Roads and Resources: Groundwater Depletion in the North China Plains*

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Abstract

A large literature in economics focuses on the relationship between infrastructure provision and economic development. However, there are no studies on the effect of infrastructure on the sustainability of natural resources. This paper studies the effect of highway building on the water table in one county in the North China Plain - which produces most of the country's food grains. We use a unique GIS-referenced dataset of all the 12,000 odd tube wells in this county to show two facts. First, that the probability of digging new wells in the proximity of new highways significantly increases in the aftermath of the construction of a highway. Second, that the construction of new highways has led to a depletion of the water table in wells located nearby relative to those farther away. The main conclusion of the study is that infrastructure building may negatively impact the environment, leading to potentially adverse effects on the sustainability of natural resources.

JEL classification: O13, O18, Q25

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1 Introduction

There is a growing literature on the relationship between infrastructure provision and economic development. However, there have not been any studies on the effect of roads on the depletion of natural resources. In this paper, we use a unique dataset on all the 12,000 plus tubewells in a small county (Lankao) in Henan Province (see Figure 1) to show that there is clear evidence of depletion close to national highways. We control for the date of drilling of the tubewell, proximity to other water sources (e.g. rivers and canals) as well as population and well density.

The main goal of this paper is to establish a causal relationship between highway construction and groundwater depletion. In order to achieve it, we first examine the impact of highways construction on the probability of digging new wells in their proximity. We then move on and analyze the impact of the construction of highways on the depth of the water table across the county at one precise point in time, 2011. In other words, and borrowing the terminology from the trade literature, we first execute an extensive margin analysis and then an intensive margin one. We then spend some time discussing the possible channels through which this relationship may work.

In order to be able to establish a causal relationship between water depletion and highway construction, we need the construction of the highway to be exogenous to economic activity in the county. In order to be able to make this claim, we separate the five highways crossing the county in two groups. A first group, highways G220, G106 and G310, contains what we denominate *historic highways*. These highways were born as simple roads and have progressively been updated to highways. Since roads used to go through every single village along their path, these highways have a high probability of being highly endogenous to economic activity. In the second group, composed by G30 and G1511, we have what we denote as *new highways* – both built between the end of 90s and the beginning of the 00s – which are just short bits of big projects planned in order to connect the est of the country to the west. As we detail later, these highways can be plausibly claimed exogenous to the economic activity in the county. Therefore, our paper will focus mainly on this latter group of highways.

The extensive margin analysis uses a panel, where the unit of observation are the cell composing a 250m x 250m grid covering the county. For each cell, we know the cumulative number of wells it contains each year. These data allow us to perform a classical difference-in-difference analysis on each of the two new highways. The treatment is defined as a buffer around each highway going from 500 meters up to 5 kilometres. The evolution of the difference-in-difference coefficient, in both cases, is positive and statistically significant, the probability of digging new wells increases around both highways. When we focus on G30 we observe a stable positive change in probability (up to 10%), while when we look at G1511 we observe a declining (from roughly 15%) coefficient. This sharp difference may be due to the fact that G1511 has been constructed very close to two of the historic highways (G106 and G220).

For the intensive margin analysis, we regress the water table depth in tube wells on the distance from the *new highways*. In order to control for the effect of the Yellow River, we control for its distance from each tube well. The idea is that tube wells located close to the river are likely to have a higher water table because of water seepage. Moreover, tube wells located closer to the river may see reduced extraction of water if farmers supplement their groundwater use with surface water. Our results show that an increase of 1 km in the distance of a tube well from G30 leads to a decrease in the depth of the water table by 46.3 centimetres. While an increase in the distance of 1 km from G1511 leads to an increase of 62.4 centimetres. Because government programs focus on drilling tube wells in selected areas within the county at the same time, we control for the decade when the tube well was drilled.

In order to eradicate all possible doubts on the causal interpretation of our specifications, we also run an instrumental variable specification. The argument of the Chinese government is that these highways have been built with specific goals in mind, which do not concern rural areas and, therefore, if we instrument the distance of each well to the actual placement of the highway with the distance to the straight line where the highway should have been had the government respected its plan, we are going to clear any possibility of endogeneity from our specification. This instrumental variable specification confirms our results.

The construction of new highways can lead to an increase in groundwater depletion through different channels. In the extreme, we may imagine that the county goes from a situation of autarky to one of free trade. All of a sudden you do not need to focus solely on production for your own consumption, but you can send your production to the market. This change may lead farmers to switch to more profitable – and more water intensive – crops, such as melons or fresh vegetables. At the same time you can also import new inputs, such as new fertilizers, which may help to increase yields, but also increase water consumption.

Section 2 provides some information on groundwater depletion in China. Section 3 contains a brief literature review on the study of roads in economics and some background information on highways in China and more specifically on those passing through Lankao

County. Section 4 discusses the data used. Section 5 provides the empirical specification, results and robustness checks. Finally, section 6 discusses possible mechanisms that could explain the results and section 7 concludes the paper.

2 Chinese groundwater

The depletion of groundwater resources is a major problem in China. China is home to more than 20% of the world population but only five to seven percent of its freshwater resources (Qiu, 2010). Grain production is mainly concentrated in the North China Plains (NCP). This region accounts for one-fifth of China's total geographic area, covering the Tianjin municipality, the southern part of the Beijing municipality, a major part of Hebei, Shandong and Henan provinces and the northern part of Jiangsu and Anhui provinces, and includes about 340 counties. About 72% of the area is under farming but only 6% has access to surface water (Lu and Fan, 2013). This flat plain is China's bread basket and produces most of its grains, as well as cotton and other crops. It accounts for two-thirds of Chinese wheat production (Lu and Fan, 2013). Most farms practice double-cropping, rotating between summer maize and winter wheat and make extensive use of groundwater irrigation. This region has only a quarter of the nation's water resources yet produces half of its grain.

The NCP is an arid region where about 70% of the rain falls during June and September. Annual rainfall ranges from 400-600 mm/year while average evaporation is about 1000 mm/year (Feng et al., 2013). Thus food production in the NCP is largely dependent on groundwater resources, especially in the winter months. Overall about 70% of irrigated water comes from groundwater (Wang et al., 2006). There is evidence that groundwater aquifers in the NCP are depleting and may be under serious threat of overexploitation. Accurate measurements from GRACE satellites suggest that between 2003-2010, the depletion rate was of the order of 8.3km^3/year (Feng et al., 2013).

Lankao county has a surface area of 1,116 square kilometers and a population density of 744 per square kilometer, much higher than the average density in the country (145 per squared km). The endowment of arable land per capita is only 0.09 ha. About 80% of the land area is under farming. Lankao is listed as one of the poorest of the 592 counties in China (WantChinaTimes.com, 2014; State Council, 2012). Five national highways and one provincial expressway go through the county, as shown in Figure 2. The Yellow River passes through the northwest corner of the county. Because of the river and of the irrigation canals that channel some of the river water to farms, Lankao has enjoyed good access to surface water for irrigation. Before the 1980s, almost all irrigation relied upon surface water. Since then, the share of groundwater in irrigation has increased at a rapid pace (Wang et al., 2006). During the last decade, the government has constructed more than 7,200 tube wells on the county's 74,635 ha of arable land in order to increase agricultural productivity.

3 Highways

The impact of transport infrastructure has been widely studied in economics. The majority of these studies focuses on the impact of roads on developing countries and in particular, on their impact on firms and productivity. A few exceptions only look at high-income countries. Michaels (2008) and Chandra and Thompson (2000), for instance, focus on the US highway system. The latter finds that highways tend to draw economic activity to counties where they pass through and have a differential impact across industries, while the former observes an increase in trade and in the real demand of skilled workers in skill abundant counties. Holl (2016), focuses on the Spanish highway system and, instrumenting its placement using postal routes and roman roads, finds that highways have a positive effect on firms' productivity.

Faber (2015) studies the China National Trunk Highway System, instrumenting placement with the ideal least cost path and finds a reduction in industrial output from non-targeted regions. Finally, Gertler et al. (2015) investigate the impact of road quality in Indonesia and find that higher quality leads to job creation in the manufacturing sector and an occupational shift from agriculture to manufacturing. Donaldson (2015) studies the impact of India's vast railroad network on inter-regional trade and finds that railroads decreased trade costs and inter-regional price differentials leading to higher real income levels. Banerjee et al. (2012) study the impact of county location, especially its proximity to major communication arteries on economic growth in China. They find a small impact of the transportation network on per capita GDP levels across sectors but not on per capita GDP growth.

Several of the most recent studies focus on the updating of the Golden Quadrilateral Highway (GQH). The GQH connects New Delhi, Mumbai, Chennai and Kolkata. Among these studies, we find Datta (2012), Ghani et al. (2013, 2016) and Khanna (2014). These papers find an unequivocally positive impact of the updating of the GQH on firms, which grew disproportionally along the network. These effects are found for districts up to 10 kilometers away from the highways and disappear for district located more than 10 kilometers away from the highway.

Highways in China and the National Trunk Highway Development Program

Over the last few decades, China has been investing heavily in the development of its highway network. Between 1990 and 2006, China invested roughly $40 billion per year in highways development and completed nearly 45,000 km of new highways. This new development of the Chinese highway system has taken place in two phases: *i)* the *kick off* phase, between 1988 and 1997 and, *ii)* the *rapid development* phase, starting in 1998. A big part of this push toward an improved highway network is the *National Trunk Highway Development Program* (NTHDP), consisting of 5 vertical (N-S) and 7 horizontal (E-W) routes with a total of 35,000 km. G30 is part of the NTHDP.

The NTHDP has been planned "strategically" in order to inter-connect the country through high-speed road corridors connecting all the important centres of activity, rather than based on a detailed economic analysis, considering projected centres of economic growth, traffic growth and distribution. The planning approach for this part of the network has been as follows. First, the tree rooted at Beijing connecting all the provincial capitals. Second, all segments must connect: *a)* all provincial capitals, *b)* all cities with population above 500,000, *c)* all rail hubs, *d)* all ports, *e)* all major airports, and *f)* the old trading routes. The entire land acquisition, resettlement and rehabilitation process for these projects is usually completed within 5 to 6 months.

