the impact of water pollution on water quality, by providing a supply of unpolluted water. Panel B indicates that collapsing the data by river basin, increases the size of the coefficient, but reduces the statistical significance slightly, possibly due to there being fewer observations. The results in columns 3-4 indicate that fertilizer use is uncorrelated with mercury. This falsification exercise indicates that fertilizer is correlated with pollutants that are associated with it (such as dissolved oxygen), while not being correlated with pollutants that are not associated with is (such as mercury).

V. Conclusion

This paper has examined a potential link between two trends observed in China in recent decades: rural to urban migration of farm workers for short-term employment, and increases in chemical fertilizer use rates among the farmers left behind. We argue in this paper that farmers were forced to compensate for labor shortages by the application of less natural fertilizer, and substitution to chemical fertilizers. This link is found using both OLS and 2SLS, where we attempt to rule out reverse causality as an explanation for the link. Our instrument, the opening of a Special Economic Zone, is associated with increased out-migration in nearby villages *and* increased use of chemical fertilizers, consistent with our posited relationship. We also find that long-term fertilizer use may be difficult to discourage, as we observe high rates of persistency over time in use rates. Lastly, chemical fertilizer use is correlated with higher water pollution, suggesting that this phenomenon could have dangerous consequences for China’s ability to tackle its water pollution problem.[11]

Our results suggest that future policy efforts aimed at curbing water pollution cannot focus exclusively on industrial sources. First, agricultural sources of water pollution are significant, and in some ways, more difficult to tackle because farmers are spread out whereas firms and their locations can be more easily identified and monitored by authorities. Second, we have demonstrated a link between labor shortages and excessive fertilizer use. If policymakers take seriously the need to curb fertilizer use, efforts should be directed at providing counsel and possibly insurance to farmers who are most likely to face labor shortages in their areas. These farmers are most likely going to substitute for labor in getting higher yields, and fertilizer may be an effective though albeit dangerous method. Third, we find evidence that fertilizer use is only increasing across villages, with strong serial correlation in use patterns. We contend that many farmers have already abused their soil and are now using excessive amounts of fertilizer to compensate. Policymakers should be aware for the need to target high-use areas in the near

[11] A study by China's Environmental Protection Agency in February 2010 said that water pollution levels were double what the government predicted them to be because agricultural waste was ignored (Ansfield and Bradsher 2010).

future, so the land can replenish itself and not lead to even higher rates of chemical fertilizer use, and the associated water pollution, in the coming years.

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Table 1

Summary Statistics for RCRE Village Data (1987-2002)

Variable	Mean (1)	Standard Deviation (2)	Min (3)	Max (4)	Observ-ations (5)
Fertilizer Use (000s kilograms)	216.69	358.35	0.00	10,456.00	3,808
Fertilizer Rate (kilogram/hectare)	1,788.55	2,033.28	0.00	42,068.57	3,760
Log Fertilizer Rate (kilogram/hectare)	7.08	1.02	1.09	10.65	3,716
Farm Labor (persons)	825.87	576.71	0.00	5,100.00	3,808
Labor Out-migration (persons)	106.26	148.51	0.00	2,002.00	3,808
Arable Land (hectare)	157.44	165.28	0.00	1,760.00	3,808
Total Sown Areas (hectare)	238.89	189.20	0.00	1,760.00	3,808
Fertilizer Productivity[1]	6.56	11.13	0.00	427.13	3,725
Total Grain Produced (000s kilograms)	843.34	882.21	0.00	19,900.00	3,808
Rainfall (millimeter)	35.92	23.27	0.00	123.46	3,513
Price Index Value [2]	92.74	11.97	72.37	122.74	2,149
Dissolved Oxygen (grade)[3]	1.83	1.29	1.00	6.00	315
Mercury (grade)	1.24	0.78	1.00	6.00	299

Source: Research Center on the Rural Economy (RCRE) Village and Household Surveys (1987-1991, 1993, 1995-2002)

Note : The data are taken from households across 318 villages for the sample period, except for 1992 and 1994, when the survey was not collected. These data are aggregated to the village and year level for our analysis. Water quality is only available for 2004, and is reported by village.