Highways in Lankao county

Lankao is a small and poor county, but it is crossed by five national highways, as shown in Figure 2. The two main new arteries going through Lankao, and focus of this paper, are the G30 and the G1511, see Figure 1. Both were constructed between 1998 and 2005. To distinguish from the old highways, we will call these two "new highways". As seen in Figure 1, G30 travels for east-west for about 4395 km, connecting Lianyungang in Jiangsu Province to Huoerguosi in Xinjiang Province. It splits slightly to the left on Lankao. The offshoot which goes towards Shandong is G1511.

Only a stretch of 10.97 km of G30 goes through Lankao county (see Figure 2). G1511 follows a straight path from east to northwest and traverses a distance of XX km in Lankao. Construction of G30 took place during the period 1998-2001. G1511 is a connector and links G30 to the Rizhao-Nanyang national highway. Both are part of the 28 main national highways according to the *Tenth Five-Year Plan for National Highways* issued by the State Transportation Department. G1511 was constructed between 2003 and 2005.

The other three national highways, the *historic highways*, crossing Lankao county – G106, G220 and G310 – also shown in Figure 2, are not part of the National Trunk System but are upgrades of preexisting roads.[1]

The placement of provincial and county roads may not be independent of the availability of water. They were likely built after people settled in villages. In Lankao, people probably settled closer to water sources. Thus these local roads may be located in regions close to economic activity and water sources, where the water table is higher. The national highways we study, however, join large urban centers and run the whole length of the country.

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4 Data

We use data on the geographical placement of roads and tube wells. Our database contains detailed information on the location, depth, date of construction and height of the water table for all the 12,160 tubewells in Lankao county constructed between 1955 and 2011. These tube wells are spread out over 389 villages in the 17 townships composing Lankao county.[2] They were dug either by private individuals or by the government. Figure 3 shows the evolution in the number of tube wells by decade from 1955 to 2011.[3] The most significant increase in the number of tube wells took place early this century, when the government stepped in and started to dig tube wells. The increase in their number seems relatively stable before

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[1] Highway G106 connects Beijing to Guangzhou City, running from north to south for 2,466 kilometers. G106 was constructed during two phases, a first one in 1956 and a second one in 1988. Highway G220, with a total length of 585 kilometers connects Binzhou City in Shandong Province to Zhenzhou in Henan Province. This highway was constructed in the late sixties and establishes the south-east access from Henan Province to Shandong Province. Finally, G310 runs for 1,613 kilometers from Lianyungang in Jiangsu Province to Tianshui in the Gansu Province. This segment was also constructed in two separate phases, a first one in 1949 and a second phase in 1978-79.

[2] Townships are essentially municipalities and the basic political unit in China. Each township has several villages in its jurisdiction.

[3] Over the years, some of the wells go out of use for a variety of reasons. As long as wells are abandoned in a random fashion around the county (i.e. not following any particular pattern) this will not be an issue for our estimations.

2000. Figure 3 also shows how in the earlier periods wells were mainly dug around canals, and only moving forward the spread to the other parts of the county.

While for the extensive margin analysis – in which the only information used about each well is the date of digging – we use all the available observations, for the intensive margin analysis we select only a subset of the wells to be analyzed. In this way we reduce the risk of measurement error in the height of the water table. The approach used is very simple, first of all we eliminate wells if, within a village we do not observe any variation in the water table.[4] Second, we eliminate all outliers. For instance if in a village containing 30 wells the depth of the water table oscillated between 12 and 16 meters in 29 wells and it is of 1 meter in one well, we eliminate the latter observation. This process leaves us with 7,526 wells which are used for the intensive margin analysis and for which we report descriptive statistics.

Table 1 reports descriptive statistics for the main variables used in our study. The first striking fact is that the mean well depth (41.95 meters) is much larger than the mean depth of the water table (13.92 meters). This difference led us to use the latter in our estimation because the well-depth may be a function of other factors such as the cost of drilling, technology and expectations of future depletion. All the data on water table depth was collected in the same year (2011), while well-depth was measured at the time of digging which varies significantly across wells. Figure 4 shows the depth of the water table in the county as measured at the tubewell in 2011. Note the general pattern imposed by the seepage from the Yellow River. The water table becomes deeper as we move towards the south-east corner of the county. In spite of this, one can still observe a remarkable degree of heterogeneity in the depth of the water table within the county.

The average tube well in the county is situated 22.04 kilometers away from the Yellow River (which flows in the north east corner). Wells on average are located only 9.72 kilometers away from G1511, which crosses almost the full length of the county and 18.77 kilometers away from G30, which is located in the south-west corner of the county. Well density is very high in the county and, therefore, wells are located close to each other, the mean distance between two nearest wells is 0.13 kilometers and the average number of wells in a circle of radius 500 m is about 14.

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[4] Since we employ a fixed effect specification, these wells would be dropped anyway during the estimation.

5 Empirical Specification and Results

In order to fully understand the impact of road construction on groundwater depletion, we adopt two separate approaches. First – borrowing the language from trade – we implement an extensive margin analysis, which focuses on whether we observe a higher probability of digging an extra well in areas closer to the new highways in the period following the beginning of their construction. Second we perform an intensive margin analysis, which focuses on the level of the water table in each of the wells existing in 2011. This second step compares what happens in wells closer to new highways with respect to wells located further away from the same roads.

5.1 Extensive margin analysis

Specification

The first step in order to run an extensive margin analysis consists in transforming our dataset in a panel. In order to construct the panel we have to first evenly divide the surface of the county in cells, say of 250 meters by 250 meters.[5] This exercise leave us with 18,362 cells. Our database contains information on the date at which each of the tube wells was dug. Thanks to these data, we are able to construct a panel, where the unit of observation are the cells of the grid. The variable of interest in this panel is a count variable representing the cumulative number of wells contained in each cell each year. Table 2 reports descriptive statistics for the panel. The number of cells containing zero wells decreases constantly and is equal to 10,691 in 2011, leaving 7,671 cells containing an average of 1.62 wells.

This newly constructed panel allows us to run a standard difference-in-difference specification for each of the two highways of interest. In order to cover the first dimension of the difference-in-difference estimation, we construct a treatment dummy (called *Treat*). A cell is defined as treated if it lies within a certain distance from the new road (G30 in the first case and, G1511 in the second), and as non treated if it lies outside that radius and

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[5] Several considerations went into the selection of the cell size. On the one hand, unfortunately, land utilization data for Lankao county are not available and, therefore, we are not able to distinguish between areas where it is feasible to dig a well and areas where it is not (because of pre-existing constructions or else). Taking this fact into account, we know that if the cell dimension is set too small we will plausibly experience a zero inflation in our data (i.e. we will have many cells reporting zero wells, but these would not be real zeros given that it is impossible to dig in these cells). On the other hand, we want to account for potential spatial spillover effects. The cell size was selected at 250m. Yet, since this number was selected ad hoc, we run two robustness tests on it. The results are robust to a change in the size of the cells to 300 by 300 meters and 500 by 500 meters.

at the same time also outside the same radius applied to the other highway. The second dimension instead, is covered by a second dummy (called *Post*) which takes value 0 for years previous to the first year of construction of G30 or G1511 and 1 for the following years.[6] The specification takes the following form

$$Wells_{ct} = \alpha + \delta_c + \delta_t + \beta_1 Treat_{ct} + \beta_2 Post_{ct} + \beta_3 Treat_{ct} * Post_{ct} + \varepsilon_{ct} \tag{1}$$

δ_c and δ_t are cell and year fixed effects. $Wells_{ct}$ represent the total number of wells in cell c at time t. Cell fixed effects account for all time invariant characteristics of a cell, such as distance to the river, to other roads, topology, hydrology and other possible confounding factors. As usual, the difference-in-difference effect of interest is given by β_3, the coefficient on the interaction term, which tells us by how much does the probability of digging a new well in the treatment area increases (or decreases) after the construction of the new highway. In order to satisfy the identification hypothesis of the difference-in-difference approach the specification is run using OLS. [7] Since the dependent variable is a count variable, we also run the main specification using a Poisson model, as a robustness test.

Extensive margin results

G30 Table 3 reports results for the extensive margin analysis of G30. In the case of G30, we defined as treated the area within 2 km of the highway, and as non treated the area between 2 km and 15 km from the two highways (G30 and G1511). Column (1) to (3) report OLS coefficients while column (4) shows coefficients for the Poisson specification. In columns (2) and (3) we add cell and year fixed effects. In this table the *Post* variable takes value 0 for years before 1998 and 1 after. The coefficient of interest is positive and statistically significant at the 5% level across all specifications, including the Poisson one. The coefficient is stable across the three OLS specifications. The probability of digging an extra well in one of the treated cells increases by 5.7% after the beginning of the construction of G30.[8]

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[6] We also run a series of robustness by changing the definition of the *Post* variable, meaning that instead of giving it value 1 starting from the first year of construction of the highway, we started from the second year and so on until the year that concluded the works. Results are robust to these changes and available upon request.

[7] The use of a non linear linking function would, for instance, violate the common trend hypothesis, since it does not allow to properly compute the differences-in-differences.

[8] We also run a falsification test for the common trends. Results can be found in column (1) of Table 4. In Table 4, we regress the dependent variable on a trend and the interaction of the trend with the treatment and the usual fixed effects over the period preceding the construction. The coefficient on the interaction term is statistically insignificant, confirming the common trend hypothesis. Before the construction of the

These numbers seem to confirm the story told by the intensive margin analysis. Yet, the size of the treated area may play a role in the size of the treatment effect. In order to check the robustness of the results we let the size of the treatment area vary between 500 meters and 5 km at intervals of 500 meters.[9] Figure 5 shows the evolution of the difference-in-difference coefficient when expanding the treatment area from 500 meters to 5 kilometers. Figure 5 shows that the effect on the probability to dig new wells is positive in a relatively stable way.[10]

G1511 Table 5 reports the difference-in-difference analysis for G1511. Even thought G1511 is a new highway, its location is very similar to the one of two of the historic highways, G106 and G220. For this reason, the area around G1511 already contains a higher than average number of wells. We can see evidence of this in Figure **??**. This figure shows the evolution of the probability of digging additional wells. As one may observe, already in the 70s the probability of digging an extra well in the corridor followed by G106 and G220 (going from the south-west to the north-east) was higher than elsewhere in the county. This pattern was still valid in the 80s, 90s, 00s and 10s. In light of these facts we will reduced the treatment area for our baseline estimation to 500 m around G1511. The non treated area being everything laying between 500 m of G1511 and 15 km from both highways. The results obtained for G1511 are stable across specifications and larger in magnitude then the one for G30. After the construction of G1511 the probability of digging new wells in the treated area increases up to 14.2%, statistically significant at the 5% level.[11]

Figure 6 shows the variation of the difference-in-difference coefficient for G1511 as we expand the treatment area from 500 m to 5 km.[12] Also in the case of G1511, the coefficient is consistently positive and statistically significant. Yet, we observe a downward trend which was not observed in the case of G30, meaning that the probability of digging new wells

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highway, the probability of digging a new well close to it was exactly the same as far from it.

[9] We limited ourselves to a 10 kilometers band around the highway, since its area of influence is probably not much larger. Yet, we run a robustness up to 10 kilometers, and the effect tend to stabilize after 5 kilometers. These results are available upon request.

[10] The first point – when the treatment area is of only 500 meters – is not statistically significant, yet this may be due to the scarcity of observations so close to the highway. We have to remember that the stretch of G30 going through Lankao is very short.

[11] Also here results are robust to a change in the size of the cells to 300 by 300 meters. Falsification test results for G1511 can be found in column (2) of Table 4. The coefficient on the interaction term is statistically significant at the 10% level, thus not completely confirming the common trend hypothesis. In the case of G1511 this result is probably due to the presence of G106 and G220 in close proximity.

[12] As for G30, we also run a robustness up to 10 kilometers, and the effect tend to stabilize after 5 kilometers. These results are available upon request.

decreases as we increase the size of the treatment area. This quick decrease may be due to the presence of G106 and G220, which already increased the likelihood of digging new wells over the previous years.

5.2 Intensive margin analysis

Specification

Several factors influence the depth of the water table. Some of these factors are natural, like the geology of the region, the shape and form of the underlying aquifer or proximity to a river, while others may be due to economic activity such as water use for agricultural or industrial use. Our goal is to check whether proximity to a road leads to higher water use and therefore, increased depletion of the groundwater table. The underlying mechanism is that a road facilitates access to markets and may lead to more intensive farming practices (Donaldson, 2015). For example, in villages far away from roads, the cost of transporting inputs and outputs may be high, leading farmers to grow subsistence crops for local consumption or for the household. However in areas closer to roads, they may grow commercially viable crops that require more timely use of inputs that are easier to access (such as fertilizers and pesticides). Farmers may also benefit from quicker and cheaper access to markets for their more perishable products, or have better information on market forces that affect their operations. These cheaper costs of inputs may lead to more intensive cultivation and hence increased use of complementary inputs such as water.

First, we need to control for seepage of water from the Yellow River which is likely to lead to a higher water table in wells located closer to the river. Figure 7 shows a local polynomial regression of the water table depth as a function of the minimum distance of the well to the river. Note that the water table gets deeper farther from the river, which is to be expected. The effect of seepage may be non-linear with respect to distance (Ghosh et al., 2014), for this reason we introduce it as a quadratic polynomial expression in our specification.

Our empirical specification takes the following form

$$WT_{iv} = \alpha + \delta_v + \delta_d + \beta_1 G1511_{iv} + \beta_2 G30_{iv} + \beta_3 (G30 * G1511)_{iv} + \beta_4 R_{iv} + \beta_5 R_{iv}^2 + \varepsilon_{iv} \quad (2)$$

where i and v denote tube well and village, respectively. WT is the depth of the water table in meters, $G30$, $G1511$ and R represent the distance of each well from G30, G1511 and the Yellow River in kilometres, respectively. Finally, δ_v represents village fixed effects and δ_d decade fixed effects. Finally, ε_{ivt} is the error term.

Since we are dealing with two separate highways at the same time, we have to take into account their interaction. The effect of roads on the water table may change if a well is located further from both roads then if it is located close to one road but very far from the other one. For this reason we introduced an interaction term, which accounts for the position of each well in relation to both roads. We expect to observe a higher depletion of the water table in a well located in close proximity to both roads, with respect to a well located close to one road but very far from the other one. In other words, we expect to obtain a negative sign on β_1 and β_2 but a positive one on β_3. Controlling for village fixed effects allows us to eliminate differences between villages in the form of topography, population density and other village-level characteristics like the quality of the village administration. Decade fixed effects are going to capture big policy changes.[13]

Intensive margin results

Table 6 reports the results for our baseline specification. Standard errors are robust and clustered at the village level. In column (1) we simply introduce the main variables of interest and village fixed effects. In column (2) and (3) we successively add the quadratic polynomial taking into account the distance from the Yellow river and the decade fixed effects, respectively.

The effect of G30 and G1511 on the water table is negative and statistically significant at least at the 10% level as soon as we control for the distance to the Yellow river. Focusing on the full specification, in column (3), we observe that a 1 km increase in the minimum distance from G1511 leads, *ceteris paribus*, to a decrease in the depth of the water table of 62.4 centimetres; while an increase of 1 km in the distance from G30 leads to a decrease of 46.3 centimetres. The coefficient on G1511 is statistically significant at the 10% level, while the one on G30 at the 5% level. The coefficient on the interaction term is positive and statistically significant at the 1% level. This positive coefficient implies that, if the distance to one highway is kept constant while the distance to the other one is increased, this increase will decrease the total negative impact of highways. In order to fully capture the implications of our main specification, we plot the marginal effect of a change in the distance to either of the two roads. Figure 8 shows the marginal effect of the distance from the two highways

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[13] The main policies that we want to capture are the following. In the 80s, the introduction of the Household Responsibility System, with a rental contract period set at not less than 15 years. This lead to a higher land fragmentation, which could make people drill more. In the 90s farmers were allowed to rent in/out land, and this policy change may have affected profit incentives. Finally, in the 00s, the contract period was extended to at least 30 years.

on the level of the water table, panel (a) shows the impact of a change in the distance from G1511 on the effect of G30 and panel (b) the impact of a change in the distance from G30 on the effect of G1511. The figure also shows, in each panel, the share of wells at each distance from the road, represented by the shaded gray histogram. The most striking feature of the two pictures, which comes to support our claim that road construction has an impact on the water table, is the monotonically positive shape of both marginal effects. The impact of highways on the water table is negative and decreases as we move away.

The coefficient on the distance from the Yellow River has the expected positive sign and it is statistically significant at the 5% level. The water table decreases away from the river. From column (3), we see that if the distance from the river increases by 1 km, the water table depth increases by 85 centimetres. The coefficient on the quadratic term is negative, implying that the effect of the river recedes with distance, also this coefficient is statistically significant at the 5% level.

Second order Taylor approximation

The intensive margin specification presented above can be pushed one step further. Instead of simply capturing the intensive margin through the two distances and their interactions, we assume a second order approximation of a non-specified non-linear relationship between the distance from G30 and G1511. This implies a specification of the following form

$$\begin{aligned} WT_{iv} = \alpha + \delta_v + \delta_d &+ \beta_1 G1511_{iv} + \beta_2 G30_{iv} + \beta_3 G1511^2_{iv} + \beta_4 G30^2_{iv} \\ &+ \beta_5 (G30 * G1511)_{iv} + \beta_6 R_{iv} + \beta_7 R^2_{iv} + \varepsilon_{iv} \end{aligned} \tag{3}$$

The only difference from equation (2) are the two squared terms of the distance. Results from this specification are shown in column (4) of Table 6. The marginal effets are now more difficult to compute, for instance, the marginal effect of a change in the distance to G30 for the water table is going to be given by the following expression

$$\frac{\partial WT_{iv}}{\partial G30_{iv}} = \beta_2 + 2\beta_4 G30_{iv} + \beta_5 G1511_{iv} \tag{4}$$

a linear function of both distances. Instead of presenting a 3D graph of the evolution of the marginal effect, using the mean distance from G30, 18.77 kilometres, and the mean distance from G1511, 9.72 kilometres, we compute the average marginal effect, which is equal to -0.112. This confirms our previous findings, as we move marginally further from G30 the depth of the water table decreases. Let us do the same exercise using G1511, in this case, the marginal effect is equal to

$$\frac{\partial WT_{iv}}{\partial G1511_{iv}} = \beta_1 + 2\beta_3 G1511_{iv} + \beta_5 G30_{iv} \tag{5}$$

and using the same mean values for G30 and G1511, we obtain an average marginal effect equal to -0.068. Therefore, also for G1511, when one moves marginally further the water table becomes shallower.

Instrumental variable specification

Chandra and Thompson (2000) and Michaels (2008) argue that highway placement is exogenous to the countryside in the US and, we could argue that this argument translates also to China. Moreover, Michaels (2008) claims that the shorter is the segment of highway to which we are interested the stronger is the plausibility of its exogeneity. Yet, in order to eradicate all possible doubts on the causal interpretation of our specifications, we run an instrumental variable specification. The argument of the Chinese government is that these highways have been built specifically to fulfil the goals specified in section 3, therefore, if we instrument the distance of each well to the actual placement of the highway with the distance to the straight line where the highway should have been had the government respected its plan, we are going to clear any possibility of endogeneity from our specification.

We first identified, for each of the two highways, the cities which they were supposed to connect. G30 is connecting Kaifeng to Xuzhou, while G1511 is connecting Kaifeng to Rizhao. Once these city-pairs have been identified, we connect them with straight lines.[14] Figure 9 the imaginary straight lines and the actual highways. We then measure the distance of each well to these imaginary straight lines. These distances are then used in order to instrument the actual distances and the interaction between the distances to the straight lines to instrument the interaction between the two actual distances.

Table 7 reports the results of this test. The table takes the same structure as the table reporting the baseline estimates for the intensive margin. The instrumental variable results are similar to the OLS results in magnitude and statistical significance and share the same sign. This similarity corroborates our claim of exogeneity in the placement of the two highways of interest.

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[14] Alder et al. (XXX) optimal placement for G30 and G1511 in this region taking into account land gradient actually corresponds to a straight line.

5.3 Robustness

Robustness tests are aimed at the intensive margin specification and are presented in Tables 8 and 9. In order to facilitate comparison, each table first shows our baseline results. Standard errors are robust and clustered at the village level in all specifications.