[1]Fertilizer productivity is defined as the mean total of grain produced (000s kg) divided by the mean total of fertilizer (kilograms). Grain production is defined as the total production of wheat, rice, and corn.

[2]Price Index Data is only avalaible from 1995 onwards, resulting in fewer observations.

[3]Higher grades reflect lower water quality (1=best, 6=worst) and a greater concentration of the listed pollutants.

Table 2

Relationship Between Fertilizer Use and Labor Out-migration

	LHS: Log Fertilizer Rate (kilograms/hectare)					
	(1)	(2)	(3)	(4)	(5)	(6)
Labor Out-migration (100 persons)	0.172*** (0.0201)	0.120*** (0.0221)	0.0970*** (0.0188)	0.0950*** (0.0191)	0.0748*** (0.0200)	0.0423** (0.0208)
Observations	3716	3716	3716	3434	3434	3434
R^2	0.061	0.079	0.198	0.194	0.228	0.781
Labor Controls	No	Yes	Yes	Yes	Yes	Yes
Land Controls	No	No	Yes	Yes	Yes	Yes
Rainfall Controls	No	No	No	Yes	Yes	Yes
Year Fixed Effects	No	No	No	No	Yes	Yes
Village Fixed Effects	No	No	No	No	No	Yes

* significant at 10% ** significant at 5%. *** significant at 1%.

Source: Research Center on the Rural Economy (RCRE) Village and Household Surveys (1987-1991, 1993, 1995-2002)

Notes : Standard errors are listed in parentheses under coefficients and are clustered at the village level. The dependent variable in all regressions in total fertilizer use in kilograms per hectare of arable land in the village. Sample is created by aggregating household data at the village level for each year. Rainfall data is missing for 1999, resulting in fewer observations for specifications with controls for rainfall.

Table 3

Regression of Fertilizer Use on Temporary Migrant Labor Days at the Household Level

	LHS: Log Fertilizer Rate (kilograms/mu)					
	Temporary Migrant Days Less Than 'x' Days					
	60	120	180	240	300	360
Temporary Migrant Days	0.000423 (0.000340)	0.000219* (0.000119)	0.000194** (0.0000758)	0.000118** (0.0000465)	0.0000857** (0.0000367)	0.0000328 (0.0000261)
Observations	75,825	81,769	86,312	92,566	96,706	103,687
R^2	0.813	0.809	0.807	0.803	0.801	0.797
Labor Controls	Yes	Yes	Yes	Yes	Yes	Yes
Land Controls	Yes	Yes	Yes	Yes	Yes	Yes
Rainfall Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Household Fixed Effect	Yes	Yes	Yes	Yes	Yes	Yes

* significant at 10% ** significant at 5%. *** significant at 1%.

Source: Research Center on the Rural Economy (RCRE) Household Surveys (1995-2002)

Notes : Standard errors are listed in parentheses under coefficients and are clustered at the household level.The dependent variable in all regressions is total fertilizer use in kilograms. The sample excludes outlier household with fertilizer use rate greater than 700 kilograms/mu (1,118 observations out of 131,300, or about 0.9 percent of total observations). Note that 1 mu is equal to 1/15 of a hectare.

Table 4

Estimating 2SLS Models of Fertilizer Use and Labor Out-migration

	(1)	(2)	(3)	(4)	(5)
Panel A: OLS Models of the Impact of an Economic Zone on Labor Out-migration					
Near an Economic Zone (1=yes)	57.58***	41.74***	40.56***	37.55***	34.63**
	(10.90)	(9.258)	(9.601)	(10.41)	(16.22)
Observations	588	588	588	587	587
R^2	0.040	0.330	0.332	0.331	0.754
Panel B: 2SLS Models of Out-migration on Log Fertilizer Rate (IV=Economic Zone)					
Labor Out-migration (100 persons)	0.869***	1.074***	0.958***	0.993***	1.223**
	(0.178)	(0.259)	(0.242)	(0.289)	(0.586)
Observations	582	582	582	581	581
R^2	.	.	.	.	0.165
Labor Controls	No	Yes	Yes	Yes	Yes
Land Controls	No	No	Yes	Yes	Yes
Rainfall Controls	No	No	No	Yes	Yes
Village Fixed Effects	No	No	No	No	Yes

* significant at 10% ** significant at 5%. *** significant at 1%.