Table 8 controls for well density in the proximity of each well. If there are more wells nearby, the water table may be lower because of the extraction of ground water by other wells. This exercise allows us to control for within village confounders. We use various measures of well density, starting with the number of wells within radii of 100m, 200m and 500m, in columns (2), (3) and (4), followed by distance to the nearest well in column (5). In column (6), we jointly control for the number of wells within a radius of 500m and the distance to the closest well. Our estimates are robust to these controls in terms of magnitude, sign and statistical significance. The coefficients in columns (2), (3) and (4) are positive suggesting that a higher density of wells in the buffers lowers the water table. Yet, only the result on the 500m radius is statistically significant at the 10% level. That is, a lower density of wells leads to less depletion. As expected, a larger distance to the nearest well leads to a higher water level in the well. Yet, also this coefficient is not statistically significant. When controlling simultaneously for the last two measures, only the coefficient on the number of wells within a 500 meters radius is statistically significant, because it captures also the information provided by the other measure of well density.

Finally, in Table 9 we check whether the highway itself may have altered the water table. The construction of the highway, by inserting a new structure underground, may have disturbed the water levels in the underlying aquifer. In Table 9, we run the baseline estimation excluding the tubewells which are closer to the road, which would likely be impacted by highway construction. After presenting the baseline estimation in column (1), in column (2) to (4) we eliminate all wells within 50 meters, 100 meters and 500 meters from the highway, respectively. It does not seem that the construction of the highways impacts the water table in their proximity. The coefficients are stable in terms of magnitude, sign and statistical significance. Finally, in columns (5) and (6), we eliminate from our sample all villages containing less than 30 tubewells and less than 40 tubewells. These last two tests significantly decrease the sample size, yet they do not affect the magnitude of the coefficients or their size, but only the precision of the estimates.

5.4 Discussion

Our results on the intensive as well as on the extensive margin clearly point in the direction of an increase in groundwater depletion in proximity of highways in the aftermath of their construction. This increased depletion could operate through different channels. The first channel is related to crops diversification. The new highway, providing a better and faster access to the market, could push households to switch their production from the more classical wheat and corn towards more profitable, yet more water intensive, cultures such as melons, fresh vegetables and peanuts. The second channel is related to culture intensification. This channel is related to the more traditional cultures (corn and wheat), the decrease in transport costs deriving from the new highway may push farmers to intensify the cultivation, for instance by providing more water. One last possible channel could be related to migration. The new highway creates new work opportunities. It is now easier for people to work farther away and, therefore, get jobs outside the agricultural sector. As a consequence, since labor is declining in agriculture, the remaining farmers may increase the other inputs used in production, such as water.

In order to provide anecdotal evidence on some of these possible channels through which highways may affect the water table we use two different datasets. The first one, contains data from a household survey that we conducted in Lankao county in the summer of 2014. The survey focused on 282 households located in 30 villages.[15] The questionnaire focused on household characteristics and on agricultural practices. For this reason, we also collected information on the 1,624 plots of land owned by these households. The average plot in our survey measures roughly 0.15 ha. The households interviewed operate a total of 649 wells throughout the county. The second dataset comes from the Chinese National Bureau of Statistics and contains information about the total surface sown in Lankao county and total output per year for the main grains and for fresh vegetables.

Let us start by looking for evidence of the first channel, do we observe a switch to *cash crops* close to the new highways? Using the survey data, we focus on the locations where different crops are cultivated. The households surveyed grow 13 different types of crops: wheat; corn; cotton; potatoes; beans,: apple, pear, peach and poplar trees; vegetables; melons; peanuts and garlic. The main cultivations in our survey are wheat and corn, accounting for 85.96% of the plots, only 14.04% of the plots are cultivated with so called *cash crops*, which are more profitable and more water intensive. Let us focus on three specific cash crops: peanuts, vegetables and melons, which alone make up 77.2% of the cash crops cultivated in

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[15] More information on the survey (randomization, ...) can be found in the appendix.

our sample.

The first thing that we observe is that the average plot size for these crops is larger than the average plot size of wheat or corn fields, 0.187 ha on average versus 0.145 ha.[16] Before moving on, it is useful to stop for a moment and think about the difference between the three types of cash crops that we are considering. Peanuts are significantly different from vegetables and melons. Peanuts are small and light, but more importantly are less perishable than vegetables or melons and, therefore, probably do not respond to the same incentives. We would expect the cultivation of vegetables and melons to take more advantage of the proximity of a highway, with respect to the cultivation of peanuts. This is exactly what we observe. The average distance to G1511 for peanuts fields is 8.37 kilometers, while the average distance for vegetables and melons fields is of only 1 kilometer. The average distance for corn or wheat fields is around 5.4 kilometers, and all this averages are statistically different from one another. Therefore, the location of the different cultivations throughout the county seems to support the first channel evoked earlier. We may be observing some diversification take place, yet, given the cross-sectional nature of our survey data, we cannot determine whether these cultivations where already there prior to the construction of the highway or not.

The aggregate data from the National Bureau of Statistics tell us a similar story. Unfortunately, data on total output from of fresh vegetables are not available, yet we have data on total area dedicated to the cultivation of fresh vegetables. Figure (10) shows the evolution of this cultivation. We can observe a big expansion starting in the late 1990, around 1999, stabilizing at the beginning of the years 2000. The expansion roughly corresponds with the construction of G30 and G1511 which took place overall between 1998 and 2005. By running a likelihood ratio test (Wald test) we quickly verify that this time series does experience a structural break in 2001.[17] While it is impossible to link this structural break to the highways construction with certainty, it seems that several pieces of evidence point in the same direction.

Let us now move on to the second channel, do we observe an intensification in the cultivation of wheat and corn? In order to answer this question we are going to analyze how the yield per hectare evolves as we move away from G30 and G1511. We use the following specification

$$Yield_{iv} = \alpha + \beta_1 G30_{iv} + \beta_2 G1511_{iv} + \beta_3 (G30 * G1511)_{iv} + \beta_4 X_{iv} + \varepsilon_{iv} \tag{6}$$

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[16] This difference is statistically significant at the 1% level.

[17] The χ^2 value of the test is 35.24.

where $Yield$ is calculated on average per crop/season/hectare over the plots served by the same well, and X contains plot level controls, such as soil quality and type, slope, quantity of seeds used, quantity of fertilizer, pesticide and herbicide used. Here again, $G30$ and $G1511$ represent the distances from G30 and G1511 in meters, respectively and ε_{iv} is an error term.

The results of the estimation of equation (6) are reported in table 10. Column (1) shows the results for the winter crop, wheat, while column (2) shows the coefficient for the summer crop, corn. Both highways, have a positive effect on wheat yields, i.e. yields decrease as we move aways from them. The result is important in magnitude and statistically significant at the 1% level for G1511. Even thought the interaction term is positive and statistically significant, it is very small in magnitude, simply telling us is that the positive effect of the highway becomes less and less important the more the distance grows.

The higher wheat yields closer to the new highways could depend on several reasons. First, and in relation to our previous results, we could speculate that farmer located closer to highways now have increased incentives to obtain higher yields, because of lower transport costs. Having a better access to the market makes it worthwhile to spend a few extra yuan for pumping the water in order to obtain a higher yield. Another reason could also be that after the construction of the highways, farmer located close to it had an improved access to better seeds, yielding higher amounts of wheat.

The various pieces of evidence collected in this section seem to point in the direction of two of the three channels highlighted above, unfortunately we have no data in order to test for the third. Given the data limitations, we cannot identify the channels with certainty, yet we have shown, using different datasets, that diversification and intensification of cultures took place in Lankao county over the period of construction of G30 and G1511. These changes are plausibly responsible for the increase in groundwater extraction that we observed in proximity to G30 and G1511.

6 Concluding remarks

There is a large literature on infrastructure and economic development but no studies on the relationship between infrastructure building and resource depletion. It is likely that while infrastructure such as roads brings economic activity into a region, it also leads to the depletion of the natural resource base. This paper shows that there is clear evidence of depletion of the water table in Lankao County, China, close to the two national highways that pass through the county. The relationship is found through two different exercises.

First, we perform an extensive margin analysis to investigate whether the construction of new highways increases the probability of digging new wells. Second, we analyze the intensive margin, in order to see how the water table is affected by the presence of new highways.

These results may be driven by the fact that a new road facilitates access to the market, in the same way railways do, see Donaldson (2015). An easier access to the market pushes individuals or communities to engage in agricultural activities that are more commercial in nature, such as the cultivation of cash rather than subsistence crops, or the use of modern varieties of seeds and multi-cropping, requiring more use of groundwater irrigation. Our findings suggest that the true benefits of road-building may need to account for these depletion effects, which are likely to impact the long-term economic productivity of the region.

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Tables

Table 1: Descriptive statistics

Variable	**Mean**	**St. Dev.**	**Min**	**Max**
Well Depth (meters)	41.95	8.33	18.00	250.00
Water Table (meters)	13.92	6.07	1.00	40.00
Distance to highway 1511 (km)	9.72	6.42	0.00	25.00
Distance to highway 30 (km)	18.77	8.39	0.00	37.00
Distance to Yellow River (km)	22.04	11.49	0.00	46.00
Distance to primary canals(km)	2.05	1.95	0.00	11.00
Number of wells within 100m radius	1.52	0.90	1.00	9.00
Number of wells within 200m radius	3.30	2.03	1.00	17.00
Number of wells within 500m radius	14.24	7.21	1.00	54.00
Distance to the nearest well(km)	0.13	0.08	0.00	1.00

Notes: The sample contains 7,526 wells.

Table 2: Descriptive statistics extensive margin

		Cells with a positive number of wells				
Year	**Number of cells with zero wells**	**Number of cells with non-zero wells**	**Mean**	**St. deviation**	**Min**	**Max**
1981	16848	1514	1.09	0.32	1	4
1982	16804	1558	1.09	0.32	1	4
1983	16756	1606	1.10	0.35	1	4
1984	16682	1680	1.12	0.37	1	4
1985	16498	1864	1.14	0.39	1	4
1986	16407	1955	1.15	0.41	1	4
1987	16341	2021	1.15	0.42	1	4
1988	16264	2098	1.16	0.43	1	4
1989	16172	2190	1.16	0.43	1	4
1990	15983	2379	1.18	0.46	1	4
1991	15895	2467	1.19	0.46	1	4
1992	15755	2607	1.19	0.47	1	4
1993	15616	2746	1.20	0.48	1	4
1994	15495	2867	1.21	0.50	1	5
1995	15176	3186	1.24	0.52	1	5
1996	14993	3369	1.25	0.54	1	5
1997	14856	3506	1.25	0.55	1	6
1998	14582	3780	1.27	0.57	1	6
1999	14489	3873	1.28	0.57	1	6
2000	14118	4244	1.31	0.61	1	6
2001	13956	4406	1.31	0.61	1	6
2002	13816	4546	1.32	0.62	1	6
2003	13591	4771	1.35	0.65	1	6
2004	13415	4947	1.35	0.65	1	6
2005	13099	5263	1.37	0.69	1	8
2006	12882	5480	1.39	0.70	1	8
2007	12748	5614	1.41	0.72	1	8
2008	12462	5900	1.43	0.75	1	8
2009	11698	6664	1.50	0.82	1	12
2010	10946	7416	1.58	0.91	1	12
2011	10691	7671	1.62	0.96	1	12

Notes: The sample contains 18,362 cells.

Table 3: Difference-in-difference estimation for the effect of the construction of G30

	Probability of digging a new well			
	OLS			Poisson
	(1)	(2)	(3)	(4)
Treat	-0.026^{*}			
	(0.012)			
Post	0.238^{**}	0.238^{**}	0.518^{**}	1.963^{**}
	(0.004)	(0.004)	(0.008)	(0.030)
Treat*Post	0.057^{**}	0.057^{**}	0.057^{**}	0.267^{**}
	(0.018)	(0.018)	(0.018)	(0.071)
Grid cell FE	no	yes	yes	yes
Year FE	no	no	yes	yes
Observations	398,195	398,195	398,195	155,279

Notes: The treatment area has been fixed at 2 km around G30. The non treated area includes all cells situated at least 2 km away from G30 and from G1511 and no more than 15 km from either of the two highways. Standard errors in parentheses are robust. *** p<0.01, ** p<0.05, * p<0.1.

Table 4: Common trend for G30 and G1511

	Prob. of digging a well	
	G30	G1511
	(1)	(2)
Trend	0.010^{***}	0.012^{***}
	(0.0003)	(0.0002)
Treat*Trend	0.0003	0.002^{*}
	(0.001)	(0.001)
Grid cell FE	yes	yes
Year FE	yes	yes
Observations	218,365	337,436

Notes: The treatment area has been fixed at 2 km around G30 and 500 m around G1511. The non treated area includes all cells situated at least 2 km away from G30 and 500 m from G1511 and no more than 15 km from either of the two highways. Standard errors in parentheses are robust. *** p<0.01, ** p<0.05, * p<0.1.

Table 5: Difference-in-difference estimation for the effect of the construction of G1511

	Probability of digging a new well			
	OLS			Poisson
	(1)	(2)	(3)	(4)
Treat	0.052**			
	(0.016)			
Post	0.272**	0.272**	0.557**	1.929**
	(0.004)	(0.004)	(0.007)	(0.025)
Treat*Post	0.142**	0.142**	0.142**	0.108*
	(0.022)	(0.022)	(0.022)	(0.045)
Grid cell FE	no	yes	yes	yes
Year FE	no	no	yes	yes
Observations	475,478	475,478	475,478	193,781

Notes: The treatment area has been fixed at 5 km around G1511. The non treated area includes all cells situated at least 500 m away from G1511 and from G30 and no more than 15 km from either of the two highways. Standard errors in parentheses are robust. *** p<0.01, ** p<0.05, * p<0.1.

Table 6: Effect of Distance of Well from G30 and G1511

	Dep. variable: Water table			
	(1)	(2)	(3)	(4)
Distance to G1511 (km)	-0.548	-0.628^{*}	-0.624^{*}	-0.979^{**}
	(0.348)	(0.366)	(0.363)	(0.453)
Distance to G30 (km)	-0.442^{*}	-0.466^{**}	-0.463^{**}	0.844^{**}
	(0.230)	(0.215)	(0.215)	(0.417)
Distance to G1511 squared				0.015
				(0.013)
Distance to G30 squared				-0.034^{***}
				(0.009)
Dist G30*Dist G1511	0.027^{*}	0.052^{***}	0.052^{***}	0.033^{*}
	(0.015)	(0.017)	(0.017)	(0.018)
Distance to river		0.848^{**}	0.850^{**}	0.582^{**}
		(0.350)	(0.349)	(0.277)
Distance to river squared		-0.024^{**}	-0.024^{**}	-0.011
		(0.011)	(0.011)	(0.008)
Village F.E.	yes	yes	yes	yes
Decade F.E.	no	no	yes	yes
Observations	7,525	7,525	7,525	7,525

Notes: All regressions contain a constant. Standard errors in parentheses are robust and clustered at the village level. *** p<0.01, ** p<0.05, * p<0.1.

Table 7: Effect of Distance of Well from G30 and G1511

	Dep. variable: Water table					
	OLS	IV	OLS	IV	OLS	IV
	(1)	(2)	(3)	(4)	(5)	(6)
Distance to G1511 (km)	-0.548	-1.181^{**}	-0.628^{*}	-0.579^{*}	-0.624^{*}	-0.592^{*}
	(0.342)	(0.586)	(0.360)	(0.339)	(0.358)	(0.332)
Distance to G30 (km)	-0.442^{*}	-0.694^{***}	-0.466^{**}	-0.446^{***}	-0.463^{**}	-0.451^{***}
	(0.226)	(0.239)	(0.212)	(0.144)	(0.212)	(0.141)
Dist G30*Dist G1511	0.027^{*}	0.103	0.052^{***}	0.061^{*}	0.052^{***}	0.059^{*}
	(0.015)	(0.119)	(0.017)	(0.032)	(0.017)	(0.032)
Distance to river			0.848^{**}	1.016^{*}	0.850^{**}	0.985^{*}
			(0.345)	(0.542)	(0.344)	(0.526)
Distance to river squared			-0.024^{**}	-0.031	-0.024^{**}	-0.029
			(0.011)	(0.020)	(0.011)	(0.020)
Village F.E.	yes	yes	yes	yes	yes	yes
Decade F.E.	no	no	no	no	yes	yes
Observations	7,525	7,525	7,525	7,525	7,525	7,525
F-stat G1511		38.73		74.72		75.31
F-stat G30		115.47		2864.12		2952.90
F-stat G30*G1511		0.82		10.09		10.13

Notes: All regressions contain a constant. Standard errors in parentheses are robust and clustered at the village level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 8: Controlling for Well Density

			Dependent variable Water table			
	Baseline	No. of wells within 100m	No. of wells within 200m	No. of wells within 500m	Distance to closest well	Both measures
	(1)	(2)	(3)	(4)	(5)	(6)
Distance to G1511 (km)	-0.624^{*}	-0.623^{*}	-0.623^{*}	-0.609^{*}	-0.622^{*}	-0.609^{*}
	(0.363)	(0.363)	(0.364)	(0.362)	(0.364)	(0.362)
Distance to G30 (km)	-0.463^{**}	-0.462^{**}	-0.463^{**}	-0.459^{**}	-0.462^{**}	-0.459^{**}
	(0.215)	(0.215)	(0.215)	(0.214)	(0.215)	(0.214)
Dist G30*Dist G1511	0.052^{***}	0.052^{***}	0.052^{***}	0.052^{***}	0.052^{***}	0.052^{***}
	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)
Distance to river (km)	0.850^{**}	0.850^{**}	0.850^{**}	0.852^{**}	0.850^{**}	0.852^{**}
	(0.349)	(0.349)	(0.349)	(0.347)	(0.348)	(0.347)
Distance to river^2 (km)	-0.024^{**}	-0.024^{**}	-0.024^{**}	-0.024^{**}	-0.024^{**}	-0.024^{**}
	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)
Number of wells in 100m buffer		0.038				
		(0.033)				
Number of wells in 200m buffer			0.010			
			(0.021)			
Number of wells in 500m buffer				0.018^{*}		0.018^{*}
				(0.010)		(0.009)
Distance to closest well (km)					-0.365	0.085
					(0.496)	(0.427)
Village F.E.	yes	yes	yes	yes	yes	yes
Decade F.E.	yes	yes	yes	yes	yes	yes
Observations	7,525	7,525	7,525	7,525	7,525	7,525

Notes: All regressions contain a constant. Standard errors in parentheses are robust and clustered at the village level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 9: Estimation without Wells close to the Highway

	Dependent variable Log Water table$_{iv}$					
	Baseline	Elimin. wells within 50m of the highway	Elimin. wells within 100m of the highway	Elimin. wells within 500m of the highway	Elimin. villages with less than 30 wells	Elimin. villages with less than 40 wells
	(1)	(2)	(3)	(4)	(5)	(6)
Distance to G1511 (km)	-0.624^{*}	-0.621^{*}	-0.625^{*}	-0.640^{*}	-0.694	-0.708^{*}
	(0.363)	(0.365)	(0.366)u	(0.380)	(0.423)	(0.358)
Distance to G30 (km)	-0.463^{**}	-0.466^{**}	-0.468^{**}	-0.485^{**}	-0.505^{**}	-0.320
	(0.215)	(0.216)	(0.217)	(0.225)	(0.245)	(0.220)
Dist G30*Dist G1511	0.052^{***}	0.053^{***}	0.053^{***}	0.056^{***}	0.061^{***}	0.070^{***}
	(0.017)	(0.017)	(0.017)	(0.019)	(0.020)	(0.021)
Distance to river (km)	0.850^{**}	0.871^{**}	0.872^{**}	0.947^{**}	1.074^{**}	0.570
	(0.349)	(0.351)	(0.352)	(0.366)	(0.423)	(0.550)
Distance to river^2 (km)	-0.024^{**}	-0.025^{**}	-0.025^{**}	-0.027^{**}	-0.030^{**}	-0.026^{*}
	(0.011)	(0.011)	(0.011)	(0.012)	(0.013)	(0.016)
Village F.E.	yes	yes	yes	yes	yes	yes
Decade F.E.	yes	yes	yes	yes	yes	yes
Observations	7,525	7,499	7,482	7,269	4,991	3,873

Notes: Standard errors in parentheses are robust and clustered at the village level. *** p<0.01, ** p<0.05, * p<0.1.

Table 10: Yield per ha

	Dep. variable: yield	
	Wheat (winter)	Corn (summer)
	(1)	(2)
Distance to G1511 (km)	-0.317^{***}	-0.058
	(0.090)	(0.114)
Distance to G30 (km)	-0.012	0.055^{**}
	(0.019)	(0.024)
Dist G30*Dist G1511	$6.7e{-}6^{**}$	$-2.3e{-}6$
	($3.2e{-}6$)	($4.2e{-}6$)
Plot controls	yes	yes
Observations	637	547

Notes: Yield is expressed in jin, where 1 jin corresponds to 0.5 kg. Standard errors in parentheses are robust. *** p<0.01, ** p<0.05, * p<0.1.