Source: Research Center on the Rural Economy (RCRE) Village and Household Surveys (1987-1991, 1993, 1995-2002)

Notes : Standard errors are listed in parentheses under coefficients and are clustered at the village level. Data is composed of cross-sectional aggregate household data averaged for before 1992 and after 1992. A economic zone is defined as being within 500 kilometeres of either a special economic zone, free trade zone, or export processing zone. Our instrumental variable is whether a village was within 500 km of an economic zone, and is set to zero in all villages prior to 1992. Log fertilizer rate is the log of total fertilizer used (kilograms) divided by total arable land in the village (hectares).

Table 5

Estimating 2SLS Models of Fertilizer Use and Labor Out-migration

	Is Village Within 'x' Distance of an Economic Zone (1=yes)				
	100 km	200 km	300 km	400 km	500 km
	(1)	(2)	(3)	(4)	(5)
Panel A: OLS Models of the Impact of an Economic Zone on Labor Out-migration					
Near an Economic Zone (1=yes)	18.53	50.15**	48.64***	46.85***	48.46***
	(36.25)	(21.03)	(17.81)	(15.91)	(15.21)
Observations	588	588	588	588	588
R^2	0.711	0.723	0.729	0.730	0.733
Panel B: 2SLS Models of Out-migration on Fertilizer Use (IV=Close Special Economic Zone)					
Labor Out-migration	0.0182	0.00721**	0.00819**	0.00912***	0.00895***
	(0.0407)	(0.00347)	(0.00316)	(0.00327)	(0.00297)
Observations	582	588	582	588	582
R^2	.	0.723	0.639	0.729	0.559
Village Fixed Effects	Yes	Yes	Yes	Yes	Yes

* significant at 10% ** significant at 5%. *** significant at 1%.

Source: Research Center on the Rural Economy (RCRE) Village and Household Surveys (1987-1991, 1993, 1995-2002)

Notes : Standard errors are listed in parentheses under coefficients and are clustered at the village level. Data is composed of cross-sectional aggregate household data averaged for before 1992 and after 1992. Panel A reports our first-stage results, and Panel B reports our 2SLS results. A economic zone is defined as being within 'x' kilometeres of either a special economic zone, free trade zone, or export processing zone. Our instrumental variable is whether a village was within 'x' km of an economic zone, and is set to zero in all villages prior to 1992. Log fertilizer rate is the log of total fertilizer used (kilograms) divided by total arable land in the village (hectares).

Table 6

Relationship Between Fertilizer Productivity and Fertilizer Use in Period T and Period T-1

Variable	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Regression of fertilizer use rate on previous year's log fertilizer use rate						
Log Fertilizer Rate of Previous Cropping Year (kilogram/hectare)	0.785***	0.775***	0.747***	0.777***	0.775***	0.348***
	(0.0206)	(0.0224)	(0.0211)	(0.0221)	(0.0231)	(0.0365)
Observations	3,382	3,382	3,382	3,104	3,104	3,104
R^2	0.680	0.682	0.686	0.725	0.728	0.837
Panel B: Regression of fertilizer productivity on previous year's log fertilizer use rate						
Log Fertilizer Rate of Previous Cropping Year (kilogram/hectare)	-3.679***	-3.756***	-3.678***	-3.950***	-3.769***	-2.494***
	(0.403)	(0.404)	(0.435)	(0.465)	(0.449)	(0.640)
Observations	3,382	3,382	3,382	3,104	3,104	3,104
R^2	0.120	0.121	0.121	0.131	0.143	0.356
Labor Controls	No	Yes	Yes	Yes	Yes	Yes
Land Controls	No	No	Yes	Yes	Yes	Yes
Rainfall Controls	No	No	No	Yes	Yes	Yes
Year Fixed Effects	No	No	No	No	Yes	Yes
Village Fixed Effects	No	No	No	No	No	Yes

* significant at 10% ** significant at 5%. *** significant at 1%.

Source: Research Center on the Rural Economy (RCRE) Village and Household Surveys (1987-1991, 1993, 1995-2002)

Notes : Standard errors are listed in parentheses under coefficients and are clustered at the village level. Sample is composed of aggregated household data at the village-level by year. The right-hand side in all regressions is the previous year's log fertilizer use rate. In panel A, the dependent variable is the current year's log fertilizer use rate. In panel B, the dependent variable is the current year's fertilizer productivity. Fertilizer productivity is defined as the mean total of grain produced (000s kg) divided by the mean total of fertilizer (kilograms). Grain production is defined as the total production of wheat, rice, and corn. Rainfall data is missing for the year 1999, resulting in fewer observations for specifications with controls for rainfall.

Table 7

Fertilizer Use and Water Pollution in China

	LHS: Dissolved Oxygen		LHS: Mercury	
	(1)	(2)	(3)	(4)
Panel A: Village-level Data				
Long-Term Average Log Fertilizer Rate (kg/ha)	0.232***	0.224***	0.0256	0.0326
	(0.0822)	(0.0834)	(0.0548)	(0.0555)
Mean of Dep. Var.	1.84	1.84	1.24	1.24
Observations	312	311	297	296
R^2	0.025	0.025	0.001	0.005
Panel B: River Basin Data				
Long-Term Average Log Fertilizer Rate (kg/ha)	0.278**	0.262**	0.0488	0.0578
	(0.108)	(0.110)	(0.0694)	(0.0713)
Mean of Dep. Var.	1.86	1.86	1.27	1.27
Observations	157	157	150	150
R^2	0.041	0.045	0.003	0.006
Rainfall Controls	No	Yes	No	Yes

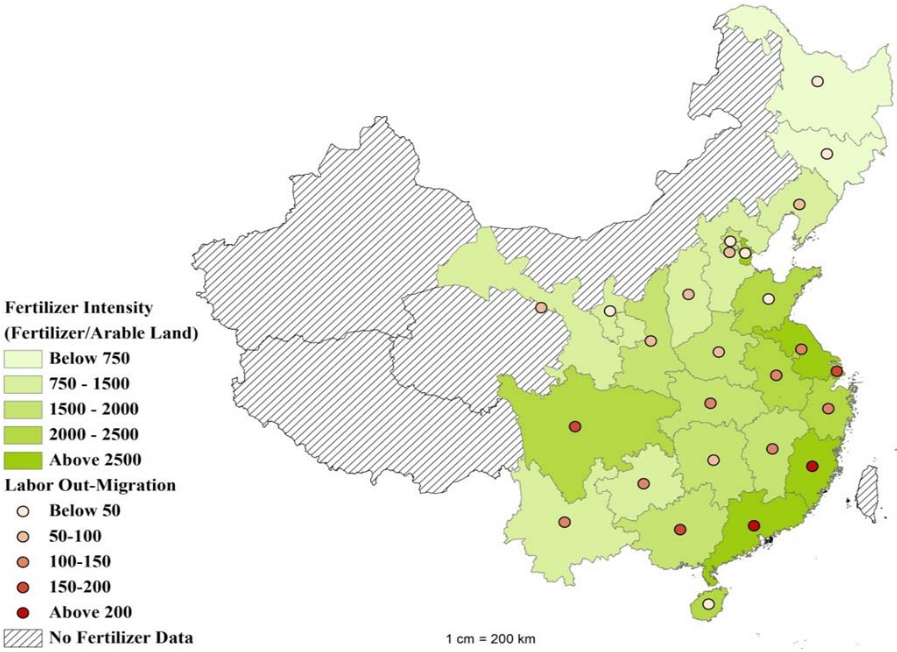
* significant at 10% ** significant at 5%. *** significant at 1%.

Source : Research Center on the Rural Economy (RCRE) Village and Household Surveys (1987-1991, 1993, 1995-2002)

Notes : Standard errors are listed in parentheses. Data on fertilizer use are long-term averages of fertilizer in kilograms per hectare by village. Dissolved oxygen measures are the average grade among monitoring stations (in 2004) within the village's river basin. Water grades are measured by the usability of water for various purposes, with higher grades reflecting lower water quality (1=best, 6=worst) and a greater concentration of the listed pollutants.