Figures

Figure 1: Location of Lankao county

Figure 2: Map of Lankao county

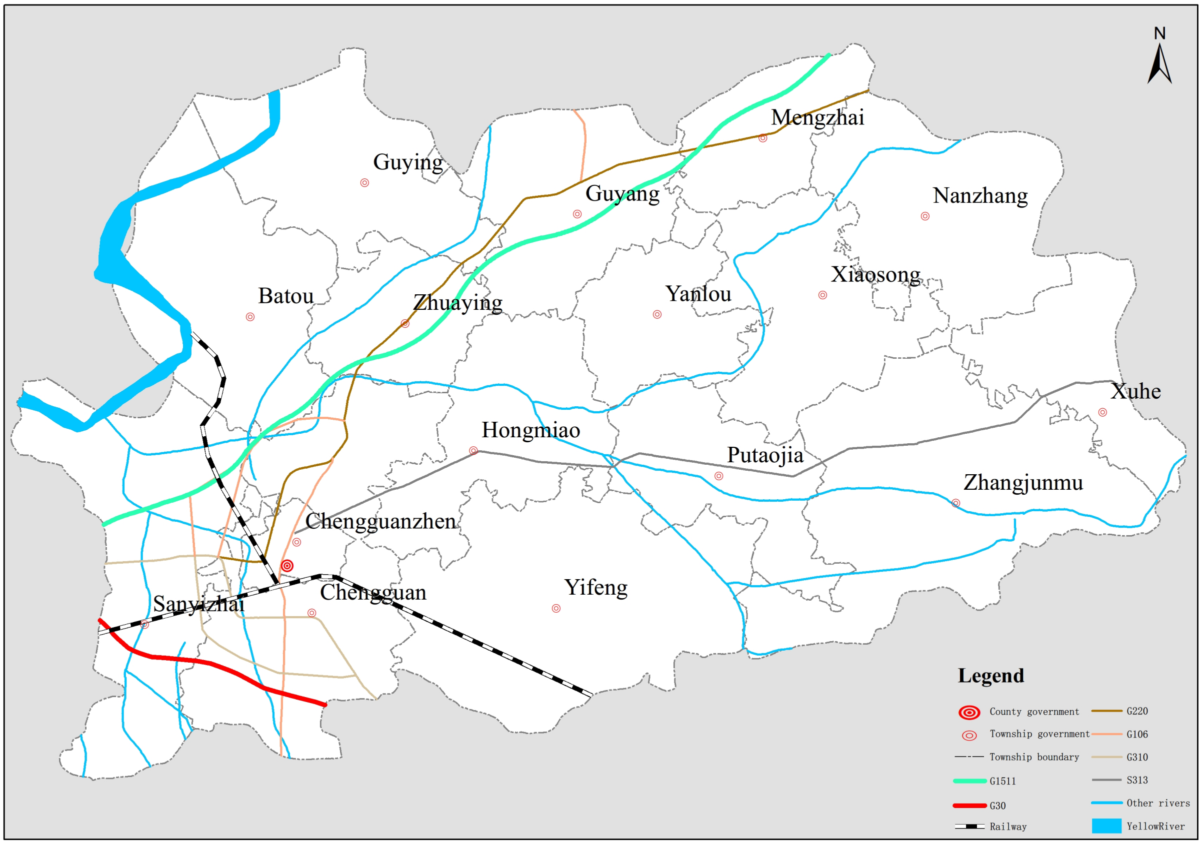


Figure 3: Tubewells evolution (by decade) from 1955 to 2011

Figure 4: Depth of watertable in tubewells in 2011

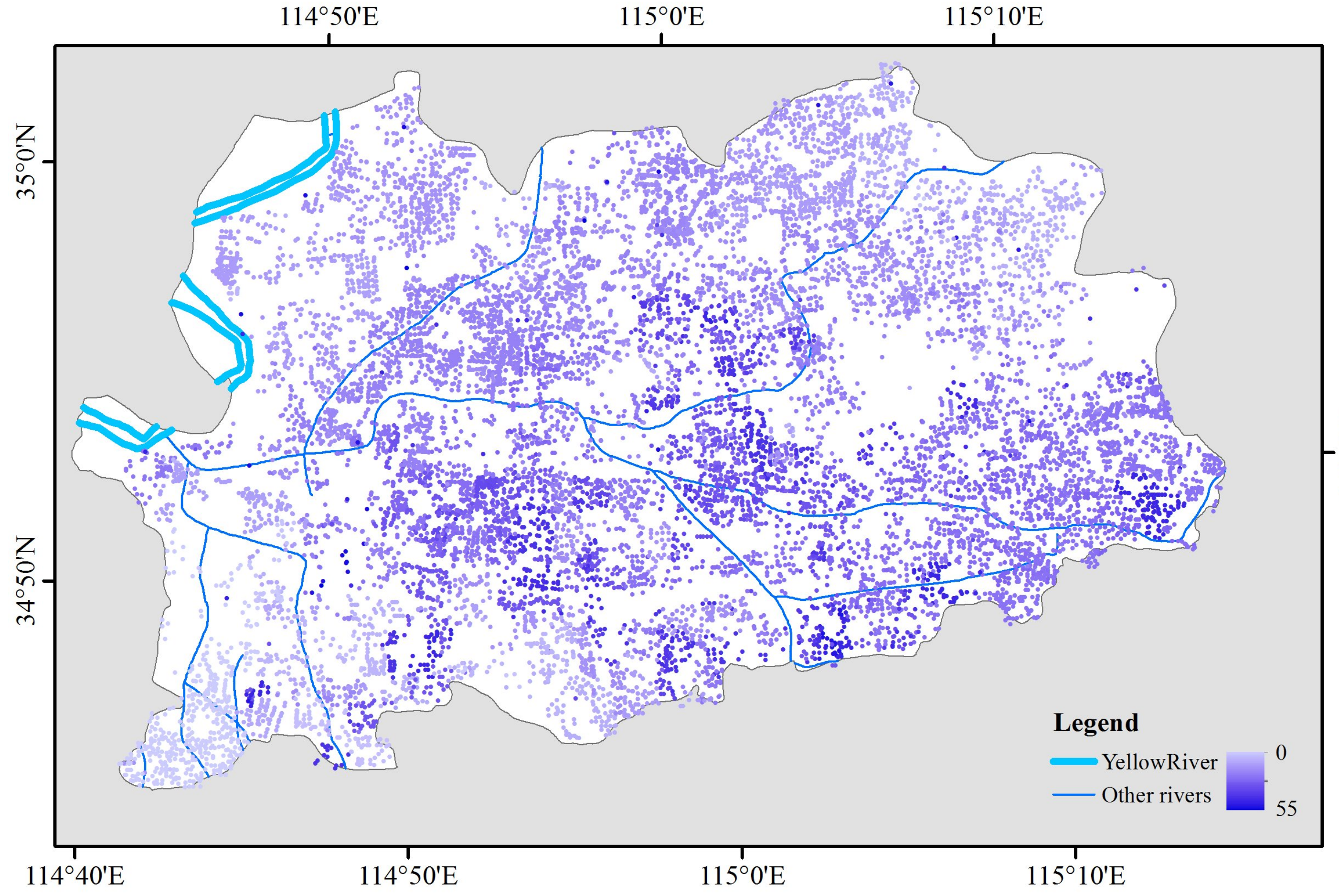


Figure 5: Variation of the DiD coefficient as the boundary of the treatment moves away from G30

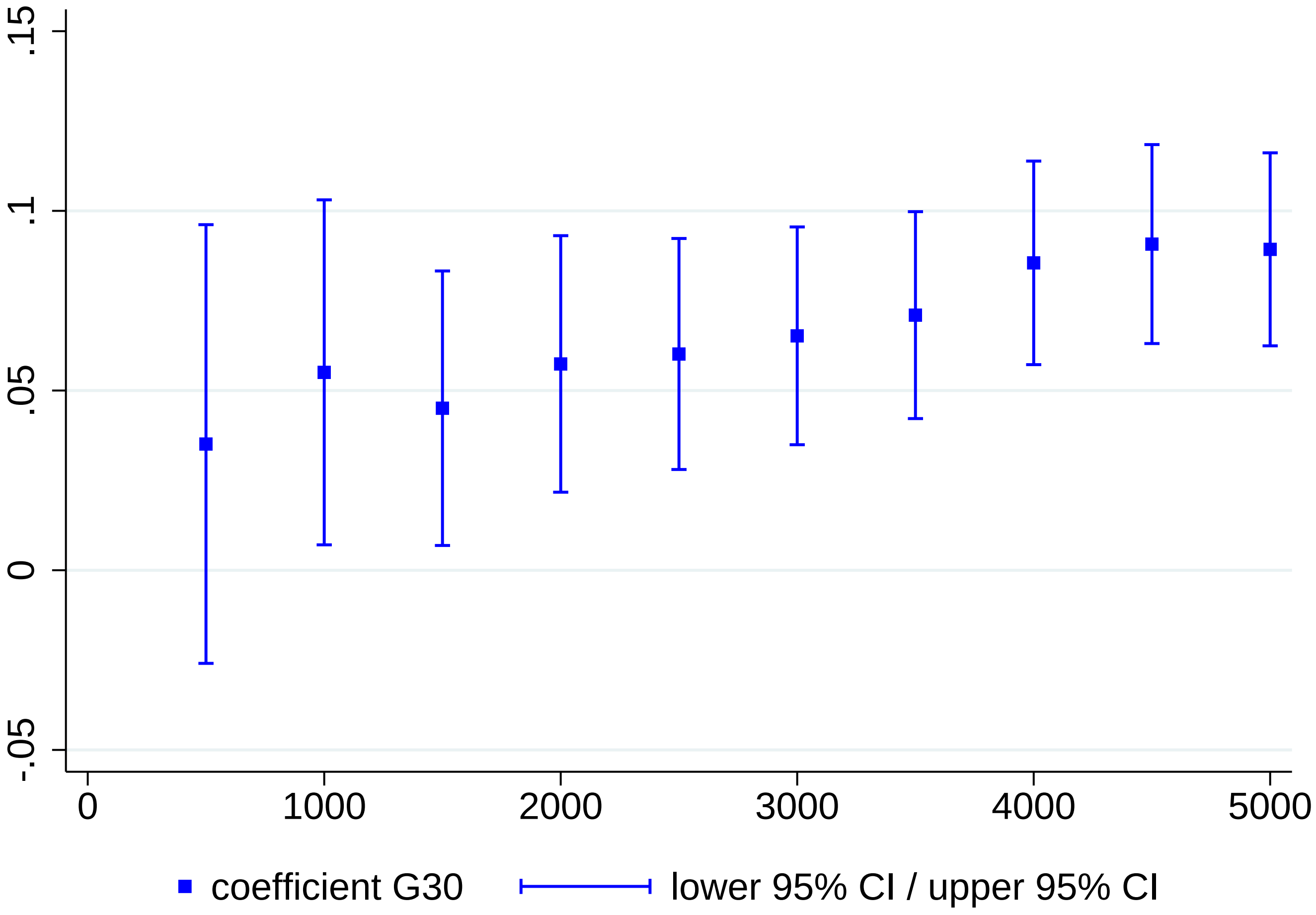


Figure 6: Variation of the DiD coefficient as the boundary of the treatment moves away from G1511