Figure 1

Fertilizer Intensity and Outmigration by Province, 1987-2002

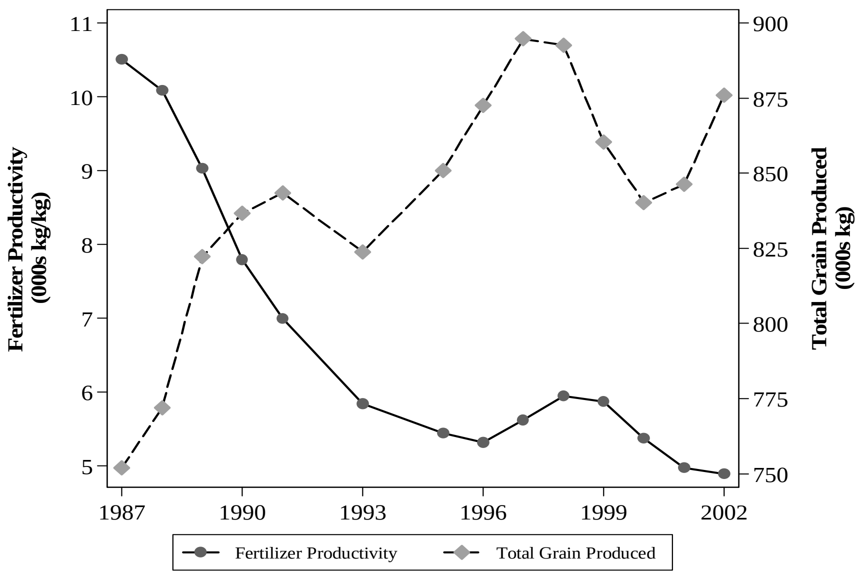


Source : Research Center on the Rural Economy (RCRE) Village and Household Surveys (1987-1991, 1993, 1995-2002)

Notes : The green polygons report province-level averages in fertilizer intensity (kilograms/hectares) across the sample of villages. The red circles report province-level averages in out-migration (persons) across the sample of villages.

Figure 2

Grain Production and Fertilizer Productivity, 1987-2002

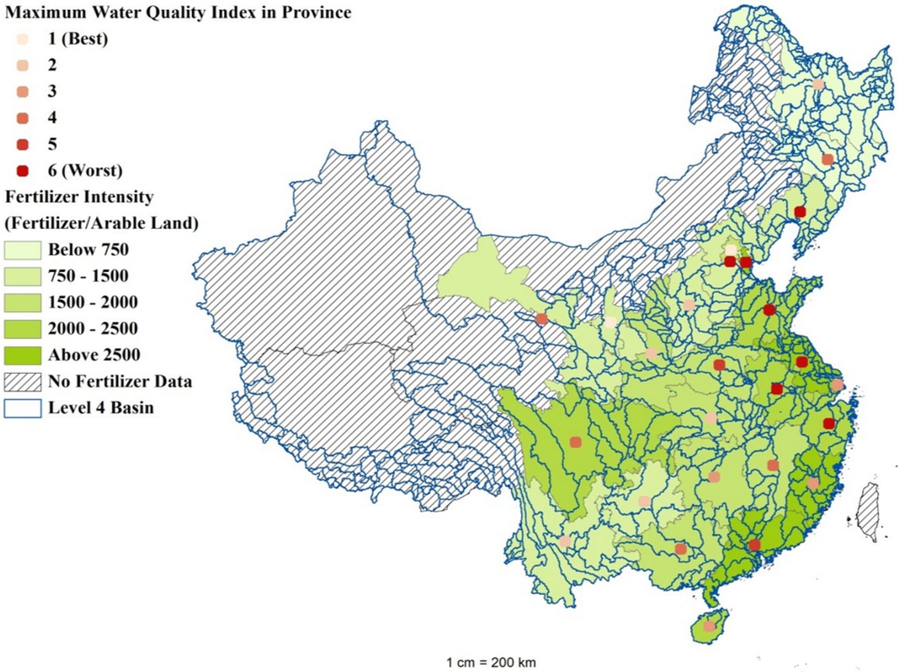


Source : Research Center on the Rural Economy (RCRE) Village and Household Surveys (1987-1991, 1993, 1995-2002)

Notes: The data are smoothed using the STATA lowess command. Fertilizer productivity is defined as the mean total of grain produced (000s kg) divided by the mean total of fertilizer (kilograms) per year. Grain production is defined as the total production of wheat, rice, and corn. No data are available for 1992 and 1994.