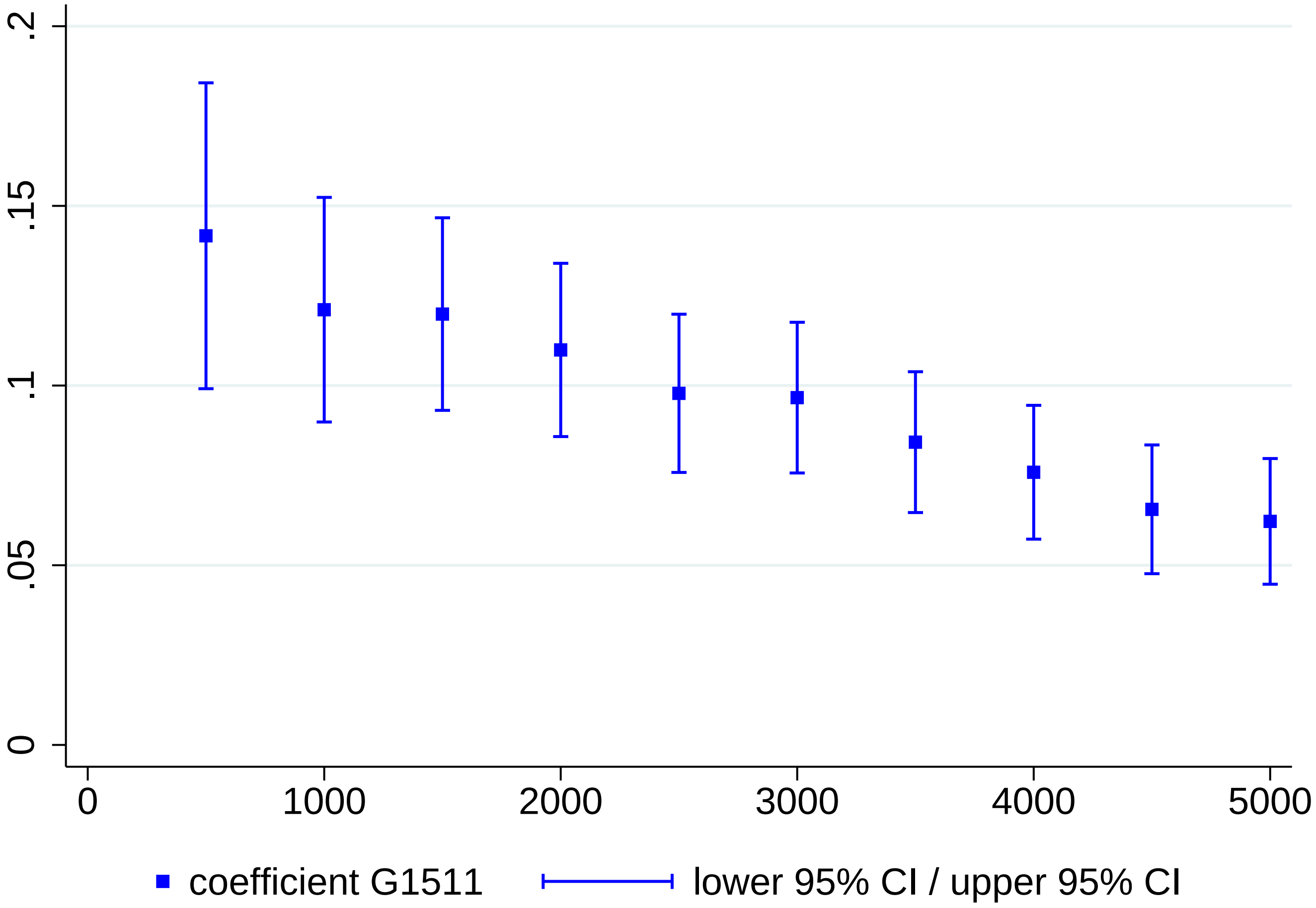


Figure 7: Depth of Water Table in Wells with Distance from Yellow River

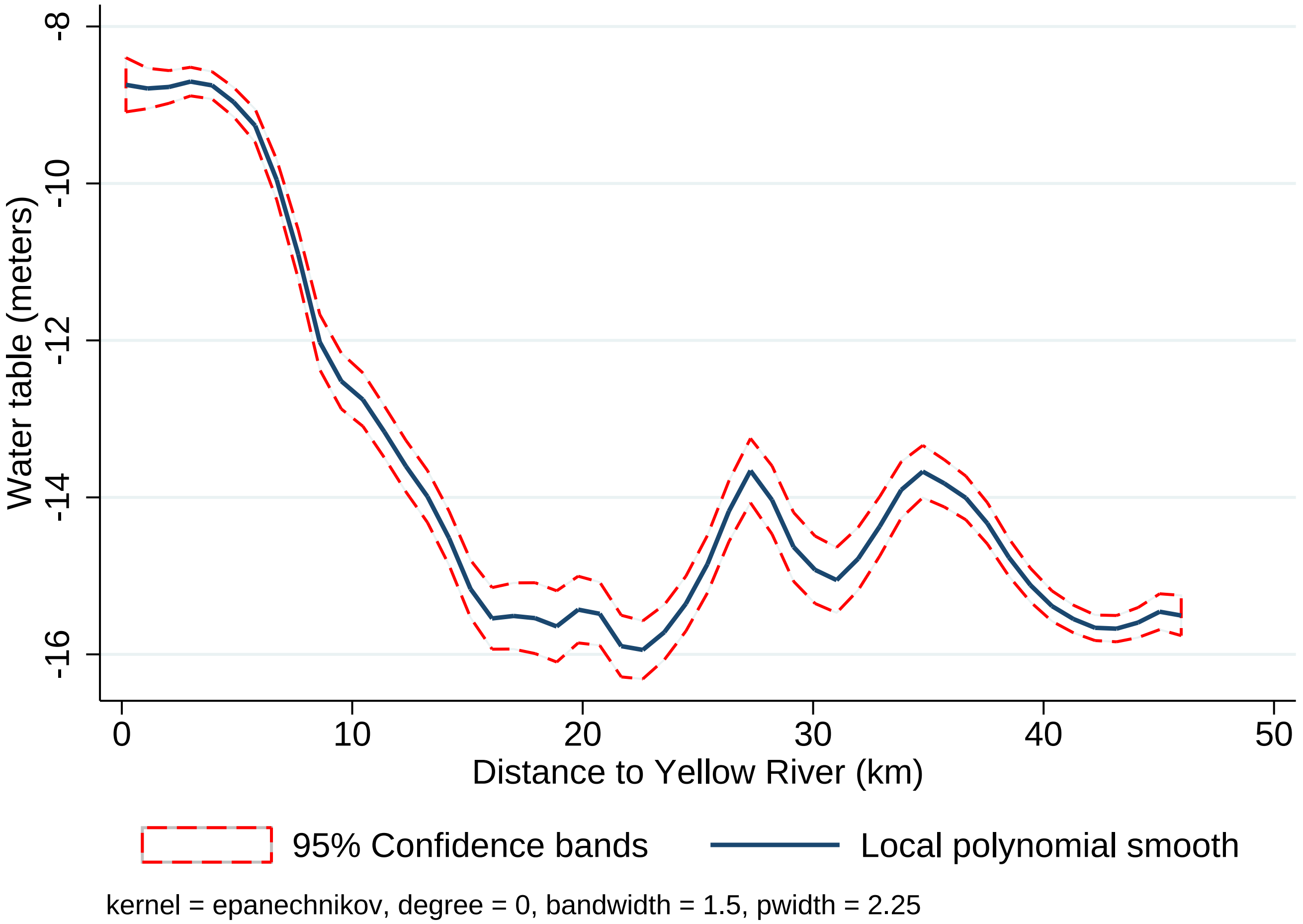


Figure 8: Marginal effect of the distance from G1511 and G30

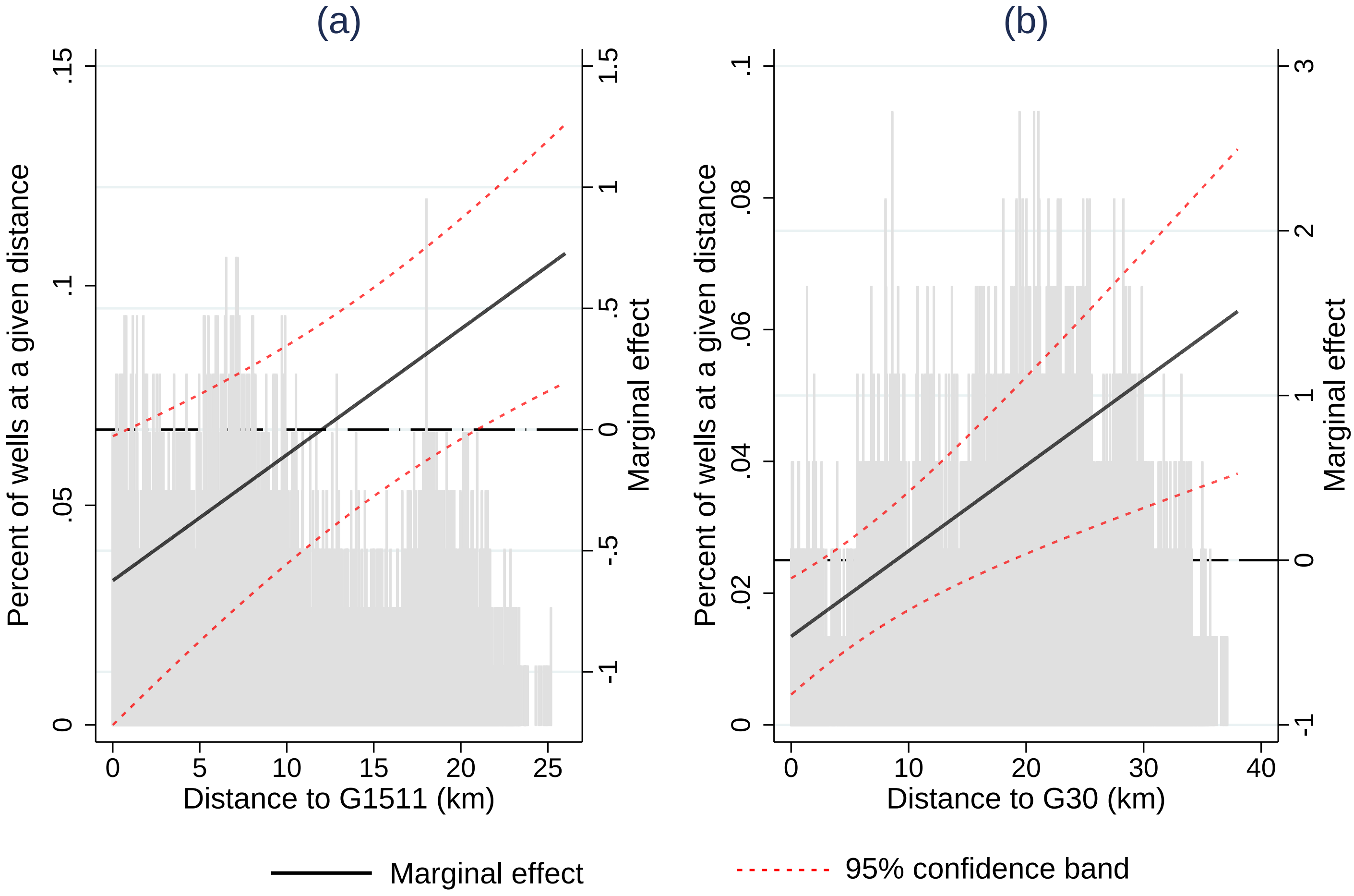
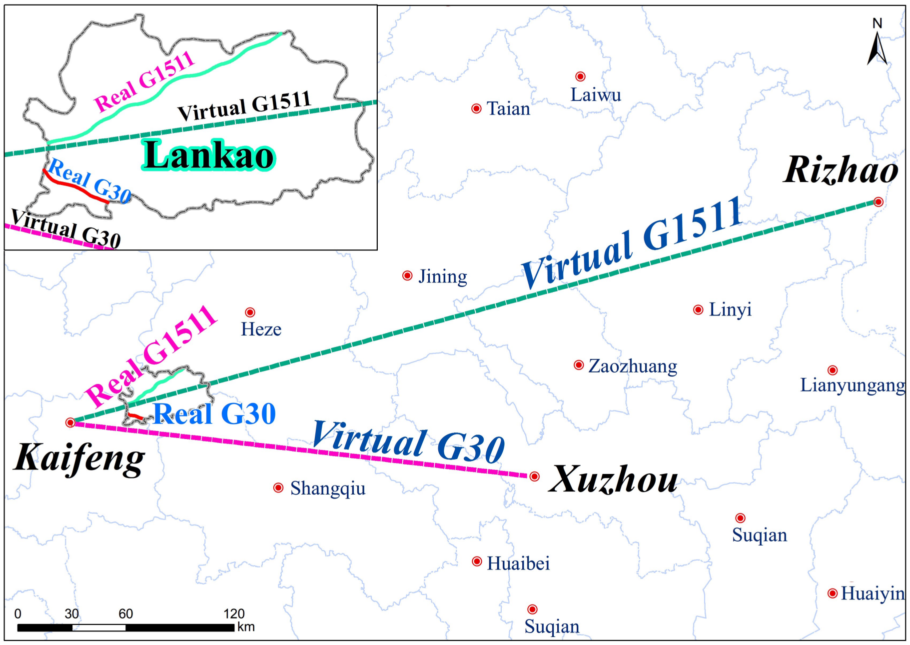


Figure 9: G1511 and G30 and the corresponding straight lines

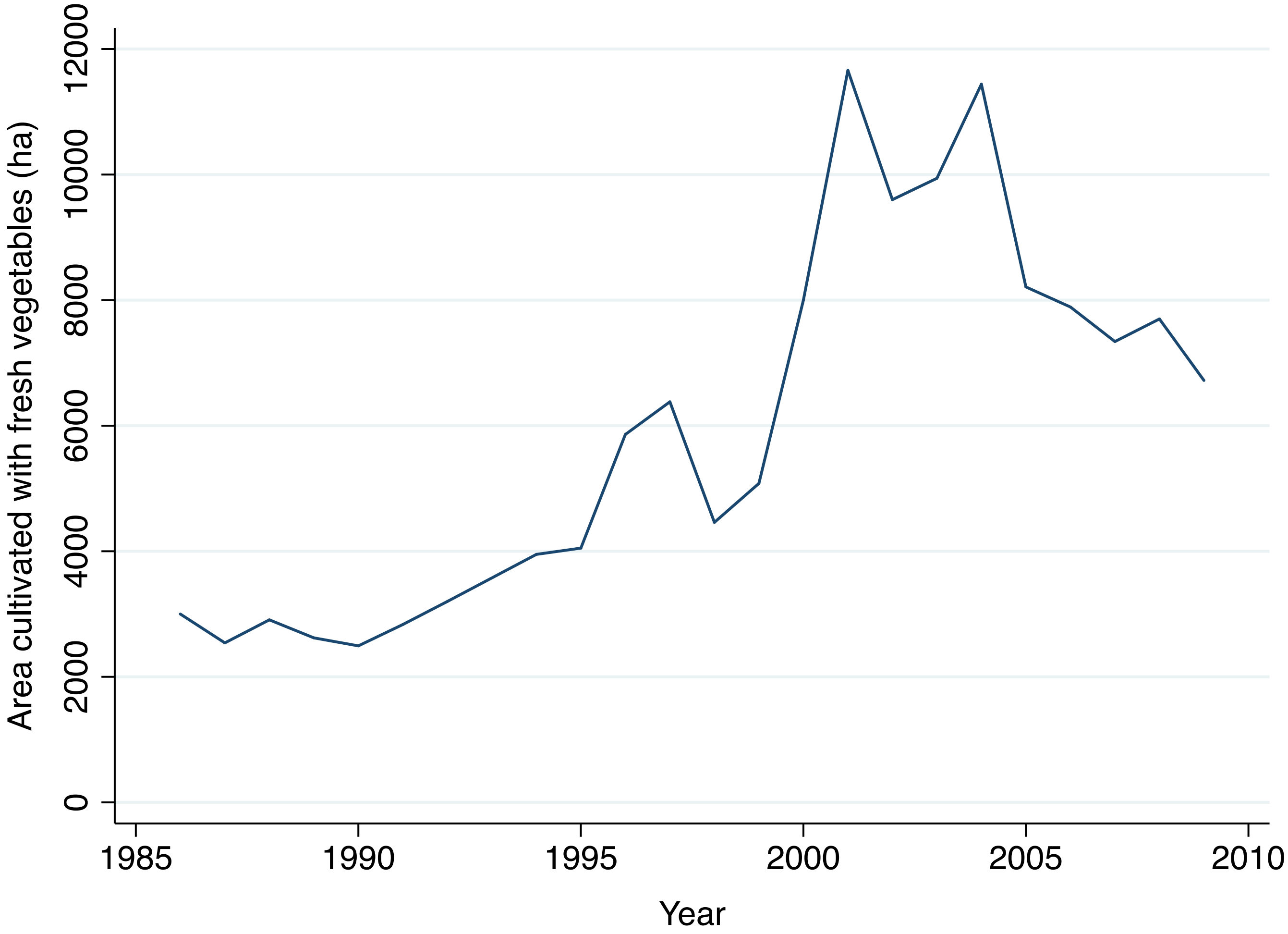


7 Appendix: Survey

We conducted questionnaire surveys with family heads of 300 households in Lankao County in summer of 2014. To choose survey respondents, we used random sampling methods. We randomly selected 30 villages from a total number of 429 villages in Lankao. These 30 villages are from 13 townships of a total number of 16 townships in the county. To randomly choose these villages, we first put all 429 villages on a list. We then generated a random number from a normal distribution and took that random number as a starting point. That starting point was the first village we chose. We then moved down to a village whose number of 14 away from the first village. With the same iteration, we chose a total number of 30 villages. In each selected village, 10 households were randomly chosen from village rosters. For each selected family, the family head was asked to participate in personal interviews conducted by our survey team.

The questionnaire used in our surveys contains the following key information: [1] family demographic information; [2] detailed information related to each of all wells used by the family in 2013. Such information includes the ownership of each well used by the family, the type of pumps used in each well, plots irrigated by each well and ownership of each well etc. In addition, information of coordinates (longitude and latitude) was collected for each

Figure 10: Total area cultivated with fresh vegetables in Lankao county (1986-2009)



well used by the family in 2013. [3] detailed information related to each of all pumps used by the family, such as types of pumps, the well corresponding to each pump, pumping time etc.; [4] detailed information related to each of all plots operated by the family in 2013. For each plot, the following detailed information was collected: slope, soil fertility, sources of irrigation water (including no irrigation), irrigation methods; wells used for irrigation (the corresponding well mentioned in [2]). For each plot, if the family has surface water to irrigate their plot, the following information was collected: frequency and time of irrigation, total cost of irrigation. For each plot, if the family used ground water to irrigate the plot, the following information was collected: frequency and time of irrigation. If the family had more than one irrigation in 2013, the following further information was collected: time of each irrigation. For each plot, information on each of all crops grown on the plot was collected. For each crop grown on each plot, information of frequency and time of irrigation during the crop growing season, input used and its yield was collected.