Figure 3

Fertilizer Use and Water Quality by Province, 1987-2002



Source : Research Center on the Rural Economy (RCRE) Village and Household Surveys (1987-1991, 1993, 1995-2002), China National Monitoring System (2004).

Notes : The green polygons report province-level averages in fertilizer intensity (kilograms/hectares) across the sample of villages. The red circles report the maximum value of dissolved-oxygen measured in a province's water station across the sample of villages. The rivers are mapped according to level 4 basin.

Table A1

Summary Statistics for RCRE Household Data (1987-2002)

Variable	Mean (1)	Standard Deviation (2)	Min (3)	Max (4)	Observ-ations (5)
Fertilizer Use (kilograms)	552.39	529.22	0.00	17,700.00	130,182
Fertilizer Rate (kilogram/mu)[1]	110.21	99.29	0.00	700.00	129,186
Log Fertilizer Rate (kilogram/mu)	4.34	0.99	-2.46	6.55	124,719
Household Labor (persons)	2.60	1.13	0.00	74.00	130,182
Temporary Migrant Labor Days	88.57	166.11	0.00	3,030.00	130,182
Arable Land (mu)	8.36	12.32	0.00	342.00	130,182
Total Sown Areas (mu)	11.24	12.69	0.10	342.00	130,182
Fertilizer Productivity[2]	6.54	8.11	0.00	538.46	125,312
Total Grain Produced (kilograms)	2,638.21	2,874.64	0.00	125,000.00	130,144

Source: Research Center on the Rural Economy (RCRE) Village and Household Surveys (1987-1991, 1993, 1995-2002)

Notes : The sample excludes outlier household with fertilizer use rate greater than 700 kilograms/mu (1,118 observations out of 131,300, or about 0.9 percent of total observations).

[1] 1 mu = 1/15 hectare

[2] Fertilizer productivity is defined as the household total of grain produced (kilograms) divided by the household total of fertilizer (kilograms). Grain production is defined as the total production of wheat, rice, and corn.

Table A2

Household Level Relationship Between Fertilizer Productivity and Fertilizer Use in Period T and Period T-1

Variable	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Regression of fertilizer use rate on previous year's log fertilizer use rate						
Log Fertilizer Rate of Previous Cropping Year (kilogram/mu)	0.665*** (0.00353)	0.664*** (0.00353)	0.595*** (0.00406)	0.653*** (0.00396)	0.654*** (0.00395)	0.0827*** (0.00385)
Observations	102,204	102,204	102,024	88,767	88,767	88,767
R^2	0.468	0.468	0.498	0.584	0.584	0.803
Panel B: Regression of fertilizer productivity on previous year's log fertilizer use rate						
Log Fertilizer Rate of Previous Cropping Year (kilogram/mu)	-2.583*** (0.0426)	-2.574*** (0.0424)	-2.516*** (0.0458)	-2.803*** (0.0520)	-2.804*** (0.0520)	-0.490*** (0.0631)
Observations	102,523	102,523	102,523	89,031	89,031	89,031
R^2	0.114	0.115	0.115	0.139	0.141	0.375
Labor Controls	No	Yes	Yes	Yes	Yes	Yes
Land Controls	No	No	Yes	Yes	Yes	Yes
Rainfall Controls	No	No	No	Yes	Yes	Yes
Year Fixed Effects	No	No	No	No	Yes	Yes
Effects	No	No	No	No	No	Yes

* significant at 10% ** significant at 5%. *** significant at 1%.

Source: Research Center on the Rural Economy (RCRE) Village and Household Surveys (1987-1991, 1993, 1995-2002)

Notes : Standard errors are listed in parentheses under coefficients and are clustered at the household level. The right-hand side in all regressions is the previous year's log fertilizer use rate. In panel A, the dependent variable is the current year's log fertilizer use rate. In panel B, the dependent variable is the current year's fertilizer productivity. Fertilizer productivity is defined as the household total of grain produced (kilograms) divided by the household total of fertilizer (kilograms). Grain production is defined as the total production of wheat, rice, and corn. Rainfall data is missing for the year 1999, resulting in fewer observations for specifications with controls for rainfall.